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THE BRAIN

THE BRAIN

Considered Anatomically, Physiologically and Philosophically

BY

EMANUEL SWEDENBORG

EDITED, TRANSLATED, AND ANNOTATED

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IN FOUR VOLUMES

VOLUME I.

THE CEREBRUM AND ITS PARTS

JAMES SPEIRS
36 BLOOMSBURY STREET, LONDON
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TO

JAMES JOHN GARTH WILKINSON

M.R.C.S. ENG., M.D.

WITH DEEPEST RESPECT FOR THE SCHOLARSHIP AND GENIUS WHICH HE HAS SHOWN AS THE TRANSLATOR AND EXPONENT OF MANY OF THE SCIENTIFIC WORKS OF SWEDENBORG

AND IN ACKNOWLEDGMENT OF MY GREAT PERSONAL INDEBTEDNESS TO HIS INTELLIGENT SYMPATHY AND ASSISTANCE

I dedicate this Work

RUDOLPH L. TAFEL

EDITOR'S PREFACE.

The present extensive work on the brain, after lying in manuscript for one hundred and forty years, comes now before the learned for the first time. And yet it will be found as fresh and original as if it had been written but yesterday. If it were an ordinary work of science which had thus been disturbed from its protracted slumber, it would appear antiquated and covered with the rust of time, addressing itself only to the learned of a bygone generation; but instead of that the work before us claims our attention as the exponent of the most recent acquisitions in the domain of the science of the brain and of the nervous system in general.

It comes introduced to us by the honoured names of Willis, Vieussens, Ridley, Winslow, Pacchioni, Leeuwenhoek, Ruysch, and others; yet while presenting to us the gist and the spirit of the works of these masters, it derives additional support and confirmation from the researches and observations of the men of the present time—Reil, Meynert, Key and Retzius, Lockhart Clarke, Ferrier, François-Franck, Luys, and others.

Swedenborg's theory of the brain must appear in the eyes of the candid observer hardly less than miraculous; for not only has he anticipated nearly all the important discoveries made since his time in the science of the brain and of the nervous system, but under the guidance of those rational doctrines which he employed in order to wrest their secrets from the facts on these subjects, he also exhibits in broad daylight the functions of such obscure bodies as the pineal gland, the infundibulum, and the pituitary gland.

The first effect, however, of Swedenborg's theory of the brain is to stir into life its silent and apparently lifeless organism, in setting every one of its parts in motion. On this subject the honoured friend[1] to whom we dedicate the work says, "Swedenborg's theory involves the motion of the brain correspondent to the motion of the lungs, and the motion of the lungs

[1] J. J. Garth Wilkinson, "Swedenborg's Doctrines and the Translation of his Works." An address delivered at the Seventy-second Anniversary of the Swedenborg Society, British and Foreign, held at 36 Bloomsbury Street, London, June 20, 1882. London: James Speirs.

as the universal physical and mechanical attraction of life into the body. It involves the motion of the highest substances, the cortical substances, according to the life of the highest faculties of the man. It therefore involves the determinate and most orderly motion of all the fluids in the brain from the principles of motion to the very ends of the same. His work is, according to the anatomy of the brain, a geography of the rivers of bodily and embodied life, a definite geography. So much for a brief word on his theory. It is embodied, embrained motion; and brain spirits and nerve juices moved, moved into the body, and constituting its momentaneous life" (p. 20).

But seizing the very inmost feature by which Swedenborg's theory of the brain is able not only to survive the changes of time, but also to borrow additional lustre from the modern facts respecting it, our friend continues: "Doctrine is the ever-potent father of Swedenborg's theory. The doctrine, namely, that there is a God, who is a Creator; and that God is the Author of the human soul. And that He made the living soul to be creative in its own finite sphere. And further, that the soul, in order to embody itself, under God immanent made the brain, which is thus the anthropoplasm of the human frame upon earth. The brain, from its first principles, conceived, through the Divine wisdom by the soul in it, all the details of its own form, fitting it to be the abode of the mind in all its faculties. The principles are the engineers of the causes, and the causes are the engineers of the effects or realized ends. So that in brain substance you have the body given, just as in a Stephenson you have the steam-engine given. But all is from the soul; because not protoplasm, but anthropoplasm, are being pleaded here. The soul also, which makes the brain mechanic, inventive, contriving for itself, imprints upon it with the form of motion also the power; and in an order and determination stupendous like the galaxies of heaven, it commands a universal motion as the pulse and radiance of a universal life. And as there can be no motion without a corresponding and adequate something moved, there are fluids which are so eminent and so ordinate that they can be embrained and ensouled, and give life to the avenues of the brain, to the body and the blood" (p. 20).

This then is the hidden power, the mainspring of Swedenborg's theory of the brain, which imparts the quality of perennial youth to all its parts, and enables it to live and thrive, and to rule and govern the stubborn and perplexing facts of modern science, after so long a sleep.

What then, let us ask, was the method which Swedenborg employed to establish his unique theory of the brain? His method was essentially analytic; that is, from the circumference of the facts of nature—in the present case of the facts concerning the brain—he strove to reach its central court, whence these facts are ruled and governed.

In analyzing the facts of nature we may, however, endeavour to reach an unknown centre; or we may, on the other hand, be guided by some previous knowledge in relation to the centre.

Swedenborg's analysis is of the latter kind. Thus in investigating the functions of the brain, and of the nervous system in general, his mind is illuminated by certain new doctrines whereby he is safely led from the circumference of the facts to their very centre. Concerning these doctrines he expresses himself as follows: "Since it is impossible to climb or leap from the organic, physical, and material world—I mean the body—immediately to the soul, of which neither matter, nor any of the adjuncts of matter are predicable (for spirit is above the comprehensible modes of nature, and in that region where the significations of physical things perish); hence it was necessary to lay down new ways by which I might be led to her, and thus gain access to her palace: in other words, it was incumbent on me to discover, disengage, and bring forth, by the most intense application and study, certain new doctrines for my guidance, which are the doctrines of forms, of order and degrees, of series and society, of communication and influx, of correspondence and representation, and of modification" (*Regnum Animale*, i. no. 17).

The truth of these doctrines is confirmed by the wonderful system into which he was able by their means to weave all the facts in relation to the brain and the nervous system known at his own time, and we may also say, for they all harmonize, those which have since come to our knowledge.

It appears that Swedenborg in drawing his conclusions spread out before his rational gaze *all* the facts set forth in the writings of the great masters of anatomy and physiology of his time, superadding the rational quantity of those doctrines which he himself had discovered and brought forth "by the most intense application and study." Modern science, on the other hand, as represented by Dr. Ferrier, one of its acknowledged leaders in all matters concerning the brain and its functions, declares that "experiments on animals, under conditions selected and varied at the will of the experimenter, are *alone* capable of furnishing precise data for sound inductions as to the functions of the brain and its various parts" (Functions of the Brain, London, 1876, p. xiv). Ferrier here not only declares in the most direct terms that experiments which strike the natural senses are the only means by which we are able to obtain trustworthy information in relation to those functions which include the highest intellectual operations of the mind; but he also asserts that vivisection *alone* is able to furnish us with precise data for sound inductions as to the functions of the brain, excluding thereby, as of minor importance, all collateral facts concerning these functions which are supplied by anatomy and histology, as well as by pathology.

One of the injurious effects which vivisection in our estimation exercises on the minds of those who indulge in its practice is to contract and limit their intellectual vision to such a point that finally they become blind to all the other facts of science, and seem able to recognise only those obtained by vivisection. A glaring instance of this contraction of vision is pointed out in our Note iv. (vol. i. p. 774 *et seq.*), where it is shown how Ferrier himself in his induction of the functions of the corpora striata and optic thalami totally ignores the anatomical relations which exist between these bodies, and is wholly oblivious of the results at which the anatomists of all times have arrived respecting the origin in these centres of the olfactory and optic nerves.

On the whole, we may say that the experience gained in editing this work has not tended to raise Vivisection in our eyes as a method of Scientific Research. And we cannot ignore the fact that there is another side to the question, one that will naturally be present to the minds of many of our readers. Vivisection is objected to on humane and religious grounds by an increasing class of the community, and also of the medical profession. What, however, is Swedenborg's position in regard to this aspect of vivisection? In his collection of facts he cites the experiments of the vivisectors without condemnation. But we think he simply took the entire range of the anatomical and physiological knowledge of his time and set the facts of the case forth; and, forming his Induction, said, This is the intelligent result, the *rationale,* of these multitudinous experiences. But in deducting the causes of his facts, we do not discover that Swedenborg gained any rational truth from the vivisections which he cites. His induction would have been the same without them. Nay, knowing the specious and persuasive character of facts obtained by vivisection, while quoting the experiments of vivisectors he seems especially careful not to be drawn away by the inferences which they drew from their experiments. Thus while quoting (p. 27 *et seq.*) a marked case of vivisection from Ridley, he is very careful not to adopt the result at which Ridley arrived; namely, that the motion of the brain is synchronous with the pulsation of the heart. On p. 225 he quotes another case of vivisection from Vieussens, which he introduces again at full length in vol. ii. in the chapter on the Olfactory Nerves. By that experiment Vieussens sought to prove that there is no communication between the subdural space and the nares through the lamina cribrosa. But Swedenborg by his induction arrived, as will be shown hereafter, at the opposite conclusion.

According to Swedenborg the only satisfactory way of arriving at a knowledge of the functions of the brain is by instituting a rational induction on the basis of ALL the facts known in relation to the brain. Thus on rational grounds he positively declined to appeal to vivisection in order to settle the debated question of the Motion of the Brain. On this subject he says, "But perhaps you will say, Why all this circuitous and operose deduction when a single *living example* would settle the matter? Be it so; yet the subject upon which we enlarge is well worthy of our pains; for it is only by the course we adopt that we can scrutinize and evolve the *causes* of the wonderful influx of motions established by the mutual connections of the nerves and vessels. . . . For to speak from a cause is to speak to innumerable effects; but to speak from an effect [and thus from a fact of vivisection] is to speak to only a few causes" (i. p. 140 *et seq.*).

We see then the attitude which Swedenborg occupies in relation to vivisection: he quotes its experiments, but distrusts the inferences which the operators drew from them; therefore he repudiates the doctrine laid down by Ferrier that vivisection *alone* is "capable of furnishing precise data for sound inductions as to the functions of the brain and its various parts." We see also that the whole stream of Swedenborg's works, which are in strict accordance with his principles, carry heart and mind away from the method of dissecting living creatures as a means of obtaining genuine principles of scientific truth.

Further, vivisection at Swedenborg's time was not carried to the fearful extent that it is now, when rational principles are at a discount, and when all questions pertaining to what is true and false in physiology are as it were by common consent handed over for settlement to vivisection, which appeals only to the lowest faculty in man, the bodily senses. Such was not the case at Swedenborg's time, and therefore from the attitude which he then occupied in relation to vivisection, we are not justified in declaring what his attitude would be now. For now vivisection is arraigned before the bar of the conscience of the Christian world; and in this country, as leading confessedly to cruelty in many hands, it has been checked and limited by Parliament. On grounds of humanity, therefore, as well as for the sake of saving science from the tyranny of the senses, we may safely affirm that were Swedenborg living now he would not be found among the vivisectors, or in the so-called experimental school of physiology.

From this brief comparison of Swedenborg's method with that of vivisection it appears that the excellency of his method consists first of all in this, that he consults ALL the facts of science accessible to him, and that he does not pick out a limited few in order to make them the basis of his induction.

That he was anxious to have all the facts of science at his disposal appears plainly from the following statement which he made in his first work on the Brain—for he wrote more than one: "In quoting so many facts of importance from those authors who have written on the blood in the brain, it may seem to some that I have given too many extracts. Yet would there had been a hundred times more facts to quote, I would have cited them all, and filled sheets with them; for these facts are just so many truths and lights; and under no other guides and leaders can the causes of things, and those of science be brought out of darkness into light" (De Cerebro, Photolithographed MSS., iv. p. 109).

Again in order to keep his mind free from bias, and not to lean in his inductions towards any particular fact of his own discovery, Swedenborg resolutely refrained from entering the lists with those who make it the business of their lives to enrich science by the accumulation of facts. His words on this subject are well worth considering:—

"Here and there I have taken the liberty to throw in the results of my own experience, but this only sparingly; for on deeply considering the matter, I deemed it best to make use of the facts supplied by others. Indeed there are some that seem born for experimental observation, and endowed with a sharper insight than others, as if they possessed naturally a finer acumen; such are Eustachius, Ruysch, Leeuwenhoek, Lancisi, etc. There are others again who enjoy a natural faculty for contemplating facts already discovered, and eliciting their causes. Both are peculiar gifts, and are seldom united in the same person. Besides I have found when intently occupied in exploring the secrets of the human body, that as soon as I discovered anything that had not been observed before, I began (seduced probably by self-love) to grow blind to the most acute lucubrations and researches of others, and to originate the whole series of inductive arguments from my particular discovery alone; and consequently to be incapacitated to view and comprehend, as accurately as the subject required, the idea of universals in individuals, and of individuals under universals. Nay, when I essayed to form principles from my discoveries, I thought I could detect in various other phenomena much to confirm their truth, although in reality they were fairly susceptible of no construction of the kind. I therefore laid aside my instruments, and restraining my desire for making observations, determined rather to rely on the researches of others than to trust to my own" (*Œconomia Regni Animalis,* i. no. 18).

It may be objected that the anatomical facts of such men as Willis, Vieussens, Ridley, Heister, Winslow, Boerhaave, Malpighi, Lancisi, Morgagni, Wepfer, Leeuwenhoek, Swammerdam, and others, on which Swedenborg based himself in his inductions, have long been superseded by other more trustworthy facts; but after a careful comparison of the facts taught by these men with those contained in the most approved text-books of modern times, we have come to the conclusion that Swedenborg in the estimation of his authorities was quite correct, where he says, "The discoveries of these men, far from consisting of fallacious, vague, and empty speculations, will for ever continue to be of practical use to posterity" (*Œconomia,* etc., i. no. 17).

But these authorities in the following pages speak for themselves; for they appear not in the quaint Latin of the last century, but in a modern English dress, great care having been taken to exchange their antiquated terminology for that at present in use. So presented these ancient authors will be found to describe the various organs of the brain as precisely and accurately as the most exact scholars of our own day.

The great advance made in modern times in relation to the brain and the nervous system in general is in microscopy, and hence in histology; for by the introduction of new methods of hardening the soft substances of the brain and of the nerves, modern observers have been enabled to represent the grey and white substances of the nervous centres, and the tissues of the nerves, in a manner greatly superior to anything attempted in the last century. Besides, the microscope in modern times has reached a state of perfection undreamed of a hundred years ago. And yet there were wonderful microscopical observers even in the seventeenth and eighteenth centuries, such as Malpighi, Leeuwenhoek, Ruysch, Swammerdam; and the faithfulness of Leeuwenhoek's representations of the tissues of the brain, and of the nerves and fibres of the body, could only in modern times be tested and verified. Compare Leeuwenhoek's sketch of the horizontal section of a nerve in vol. iv. of his "Arcana Naturæ," p. 312, with Key and Retzius' magnificent representations of the horizontal sections of the optic and other nerves ("Studien in der Anatomie des Nervensystems," Stockholm, 1875 and 1876).

On comparing the descriptions which Swedenborg collected from the works of the anatomists of the last century with those which we have quoted from modern works on anatomy, and by which we have considered it useful to supplement his collection of facts, it will be found that these descriptions agree in all essential particulars. The modern works on the whole abound more in subdivisions, new names being given to many of these subdivisions. So the medulla oblongata in modern text-books is represented as not extending beyond the pons Varolii; the medulla of the cerebrum beyond that part now passing under the name of the crura cerebri or the peduncles of the cerebrum. These crura or peduncles in the ancient text-books are treated as prolongations of the corpora striata and the optic thalami; while these ganglia themselves are styled the upper and lower beginnings of the medulla oblongata; so that the medulla oblongata by the older anatomists was regarded as extending into these central ganglia. With this exception the divisions of the encephalon and the spinal cord have remained the same.

That Swedenborg's theory of the brain, however, is not contradicted by any new fact discovered since his time is shown at great length in the Notes appended to each of the four volumes of this work. And again, where modern physiology professes doctrines different from those of Swedenborg, it is proved in these notes that Swedenborg, and not modern physiology, is in agreement with the real facts of the case. Often, however, in order to demonstrate the agreement of Swedenborg's theory with the facts of modern science, have we been obliged to go outside the general text-books, and to pick up facts which had been left unnoticed by the authors of these text-books. Not unfrequently also has it happened that facts confirmatory of Swedenborg's positions have turned up only within the last seven or eight years. A fruitful source of such discoveries has been the elaborate work of Swedenborg's countrymen, Key and Retzius, on the anatomy of the nervous system and the connective tissues, published in 1875 and 1876. To those familiar with the literature on the brain the list of authorities quoted at the end of this preface, and at the close of Note i., will be an evidence that in our attempt to supplement Swedenborg's facts from modern sources no work of any consequence on the subjects treated in volume i. has been left unnoticed.

In order to economize our space, in making these additions from modern authors, we have confined ourselves to the most approved text-books on anatomy in use in England and on the Continent, namely, to those of Quain, Todd, and Ellis in England, of Cruveilhier in France, and of Luschka and Henle in Germany. From these authors we selected what appeared to us the best presentation of any of the parts connected with the brain, and these authoritative statements we supplemented from monographs and special treatises on parts of the brain. The authors on whose works we have drawn most extensively are Key and Retzius and Meynert. Other authors quoted in the text of vol. i. are Monro, Reil, Burdach, Arnold, Solly, Jung, Luschka, Hirschfeld, Gerlach, Heubner, Duret, Mierzejewsky, Ferrier, Pitres, Bevan Lewis. In the Editorial Notes appended to Vol. I. we have studied the bearing which the facts quoted from these authors have upon the various parts of Swedenborg's theory of the brain, strengthening these facts, when necessary, by references to other writers, and refuting the theories set up by other authors.

In Note i., "on the Motion of the Brain," which deals with the fundamental principle of Swedenborg's theory, we have referred to the works of upwards of a hundred authors, and with the aid of the modern school of physiologists representing the "Graphic Method" introduced by Professor Marey in Paris, we believe that every one of the positions laid down by Swedenborg in reference to the motion of the brain is now definitely and satisfactorily established.

The following are some of the principles and scientific facts in relation to the brain and the nervous system which Swedenborg set forth in his manuscript treatise on the Brain, written between 1741 and 1744; in his "Œconomia Regni Animalis," published in 1740 and 1741, and in his "Regnum Animale," published in 1744 and 1745; which principles and facts have since been discovered by other observers, and are attributed to them.

1. The coincidence of the motion of the brain with respiration, which was first publicly set forth by Swedenborg in his "Œconomia," etc., Vol. II., published in Amsterdam in 1741, pp. 1-34, 4to. The discovery of this fact is now universally attributed to J. Daniel Schlichting, a physician of Amsterdam, whose observations on the motion of the brain were published in 1750 in the "Mémoires de mathématique et physique présentés à l'Académie Royale des Sciences. Savants étrangers," tom. i. p. 113. See Note i., on the Motion of the Brain, p. 666.

2. The extension of the respiratory motion of the brain and lungs to the extremities of the body, which Swedenborg distinctly announces in his "Regnum Animale," vol. ii., published at the Hague in 1744, pp. 116-121. The discovery of the respiratory motion in the extremities is attributed to Dr. Piégu, who published in 1846 a "Note on the Double Movements observed in the Limbs," etc. (Comptes Rendus, Académie des Sciences, 1846, tom. xxii. p. 682.) See Note i. p. 669 *et seq.*

3. The independence of the animatory motion of the brain of the respiration of the lungs, which is declared by Swedenborg in his "Regnum Animale," vol. ii. pp. 122, 123, and which has

been experimentally established by Mosso in his "Kreislauf des Blutes," Leipzig, 1881, p. 71, fig. 20. See on this subject Note i. no. 20, p. 671 *et seq.*, and *ibid.*, no. 12, p. 659.

4. The reality and existence of the cerebro-spinal fluid, which Swedenborg discovered as early as 1736 or 1737, a whole chapter of his first work on the brain (Photolithographed MSS., vol. iv. pp. 193-203) being devoted to this subject. See Part II. of the present work, chap. iv. The same subject he further treats in Part I. chap. xxiv., on the fourth ventricle, and in Part II. chap. iii. on the arachnoid membrane. The discovery of this liquid is ascribed to Cotugno, whose treatise, entitled "De ischiade nervosa commentarius," was published in Naples in 1764. See on this subject our note on the Cerebro-spinal Liquid in vol. ii.

5. The circulation of the cerebro-spinal liquid through the interstices between the fibres of the nerves of the body, which Swedenborg describes most minutely in Part II. of the present work, in nos. 493, 503, 509, 511, 512, and 529-531. See our note on the Cerebro-spinal Liquid in vol. ii. This fact, which has not yet been adopted by the compilers of our text-books in anatomy and physiology, is confirmed in all its particulars by Key and Retzius in their "Studien," etc., vol. ii. pp. 1-125; and their results are confirmed by Quincke and Schwalbe; by the latter so far as the optic nerve is concerned.

6. According to Swedenborg, the fibres of the cerebrum tend towards the anterior parts of the spinal cord, but the fibres of the cerebellum, *i.e.* of its third or restiform process, seek the posterior parts. See Part I. chap. xxxii. on the Spinal Cord and the Production of its Nervous Roots, no. 805. Meynert, the most recent, and one of the most successful investigators of the course of the fibres in the brain and the medulla oblongata, declares that "the cerebellum sends no fibres directly to the antero-lateral columns of the spinal cord, but on the other hand gives rise to a great part of its posterior columns" (Brain of Mammals, in Stricker's "Manual," etc., American edition, pp. 714, 716, 717); while he shows, on the other hand, that "the anterior pyramids of the medulla oblongata pass into the lateral columns of the spinal cord (*ibid.*, p. 686); and again, that "all the spinal cord fibres belonging to the basis cruris cerebri take part in the decussation of the anterior pyramids" (*ibid.*, pp. 707, 709); and further, that "groups of fibres of the tegmentum cruris cerebri are destined to form the anterior spinal columns" (*ibid.*, p. 719).

7. Swedenborg teaches plainly that the fibres of the cerebrum and cerebellum run through the longitudinal dimension of the spinal cord, while those fibres which the spinal cord generates

from its own grey substance intersect the former transversely and obliquely. See Part I. chap. xxxii. nos. 804, 805. Solly[1] says that "Bellingeri was the first who in 1823 demonstrated the double origin of the spinal nerves from the grey as well as the white matter of the cord; that this fact, however, was not established, or generally believed in England, till 1837, when Mr. Grainger published his treatise entitled 'Observations on the Structure and Functions of the Spinal Cord,' in which he distinctly enunciates this important truth."

8. The anterior province of the cerebrum, according to Swedenborg, is the seat of the intellect; thence also the voluntary efforts proceed. "If this portion of the cerebrum is wounded," says he, "then the internal senses—imagination, memory, thought—suffer; the very will is weakened, and the power of determination is blunted. This is not the case if the injury is in the back part of the cerebrum." See Part I. p. 73. Dr. Althaus in summing up the results obtained by Fritsche and Hitzig in 1870, and Ferrier a short time afterwards, says, "The anterior or frontal lobes, corresponding to the forehead, are the actual seat of the intellect. . . . Patients have now and then recovered from the most fearful injuries to the anterior lobes; . . . but it has always been shown on close examination that there had been a profound change in the character and behaviour of such persons, and that their temper and their moral faculties had become deteriorated" (*Nineteenth Century*, 1879, p. 1031).

9. Swedenborg's division of the brain into lobes differs from that in use at the present day. His division is that which is presented by the median aspect of the hemispheres. His highest lobe is bounded by the marginal convolution and the quadrate lobule; his middle lobe by the lower part of the marginal convolution and the gyrus fornicatus; and his third lobe is identical with the temporo-sphenoidal lobe. On the basis of this division he says, "The muscles and actions which are in the ultimate parts of the body, and thus in the soles of the feet, depend more immediately upon the highest portions of the cerebrum; upon the middle lobe the muscles belonging to the abdomen and thorax; and upon the third lobe those which belong to the face and head; for they seem to correspond to one another in an inverse ratio." See Part I. no. 68. As shown in Note i. in vol. iv., this is a general statement of the results at which Ferrier arrived by an electrization of the cerebral hemispheres of living animals. See Ferrier's "Functions of the Brain," pp. 141-157.

10. Swedenborg says, "The corpora striata are vicarious

[1] "The Human Brain," etc., second edition, London, 1847, p. 202 *et seq.*

cerebra, and they succeed in the place of the cerebrum whenever it is deprived of its power of acting" (i. no. 939). Again he says, "The corpora striata initiate motions which at first originated with the cerebrum and were voluntary; for it is a well-known fact that voluntary acts by daily habit become spontaneous, or that habit is like second nature" (i. no. 941). This is exactly what Ferrier and his school have established by experimenting on the corpora striata. Dr. Althaus in summing up their experiments says, "The central ganglia (*i.e.* the corpora striata and the optic thalami) have the function to render certain complex movements which are intimately connected with sensations, and which are, in the first instance, only excited by volition and consciousness, gradually, as it were, mechanical and automatic" (*Nineteenth Century* for 1879, p. 1026). For further particulars see Note iv. in the present volume, on the Functions of the Corpora Striata and Optic Thalami, p. 770.

11. Swedenborg established the connection of the corpora quadrigemina with the sense of sight. He says, "These fibres [*i.e.* those of the corpora quadrigemina] tend upwards into the surface of the optic thalami, and at the same time penetrate more deeply into them; and thence in conjunction with the fibres of the cerebrum they direct their way towards the bulb, the coatings, the humours, the iris, and the pupil of the eye, that is, chiefly towards those parts of the eye which are being adjusted to the objects at the time, and indeed spontaneously" (i. no. 531). Ferrier says, "Flourens [in 1842] first experimentally demonstrated that the optic lobes [*i.e.* corpora quadrigemina] were the centres of co-ordination between retinal impressions and movements of the iris" ("Functions of the Brain," p. 71). And again he says, "The facts of anatomy and those of physiological experiment mutually support the view that the corpora quadrigemina, though not the centres of conscious vision, are centres of co-ordination of retinal impressions with special motor reactions" (*ibid.*). See Note iii. Sub-section E, on the Functions of the Corpora Quadrigemina, p. 764 *et seq.*

12. Concerning the corpus callosum Swedenborg says that "its fibre is concentrated in the body of the fornix" (i. no. 37). "Thence," he further says, "these fibres are not allowed forth any further, nor do they return to their origins, but they stop there and are consumed there" (i. no. 443). A similar view to this has been adopted fifty years later by Gall, Reil, Burdach, Arnold, Herbert Mayo, Solly, Hirschfeld, and others. Meynert says, "As regards the system of the corpus callosum, microscopic examination of cross-sections from small mammal brains confirms the opinion expressed by Arnold, that the corpus callosum

is made up solely of commissural fibres, connecting symmetrical territories of the cortices of the two hemispheres, and not, as Foville wished to prove, of fibres of the projection system, crossing the middle line to enter the ganglia of the opposite side" (in Stricker's "Handbook," etc., American edition, p. 676). See Note iii. Sub-section C, on the Functions of the Corpus Callosum, p. 730 *et seq.*

13. According to Swedenborg, the choroid plexuses in the lateral and third ventricles must be made up in some measure by the fimbriæ of the fornix, fibres of which enter into the texture of the choroid plexuses, for the sake of the important use detailed in Part I. no. 511, as well as in Note iii., Sub-section C, which deals with the function of the choroid plexuses. Science generally regards the texture of the choroid plexuses as a continuation of the velum interpositum; but Key and Retzius by their recent investigations have shown that the choroid plexuses in the lateral ventricles consist of two leaves, of which the upper leaf is derived entirely from the fimbria of the fornix, and the lower leaf partly. See Key and Retzius, "Studien," etc., vol. i. pp. 103-107, and also below, pp. 599-604.

14. Swedenborg says, "In order that the brain may have the faculty of performing its functions, it must be constantly purged and relieved from that liquid which is perpetually expressed from its members and arterial vessels. . . . There are a number of foramina by which the lamina cribrosa of the ethmoid bone is pierced in many places. Not only fibres, but also the pia, and at the same time the dura mater, pass through these foramina; the pia mater investing the fibres, and the dura mater lining the orifice. . . . The above liquid [between these membranes] passes into the cavities of the nose through those openings." The discharge takes place during the expansion of the cerebrum, when, according to Swedenborg's theory, the nerves are extended and elongated, thus granting passage to a liquid through the foramina of the lamina cribrosa. "In defunct brains, however," he declares, "and in such as are collapsed, these communicatory passages must needs be closed." See Vol. II. nos. 825-827. The truth of this doctrine, which is diametrically opposed to that set forth in our text-books, has recently been confirmed by experiments which Key and Retzius made on the bodies of rabbits that had just been killed. Subdural injections penetrated through the foramina of the lamina cribrosa into the mucous membrane of the nares, and "through special channels in the epithelium of that membrane reached its surface." In human subjects they now and then succeeded in injecting the perineural sheaths of branches of the olfactory nerve which passed through the lamina cribrosa.

See Key and Retzius, "Studien," etc., vol. i. p. 220, and also our Part I. chap. xxxiii. on the Olfactory Nerves.

15. In relation to the cortical substance of the brain Swedenborg says, "The brain is made up of as many similar forms and natures as it has discrete cortical parts" ("Œconomia," etc., Part II. no. 304). "External sensations reach no goal beyond the cortical spherules, since these are the beginnings of the nervous and medullary fibres. . . . Therefore it is the cortical substance collectively that constitutes the internal organism, corresponding to the external organism of the five senses" (*ibid.*, no. 191). "The cortical substance is the unit of the whole brain: in this unit or substance, then, we ought to find that superior power of which we are in quest. Therefore in this, and not in any ulterior unit, because the cortical substance is the ultimate unit of the brain, we ought to find the soul's faculty of understanding, thinking, judging, willing" (*ibid.*, no. 304). Swedenborg wrote and published this in 1741, and yet how very much like a sentiment of Dr. Althaus published in 1879: "The highest development of brain-matter is found in the hemispheres, convolutions, or *grey* [cortical] *surface of the brain*, which is the material base of all mental and moral activity. This portion of the brain, which may be called the seat of the soul, is not a single organ, as was formerly supposed, but consists of a number of thoroughly differentiated organs, each one of which possesses certain functions, yet is in the closest possible connection with all the others. To define all these various organs with accuracy, to determine their intimate structure as well as their individual energy, . . . is the greatest problem for the anatomy and physiology of the twentieth century; and when this problem is solved, a complete revolution in psychology must be the result" (The Functions of the Brain, in *Nineteenth Century*, 1879, p. 1027 *et seq.*).

16. As to the origin of the cortical glands Swedenborg says, "The cortical substance is so connected with the minute vessels of the brain that you would believe that the cortical glands derive their origin from these vessels. . . . The above-mentioned glands do not spring forth immediately from the little arteries; but while the arterial vessel continues its course, it produces from its coating such an offspring, and nevertheless pursues its course beyond as an artery" (Part II. no. 329). In offering this as his conclusion he says, "We own we are not able to add here ocular experience in the way of confirmation; for who is able to reach with the microscope the ramifications of the arteries themselves, and the stamina or threads which burst out of the coatings of the arteries? . . . Meanwhile, using analogy and comparison for principles, we deduce thence a series of

consequences; and if these are fully borne out by the individual proofs of experience, we must come forth crowned with certainty as to the truth of our principles. . . . This, then, is the consequence or conclusion: *The cortical glands hang down and sprout forth from the sides and coatings of the producing and generating arteries, scarcely otherwise than as grapes and berries are wont to hang down and to sprout forth around the tender tendrils and shoots of a tree, and do not spring forth and produce their fruits from the woody and marrowy part, but from its inner and outer bark*" (*ibid.*). The confirmation of this conclusion was furnished quite recently by Bevan Lewis in a paper published in the "Proceedings of the Royal Society," vol. xxvi., London, 1877. He says, "The next stage in my observations was arrived at by the discovery that a minute blood-vessel invariably ran in close contact with all the large nerve-cells. . . . In all cases I never failed to recognise on careful examination a small capillary either passing immediately across the nerve-cell or running with a gentle curve along the confines of the pericellular space. . . . With regard to the mode of connection, it must be remembered that the pericellular sacs are laterally disposed along the sides of the smaller capillaries, and in no case occupy a terminal position. . . . Does this distribution in any way indicate the mode of development of the nerve-cell? With the view of answering this query I examined several brains of fœtal and adult animals. . . . These sections [*i.e.* sections from these brains] strongly confirmed the views adopted above, and indicate likewise a development of nerve-cells from within the perivascular sheath, projecting from its walls in egg-shaped ampullæ. The nerve-cells are seen in the specimens to follow definitely the course of the blood-vessels, and often surround the latter in crowds, and assume with the direction of the vessel a linear or arched course. . . . Such appearances would seem to indicate that the nerve-cells of the cerebral cortex are lymphatic outgrowths" (pp. 330, 331). See also vol. i. p. 362 *et seq.*

17. From the point of view of his rational induction Swedenborg declared that at the base of the fourth ventricle in the calamus scriptorius there must be one or several foramina through which the cerebro-spinal liquid is discharged from that ventricle. He says, "Upon examining the connection of this ventricle with the double lamina of the pia mater—the tela choroidea inferior—it appears that this lymph is expressed or excreted between the duplicatures of that membrane, . . . which appears remarkably dense around the terminus of the calamus scriptorius. . . . It is thus discharged into the duplicature between the pia mater and the arachnoidea, and thence through the continuous ducts and follicles of the arachnoidea

it is derived especially into the posterior part of the medulla oblongata, where that membrane floats about quite densely and loosely" (Part I. no. 714). A distinct foramen in the tela choroidea inferior has since been discovered by Magendie, which has been called after its discoverer, the foramen Magendii. Concerning this foramen Marc Sée says that "its dimensions are very variable, and that it seems to be but one of the lacunæ which are left between the connective fascicles of the lamina, *i.e.* the tela choroidea" (Revue mensuelle de Médecine et Chirurgie, iii. 1879, p. 300).

18. In addition to the place pointed out by Swedenborg, where since his time the foramen Magendii has been discovered, he hints also at the existence of a channel from the fourth ventricle immediately into the spinal cord. He says, "Whether there are still other channels for the discharge of the lymph; namely, whether such a channel is opened immediately from the calamus scriptorius into the medullary portion of the spinal cord, to my knowledge has not yet been discovered. For this purpose the fourth ventricle is contracted into the narrower form of a goose-quill (calamus scriptorius)" (Part I. no. 714). This supposed channel has since been discovered, and is described in the most recent text-books of anatomy under the name of "the central canal" of the spinal cord. That this central canal is demanded by Swedenborg's theory of the motion of the encephalon and the spinal cord is shown in the note on the Central Axis of the Brain and Spinal Marrow in vol. ii.

The cases here submitted to the careful consideration of the reader, include some of the most remarkable instances in which Swedenborg anticipated the discoveries of later anatomists and physiologists. We have collected them with a view of proving thereby the excellency of the method which he employed, and by which he was enabled from an apparently meagre supply of facts to deduce true scientific principles. Without those rational doctrines to which we have alluded above, he would not have been able to deduce a theory of the brain so perfect, that during an advance of one hundred and forty years science has not been able to go beyond a single position which he then and there laid down.

Foremost among these doctrines is the Doctrine of Degrees—of those degrees which exist between end, cause, and effect, and the equivalents of which in man are the soul, the brain, and the body. These three occupy each a distinct sphere in man. The sphere of the soul being the highest, the sphere of the brain the intermediate, and the sphere of the body the lowest. These three spheres, Swedenborg holds, are perfectly distinct from each other; and yet the higher spheres are present in the lower sphere, and impart to it life and the power of acting, just as the cause is present in the effect, and imparts to it life and the power of acting. That property, however, which enables the higher to flow into the lower, and to be present therein, is Correspondence. The higher thus corresponds to the lower and is represented in it, and therefore the higher can flow into the lower, and be present in it, without on that account being absorbed and swallowed up by the lower. And, on the other hand, as the higher sphere is represented in, and corresponds to the lower, we may therefore draw inferences and conclude from the form and organization of the lower sphere as to the form and organization of the higher sphere. On this ground Swedenborg holds that as the heart is the centre of motion in the body, and as there is a system of afferent and efferent vessels conveying the blood from the heart to the circumference of the body, and thence back again to the heart, so in the brain there must be centres exercising a function corresponding to that of the heart, and likewise afferent and efferent vessels conveying a fluid of the most refined nature from the brain to the interior parts of the body, and thence back again to the brain. The grey substance, according to Swedenborg, exercises in the higher sphere of the brain a power analogous to that which in the lower sphere of the body is exercised by the heart, while the afferent and efferent vessels are the fibres of the brain and of the nervous system in the body. In addition to the sensitive and motory fibres, however, which the cortex of the brain despatches to every part of the body, Swedenborg maintains that there are also fibrous vessels which perform a function analogous to the veins of the body, and by which nourishment is conveyed from the circumference of the body immediately to the cortical substance of the brain. These fibres Swedenborg calls *Corporeal Fibres.* Their origin and use is described minutely in Part II. of the present work. A similar relation to that which exists between the brain and the body, according to Swedenborg, exists also between the brain and the soul, which occupies a sphere interior to that of the brain.

The gross method of vivisection, on the other hand, and indeed the method followed by the whole modern school of anatomy and physiology, acknowledges only one sphere, and hence only one degree in man, the parts of which are related to one another like the greatest and the least, the hard and the soft, the gross and the rare.

The respective value of these two methods of looking at nature, Swedenborg explains in Part I. p. 78, where he endeavours to show that the modes or activities of a lower sphere cannot ascend into a higher sphere, but that in that sphere they give rise to a higher kind of modes and activities. He says, "Those modes which from the senses press into the superior sphere, put on there as it were a new habit; they lay aside more and more the finite limits, and become rational modes; and they contemplate only truth and falsity, and are affected by moral, and finally by spiritual good and evil. This at first blush appears indeed paradoxical, but this is due to an obscure notion, or to an entire absence of notion, of the doctrine of order and of degrees; or because we have not imagined to ourselves any other order, or any other degree, than such as exists between what is greatest and what is least. The relation between greatest and least exists indeed in every sphere. The higher sphere, on the other hand, puts on an altogether different essence and nature, which is unable to penetrate to the sensation of a lower sphere; but the higher it is, the nearer it approaches to the spiritual nature and essence of the soul."

In order that science may be cultivated to the best advantage, it requires feet to stand on *terra firma*, and wings to rise to the rational and intellectual heights of the soul. The ordinary men of science who make it their business to enrich the domains of its natural facts, cultivate the feet of science; but those who, like Swedenborg, believe in the eternal, rational truths of science, which are akin to the principles of what is right and wrong on the civil, moral, and religious planes of our existence—these are able to lend wings to science, and to impart life and a soul to the dead facts of merely sensual knowledge.

These persons also, from man, who is the image of his Creator, look down on the animal and vegetable kingdoms below; and therefore they behold in man the ideal development of the brain; while in animals in a decreasing ratio they perceive a deviation from the perfect brain of man. As the animals therefore degrade from a higher into a lower stage of development, their cerebra and cerebella are found to diminish in size and organic perfection; and as these organs decrease in importance, other organs, such as the corpora quadrigemina, the spinal marrow, and also the optic and olfactory nerves, rise in power. Nay, at last, as in the caterpillars, nearly the whole encephalic power seems transferred to the spinal marrow; and therefore, according to Swedenborg, the spinal marrow in silkworms not only performs the function of the spinal cord, but the functions of the cerebrum and cerebellum are also in a great measure transcribed into it. We need not wonder then that in the lower order of animals the higher nervous centres may be mutilated or totally excised, while the bodies of these animals are still in a condition to live in a certain way by the aid of the lower nerve centres.

Those who regard the senses as that faculty in man which is to determine the causes of natural phenomena, do not consider the diminished nervous centres of animals in the light of the nobler organs of man; but they invert the process, and look upon the encephalic organs of man from those of the lower animals. As in the fish and pigeon, for instance, the power of the cerebrum and cerebellum, compared with that of the spinal marrow, is found to be comparatively small, and as the spinal marrow, without the higher organs, is able in these animals to continue the functions of the body in a certain way, they at once pronounce it to be a scientific truth that the cerebrum and cerebellum in man have no more power than they possess in these animals. Thus Dr. Carpenter, in his text-book on "Human Physiology" (seventh edition, sec. 568), makes the following declaration in respect to the cerebrum of man: "The anatomical relations of the cerebrum to the other encephalic centres clearly demonstrate that it is not one of the essential or fundamental portions of the nervous system, but a super-added organ receiving all its impulses to action from the parts below, and operating upon the body at large through them."

As in the lower animals a great portion of the power of the cerebrum and cerebellum is transcribed into the corpora quadrigemina and into the spinal marrow, these latter organs in such animals are relatively of more importance and power in preserving the state of their bodies than their cerebrum and cerebellum; yet it does not follow by any means that such also is, and must be, the case in man.

This, however, is but one of the many fallacious consequences resulting from the practice of regarding the perfect brain of man in the light of the imperfect brains of animals, and of extending to the brain of man the conclusions which have been drawn from the imperfect state of the brain in the lower classes of animals.

Another principle prolific in important results is the Doctrine of Series and Society, according to which there is no independent organ or part in the body, but all its parts are wonderfully subordinated to, and co-ordinate with, one another. Swedenborg, therefore, in determining the function of any part in the body studies most carefully its anteceding and succeeding parts, and thus the series which it constitutes with other parts, and the condition under which it is associated with them. This condition, however, is mutual usefulness, and that principle of mutual usefulness, or, as he terms it, of Use, he has first pressed into the service of science as an indispensable means of arriving at a knowledge of the causes in the human body.

On this subject he says, "The use or effect which carries out the end must be the first object of analytical inquiry. The nature and quality of a member or organ [of the human body] is known from the use. The use determines what a thing is in itself, or in its own form; what it is in series with other things which are contiguous to it or surround it, and which in continuity precede, and in continuity follow it; it determines also what it is, in order, with those which are above and below, or prior and posterior to it. All these and their uses indicate the nature and quality of the thing under investigation. The use and end also are the first things which manifest themselves; for the end is in a manner all in all in every stage of the progress, from first to last, the very soul of the thing. Thus all things that belong to the body, and that flow forth into act from the body, manifest to the life the quality of the soul" (*Regnum Animale*, Part I. no. 32).

The relation which this doctrine of series and society holds to the doctrine of order and degrees discussed above, Swedenborg thus explains: "We must clearly distinguish between those things which precede and follow continuously, and those which are prior and posterior. . . . Those things which *precede and follow continuously* are in the same series, or in the same degree; members of the same society; and they are homogeneous, for they are referrible to the same, or to similar unities. *Prior* and *posterior* things, on the other hand, are in series and degrees which are above or below; as the cerebrum, the cerebellum, and the medullæ continuous therewith, relatively to the organs of the body; or as the medullary and the nervous fibres, relatively to the moving fibres, which are the unities of the muscles: the former are above, and are not homogeneous with their inferiors, for they are the causes and the principles of posterior things" (*ibid.*, footnote *b*).

The principle of series which governs the connection of the various medullary portions of the brain, and determines the course of their fibres, has of late been followed out with the most painstaking exactness by scientific explorers and reformers of the stamp of Reil and Meynert. And yet this principle is constantly violated by the modern school of physiology, which draws its inspiration from vivisection. According to that method the spinal cord, the medulla oblongata, the corpora quadrigemina, the cerebellum, and the ganglia of the great sympathetic nerve, are all treated as independent centres of motion; and the endeavour of those who apply this method would almost seem to consist in trying to prove the independence of these organs from one another, and from the cortex of the cerebrum.

There is a difference, however, between the series resulting from a continuity of fibres and thus of structure, and between the series of uses performed by contiguous organs. It is this latter principle which has disclosed to Swedenborg the functions of those obscure bodies, the pineal gland, the infundibulum, and the pituitary gland; for it pointed out to him the relation which these bodies hold on the one hand to the ventricles and their foramina, as well as to the fornix, the corpus callosum, and the choroid plexuses; and on the other hand to the system of sinuses by which the pituitary gland is surrounded. In short, it enabled Swedenborg to establish the wonderful *chymical laboratory of the brain,* where the white, that is, the lymphatic blood, the parent of the red blood, is elaborated, and without which the lymphatic supply in the body would be speedily exhausted.

But the most sublime acquisitions which Swedenborg's powerful method of induction enabled him to make are in the sphere of the soul, and hence in that sphere which governs and controls sensation and motion, and which is the organic home of intellection and volition. Swedenborg applies there the higher form of his method of induction, which occupies the same relation to its lower form that the higher analysis of the integral and differential calculus holds to analytical geometry. An exploration of the hidden depths of the cortical substance by means of his inductive method leads him to the principles of a rational psychology, by which he is enabled *a priori* to determine the character of the various affections and disorders of the higher and lower minds, and of the diseases to which the brain and the nervous system in general are exposed.

Swedenborg's theory of the brain is therefore in reality an embodied system of philosophy; and yet a system which is not an arbitrary creation of the human mind, and independent of the facts of the human body, but a system in which philosophy and the solid facts of science, theory and practice, are so intimately blended that you can scarcely tell where the facts end and where the theory begins.

As Swedenborg by his inductions, therefore, has successfully and harmoniously fitted together the solid facts of the science of his day, and as after the lapse of a hundred and forty years the truth of his inductions is still confirmed by the host of facts which science since his time has accumulated, we have the greater surety that the whole of his theory of the brain is true, and that, like the truth, it will stand for all ages to come.

The manuscript from which the greater part of Swedenborg's work on the brain has been translated was discovered by the editor in Stockholm in 1868, whither he had been sent by the General Convention of the New Church in America for the purpose of instituting a careful examination of all the MSS. of

Swedenborg which are at present preserved there in the Library of the Academy of Sciences. This MS., under instructions received from the Committees appointed by the General Convention of the New Church in America and the General Conference of the New Church in Great Britain, he had photo-lithographed; and it is from the facsimile copy of the original MS. contained in volume v. of the Photolithographed MSS. of Swedenborg that Parts I. and III. of the present work have been chiefly translated. Of these Part I. fills two volumes, viz. vol. i. and vol. ii., and Part III. one volume, viz. vol. iv.

Part II., which constitutes vol. iii., has not been prepared by Swedenborg for the press, and the editor had to compile it from the various printed and MS. works of the author. The greater part of the volume is translated from a treatise entitled *De Fibra*, which Dr. J. J. Garth Wilkinson edited in the Latin language as part iii. of the "Œconomia Regni Animalis." One chapter on the Animal Spirit is introduced from a little work embracing several monographs which Dr. Wilkinson edited under the title, *Opuscula quædam argumenti philosophici*, and which he translated into English under the title, "Posthumous Tracts." Another chapter treating of the Cortical Substance is introduced from part ii. of the "Œconomia," etc. And the remaining chapters are taken from the author's MSS. reproduced in vol. vi. of the photolithographed edition of Swedenborg's MSS., and also in vol. iv., which is entitled *Fragmenta de Cerebro*.

These "Fragmenta de Cerebro" are what remains of an earlier work of Swedenborg on the subject of the Brain, which has not been superseded altogether by the later work. For in the first place it treats of subjects which Swedenborg had reserved for Part II., our volume iii.; and besides, in his later work Swedenborg carefully confined his theory to the facts known at his time. In his earlier work he allowed a freer scope to his analysis, and while repeatedly going beyond the facts of his time, in his forecasts he not unfrequently anticipated important scientific facts and principles.

Whenever Swedenborg thus anticipated future facts, as in the case of the dura mater, pia mater, corpus callosum, and fornix, we have drawn on the substance of the earlier work for appendices to the chapters of the later work. Sometimes these additions are of great value, and in the chapters on the Corpus Callosum and the Fornix the appendices are more than twice the size of the chapters to which they are appended.

In order to exhibit the whole of Swedenborg's theory of the brain we have in this manner drawn more or less on all his published and unpublished writings, and the parts extracted we have inserted either bodily into the work itself, like chapter ii. of volume i., which treats of the motion of the brain, and to which Swedenborg referred in the text, or we introduced them in the form of appendices to the several chapters, distinguishing them from the body of the work by a special method of numbering. Thus the last paragraph in chapter iv. on the Dura Mater is numbered 286, and this number, with the addition of the letters *a*, *b*, *c*, *d*, etc., viz. 286*a*, 286*b*, 286*c*, 286*d*, etc., is continued through the whole of the appendix.

The same system of numbering is introduced also in the case of those extracts from "Modern Authors" by which Swedenborg's quotations from the old authors have been supplemented.

Again, inasmuch as Swedenborg makes frequent mention of the movement of respiration as being universal in the body, and as corresponding there to the movement of the brain, his chapter on the Lungs is given, among the Editorial Notes in the appendix to Vol. I., to complete the subject.

The quotations made by Swedenborg himself from the anatomical authorities of his day have all been verified, and as in his MS. he gave only the extracts, without any references to the pages and chapters of the works of the authors from which they were taken, the references have now been supplied at the expense of considerable labour and patience on the part of the editor.

In order to enhance the use of the present work, it is the intention of the editor in an accompanying atlas to reproduce some of the most approved drawings of the brain and its parts.

In conclusion the editor takes great pleasure in acknowledging the valuable aid which he has received in the publication of the present work from the Rev. Augustus Clissold, M.A., and Dr. J. J. Garth Wilkinson. The former by his munificence has enabled him to include in the present edition the additions from the Modern Authors and the extensive Editorial Notes, by which it is hoped the present work, though written so long ago, has been brought up to the level of modern science. And the latter by his most painstaking assistance in the proof-reading has in a most efficient manner seconded the editor in his endeavour to introduce Swedenborg into the circle of modern science in a becoming and worthy garb, and speaking a language which, while being clear and intelligible, is at the same time not destitute of the graces of a pure English style.

As a third among those who by their sympathy and generous aid have assisted in the publication of Swedenborg's work on the Brain, we have to mention here the late Rev. Henry Wrightson, M.A., who had intended to defray the whole cost of

translating and publishing this work, but who died just on the eve of making a contract to this effect with the publisher.

May this work be a means of directing the attention of the learned to Swedenborg's method of investigating the facts of nature; the only method by which science can be emancipated from the thraldom of the senses, and freed from the ban under which the advocates of vivisection pure and simple would place it at the present day.

LONDON, *September* 22, 1882.

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EDITORIAL NOTES.

PART I.

THE ENCEPHALON, SPINAL CORD, AND THE NERVES IN GENERAL

INTRODUCTION.[1]

1. In every universe, in every world, kingdom, body, or system there are essences of a superior and an inferior kind. Things universal and things individual agree in this, that in the highest or supreme things is the idea or ideal of the universe which is below; and that in the lower things is a representation of the universe which is above. It therefore follows that that which is higher or superior is the exemplar of those things which are below; and that that which is below is the type and image of those things which exist above. That which is highest or supreme in every system is either called soul, or is compared to the soul; that which is lower and lowest, however, is either called body, or is compared to the body. In the highest or supreme things, where reside the ideas or ideals of the universe, are the beginnings or principles of the lower things. In the lowest things—ultimates—are the effects which are ultimate determinations from the principles, or things determined by the principles through causes; wherefore the middle ground is occupied by the causes, which depend upon the principles, and which are in the place of principles to the effects, so that they are the middle or mediate causes for the principles in respect to the effects. Each series, therefore, in order that it may be determined, is distinguished into its higher and lower SPHERES: the highest is the sphere of principles, the middle the sphere of causes, and the last that of effects. These spheres are subordinated and co-ordinated in such a manner that the highest, as an exemplar

[1] From Codex 58, Photolithographed MSS., vol. vi. p. 58, where the author makes the following statement respecting it: "Preface to the Part on the Brain, to be placed immediately before chapter i."—Editor.

and an ideal, has respect to all those things which are below it, and that it takes cognizance of everything that exists there in reality; nay, that it even disposes into action the lower things according to its representation in them: and again, that the lowest, as a type and image, refers back to the highest that which exists in reality and happens; and that it has respect to this highest as represented in itself, and obeys it, being subordinated to its beckonings and nods. There is therefore a wonderful intermediate bond, according to which that which is highest or supreme flows into that which is lowest, and the lowest flows back to the highest; so that all is in concord; that there is one mind and a unanimous consent in all things, and hence an influx and reflux; and that there is in reality a harmony which is co-established, and which the highest or supreme ideal contemplates in itself so to say as pre-established, because as simultaneous.

2. It follows thence that in every series, the greatest as well as the least, in order that it may be fully determined, there must be three spheres—namely, *first*, the sphere of principles; *secondly*, that of causes; and *thirdly*, that of effects: consequently that in the sphere of effects is represented the type and image of all those things which are contained ideally in the highest or supreme sphere, or in the principles; that the body consequently is the image of the soul, and that as a type it is organically formed in accordance with its idea: wherefore by the one we are able to be led to a knowledge of the other; and from the body we are able to behold what is contained in the soul, and from the soul what is contained in the body. The physical investigation of the body, and the psychological one of the soul, both joined together, lead us therefore to a full knowledge of either; nay, the investigation of the body leads us to a knowledge of the universe, and of all the things in the universe; for a similar order, and similar laws of order reign everywhere; and, further, it leads us to a knowledge of nature which presents differences only in specific and particular things.

3. The sphere of effects in our animate world is properly that

which is called body, or that which is constituted by the viscera of the abdomen and the thorax, and by the organs of motion and of the external senses. The sphere of causes, however, is properly the cerebrum, the cerebellum, the medulla oblongata, and the spinal marrow. The sphere of principles, finally, is the cortical and grey substance regarded as it were from its individual constituents. These are the spheres of which our animal system is organized. The sphere of effects has been discussed in preceding volumes;[1] we are about to treat now of the sphere of causes, or of the brain; and afterwards of the sphere of principles, or of the cortical substance. By the analytical way we press in this manner from the lowest things in our body to the highest; and for this purpose we shall set forth doctrines which have been extracted from the lowest things or by the analytical method, and with their aid we shall be able to descend from the highest to the lowest, or as it were from heaven to our atmosphere and to our planet. Such also is the field in which human minds take their exercise.

4. As we have now left the sphere of effects, and are about to enter the sphere of causes, it is necessary that we should exhibit a general idea or notion of each sphere; lest without some general light on the subjects, we should grope about in obscurity and darkness. For without such a light nothing appears distinctly.

5. The lowest sphere, or that of effects, uses, or final determinations, is properly the corporeal sphere, or that of the body. Wherever effects are, there are determinant organs, both of sense and of motion: organs of sense that they may receive the phenomena of the ultimate, circumfluous world; those of motion that they may manifest the actions of the body; the former that they may carry to the soul the things which impinge upon the body, and the latter that they may bring down from the soul actions, both such as are natural and such as are the results of volition. On this account the organs both of sense and of motion are placed in the ultimate parts of the body, and in

[1] In volumes i. and ii. of the *Regnum Animale*, or "Animal Kingdom." London, 1845.

immediate proximity to the surrounding world. Thus the muscles are placed in the outer parts of the body, and extend from the arms, elbows, and hands towards the fingers, and from the loins, feet, and soles towards the toes, and thus towards the last or ultimate things. The organs of sense, however, are placed partly around the whole outer surface of the body, as the sense of touch, and partly they are placed so as to meet the particles and modifications of our surrounding world, which are conveyed towards them.

The organs of motion and of sense in order to be, require essential determinations peculiar to their sphere, and adapted to the production of effects, hence arterial and venous vessels; these vessels require blood, which is the essence of that sphere. Blood, however, requires a general fountain of the blood, or a heart, whence these determinations flow, and whither they return; and where the circle begins and also ends. That the blood may perpetually subsist, even as it exists, and that the organs which are determined by the blood-vessels may be in the flower of their age, and may continually exist anew, viscera are required, by which the blood is prepared, purified, and renovated, which consequently receive the food, masticate it, convey it into the stomach, digest it into chyle, perfect the same, and turn it into blood. Smaller viscera are hence also required, for introduction, dissolving menstrua, and finally such as conclude the operation.

In order that these operations and effects may be carried on in full vigour, it is necessary that in all these organs there should be excited a suitable and appropriate motion; whence the lungs. It now appears how one effect and use acts upon another, and how a constant chain of all things exists in that external sphere; and indeed entirely for this purpose that the organs of motion and of sense, and through them actions and sensations which are the ultimate forms of life of this animate world, may exist and subsist.

This sphere is therefore distinctly divided into its regions. The lowest is that of the abdomen, containing the viscera which prepare the chyle and the blood; the middle is that of the thorax, containing the sources of the determinations of the blood and of motion, or the heart and lungs; the highest is that of the head, containing the organs of sense, namely, of taste, smell, hearing, and sight. All these are covered with an armour by the muscles, which are disposed and articulated into a wonderful order. The circle of this sphere, however, has been run through in previous Parts.

6. The second or middle sphere, or that which is immediately above the former, is that of the causes which determine the principles into effects, or the ends into uses; in this wise [*i.e.* through the sphere of causes] the soul does the things which are to be determined in the body; for this sphere conveys the sensations from the organs of the body to the soul, and the actions from the soul into the body. The cerebrum is therefore called the common or general organ of motion and the common sensory, and it is divided and separated from the lower sphere by walls of bone, namely, the skull and the vertebræ of the spine, so that there is no communication between these two spheres except through foramina or holes. This second sphere, therefore, is the principal medium by which the principles are united with the effects, or the soul with the body; it is also a complex of determinants, which it arranges and disposes in such a manner that it performs aright the part of an efficient cause; for it gathers and folds together the fibres which spring from the principles, and sends them out into the provinces of the body, in such a manner that it keeps constantly under the intuition and rule of the soul the organs of sense and of motion, and the remaining members of the lowest sphere.

Besides, the cerebrum also works up into a certain lymph or into a kind of purer blood the animal spirit, which is conceived, elaborated, and produced in the cortical substance. This lymph, together with the chyle, produces the red blood of the body. On this account the cerebrum acts also in the body the part of the mediate and efficient cause of the blood. This is the purpose of the organs of the cerebrum, namely, of the corpus callosum, the fornix, the two lateral ventricles, the third or middle ventricle, the aqueduct of Sylvius, the corpora quadrigemina, the pineal gland, the choroid plexus, the infundibulum, the pituitary gland, the cavernous sinuses, and several more, concerning which we shall treat hereafter.

When the brain is taken at large or in its whole complex, it is likewise divided into three regions, like the body or the lowest sphere. The highest region is constituted by the cerebrum, which is placed over the voluntary sensations and actions; the second by the cerebellum, which presides over those sensations and actions which are natural; and the third by the medulla oblongata, which begins at the pons Varolii and the region of the corpora quadrigemina, and is continued into the spinal cord down to the last apex of the cauda equina: this is placed partly over the voluntary, and partly over the natural operations, for it consists of fibres both of the cerebrum and the cerebellum, and it is besides formed of its own fibres.

7. The third or highest sphere is that of the principles, from which arise the causes, and by them the effects. This sphere is constituted by the cortical or grey substance of the brain taken at large; the brain, however, not being regarded as an aggregate, compound, or concrete body, but being contemplated in its least parts or individual substances. Into this sphere, according to their fibres, penetrate the senses of the body; especially the more simple among them, or the sense of sight; out of this sphere also flow down the actions according to the fibres; there also the organs of sense and of motion of the body are in their principles; for there are the first and the last termini of the fibres which are the determinations of the modifications of the senses, and also the highways of those forces whence proceed the vital actions. All things pressing upwards towards this substance, and thus into their units, enter into this higher sphere, whence our rational psychology has to derive its principles.

Each of these substances, or each cortical gland, as it is called, is not divided into its regions, but again into spheres, which are as it were celestial; for they are like the heaven or sky of the world below. The *first* of these is the inmost, or the very sanctuary and the holy of holies; where, as the ideal of the universe which is animated by it, resides the soul invested with the power of governing all things; this is the only essence which is living, and whence the remaining things derive their life. In the soul also is the nature and force of all those things which in the lower spheres finally become subject to the senses. It is as it were the deity of its microcosm, wherefore it inhabits this inmost heaven of nature: thence there is an ascent to the supreme mind, or to the heavenly sphere of the universe represented in it. The sphere nearest to the first, or the *second* sphere of celestial things or of principles, is that where our inmost sensation with intellection, the rational mind and its will, reside. This is as it were the outer court of the soul, and its subordinate council-chamber, through which it rules its subjects and governs the circumferences. The *third* sphere, however, is that where the interior sense of sight with its imagination, the first memory, and the animal mind (*animus*), and likewise the very determination of the will into act, reside. By these spheres the soul is girt about or involved as it were with walls or organical togas, and is thus most highly protected in its own centres.

To these spheres, however, we are utterly unable to press through, unless the lower spheres, *i.e.* the body and the brain, are first unravelled and unfolded. From Athens or the Lyceum we have to ascend to Parnassus, the seat of the seven virgins; and after having tasted the water of its spring, we may attempt the way to Helicon or to the hall where the soul dwells. Three shrines are there, and through heaven or the sky only is there an entrance to the holy of holies; and of what takes place there our mind can become cognizant only in a universal and not in an individual manner. Let us therefore take a broad view of the things below, and let us elaborate doctrines by the aid of which we may be enabled to take a universal view of the individual things which are around and below. And thence let us raise the sight of our mind towards the higher things which will then be nearer, and let us regard with veneration the heavenly things which will then meet us, and let us worship the Divine things. This is the analytic ladder which I intend to ascend, well knowing that no other road to Olympus is granted to human minds.

CHAPTER I.

THE CEREBRUM, ITS FABRIC, MOTION, AND FUNCTION IN GENERAL.[1]

A. *The Cerebrum, its Substances and Members in general.*[2]

8. Th. Bartholin.[3]—"The external part is properly and strictly called the cerebrum, and it comprises the whole of that mass which forms its circumference, and appears soft, and of an ashy-grey, or of a yellowish-white colour. . . . The internal part constitutes the rest of it, which is hidden away interiorly; it is harder, and more compact, and of a more shiny white colour: this part may be called the medulla or marrow, and in it, not, however, in the cerebrum itself, are situated the so-called ventricles. . . . The size of the human cerebrum is considerable, compared with the rest of the body; and generally man has twice as much cerebrum as an ox, namely, from four to five pounds; and among human beings again males have more

[1] The author's instructions in respect to the citations from the old anatomists which are to be inserted here, as contained in Codex 58 (Photolithographed MSS., vol. vi. p. 62), are as follows: "There is to be premised the experience collected in chapter vii. p. lxxiii, of the first projection [Codex 55 of the Swedenborg MSS. preserved in Stockholm]; also concerning the motion of the brain perhaps the experience collected in chapter i. [*ibid.*], and likewise what has been said respecting the cortical and medullary substances in general elsewhere, both in my manuscripts and my printed works. Note: *I have been commanded* (*Obs. jussus sum*)."

The plan of chapter i. of the present work is given on pp. 62 and 63 of the same MS. in these words: "*a.* The cerebrum; *b.* the fabric of the cerebrum—see chapter vii. of our first projection; *c.* the motion of the cerebrum—see chapter i. of our first projection; *d.* the function of the cerebrum."—Editor.

[2] The anatomical experience contained in subdivision *A* of chapter i., in agreement with the above instructions, is supplied from chapter vii. of Codex 55, Photolithographed MSS., vol. v. pp. 134-140.—Editor.

[3] *Thomæ Bartholini Anatome*, etc., Leyden, 1673, lib. iii. cap. iii.

cerebrum than females. . . . Its shape is roundish, almost like that of the skull, but in front the cerebrum has some protuberances, which are called the olfactory bulbs. The external surface of the cerebrum is full of winding sulci, and it has convolutions and various gyres, similar to those of the intestines. These are not subservient to the understanding, as we must remark with Erasistratus, since the asses also have them; nor are they for the sake of imparting lightness, as Aristotle maintained; nor are they without any end and use, as others think—but they are for the purpose that the vessels of the cerebrum may be conducted more safely through these sulci: and lest from the incessant motion there may be danger of a rupture. . . . On examining these tortuous fissures and sulci more minutely, we shall find, as Fr. Sylvius has first informed us, that they dip in rather deeply, and that the cerebrum, in addition to that middle division made by the falx, is divided into two halves by a winding fissure, which commences in front about the root of the eyes, and then, following the direction of the bones of the temples, extends backwards over the root of the spinal marrow, and thus distinguishes the upper part of the cerebrum from the lower. Sometimes, however, this large fissure can be scarcely discovered; and then in its place I found a certain smaller lateral fissure, which can be easily pressed apart; in a general dissection also this may be found near the cavernous sinuses, which are filled with the carotid arteries. The internal surface also has its various protuberances and cavities. . . . The temperament of the brain is cold and damp, which follows from its whiteness and viscidity. Hence the cerebrum, according to Hippocrates, is the seat of what is cold and glutinous. Reasoning and sleep are obstructed by too great a heat of the cerebrum, as appears from the case of those who are delirious. . . . The substance of the cerebrum is peculiar; there is none other in the body like it. Hippocrates compared it to a gland, on account of its colour and its plentiful humours. It is not so soft as to melt; but there is consistency in its softness, so that when anything is impressed the impression remains there for some time; for the brain is also the seat of the memory. . . . According to the followers of Des Cartes, the cerebrum is woven together out of soft and pliable fibrillæ, which are contiguous, yet allowing interstices for the pores; through them impressions are made on the cerebrum by the images of things" (pp. 467-472).

9. HEISTER.[1]—"In the cerebrum, strictly so called, are to be noted: its *shape*, which is globular on top, but somewhat unequal, with its tortuous windings, its sulci or gyres representing diminutive intestines; its *division* into two hemispheres as it were by the interposition of the falx cerebri; and these into anterior, middle, and posterior lobes. The *size* or the mass of the whole cerebrum amounts to about four pounds, and thus is almost three times as large as that of an ox. Its *substance*, when a portion of it is cut through, appears twofold: the *exterior*, which is called the grey or cortical mass, is almost two lines in thickness, and penetrates the cerebrum, sometimes deeply, creeping in a serpentine manner; its structure, according to Malpighi and Bidloo, and several recent writers who follow them, is glandular; according to Ruysch, Berger, Vieussens, and others, however, it is entirely vascular; in my estimation also, if glands can be demonstrated in other viscera, they cannot in the present case. The *interior* substance is white, and is called medullary; its structure appears to be fibrous and tubular, and it constitutes the whole remaining part of the cerebrum; its origin is from the least arteries of the cortical substance; its terminations are the beginnings of the nerves, all of which arise from it. Its consistency is slightly harder than that of the cortical substance" (p. 134).

10. WILLIS.[2]—"The parts of the cerebrum itself are so com-

[1] *D. Laurentii Heisteri Compendium Anatomicum*, Amsterdam, 1748, vol. i.

[2] Thomas Willis, *Cerebri Anatome cui accessit nervorum descriptio et usus*, London, 1664, 4to and 8vo; Amsterdam, 1681, 12mo. It was reprinted in Manget's "Bibliotheca Anatomica," from which it was probably quoted by Swedenborg. An English translation was prepared by S. Pordage, and published in London in 1683 and 1684 under the title, "The Anatomy of the Brain," in a collection of all the works of the author. The references are to the pages of the original Latin edition of 1664 in 8vo. The above extracts are contained in chapters i. and x.—EDITOR.

plicated and involved, and their mutual relations and outward forms are so difficult to trace, that it seems to be a more arduous task to institute a perfect anatomy of it than to delineate on a plane the windings and meanderings of a certain labyrinth; since we are unable to estimate the measure or sketch the structure of either without first searching to the bottom the mass of the subject, and without breaking up into pieces its organism. Hence the old anatomists—without taking properly into consideration which parts, on following the order of nature, ought to come first, which in the second place, and which afterwards—in dissecting the brain, cut up its mass as it were into slices or parts, and the pieces which resulted from such a dissection they were led to regard as the genuine parts of the brain; whence it happened that when others proceeded in their dissection in a different manner, they arrived at entirely different conclusions in respect to its parts and processes. The reason of this is that the organism of the brain and of its appendage which is contained within the skull is so circumstanced that in it many tuberosities with various stems or peduncles are pressed together, and yet all are distinct from one another, and arranged in forms which are expanded in various modes; and all these, in order to occupy a smaller space, are crowded together as it were into one ball, and are there so interlaced into one another that it is difficult to tell where the beginning and end of the brain is, and where the limits and breaks of neighbouring parts are. And again, in order that the parts which are thus woven together may retain their places, and when loosened apart may not stray away, they are held back in their proper foldings by fibres and membranes stretched out from one part to the other" (pp. 1, 2). "When the mass of the brain is taken out it appears of a roundish and almost spherical shape, and in its upper and convex part the cerebrum and cerebellum are exhibited to the sight; while its base or its lower part is totally occupied by the medulla oblongata, and the outermost borders of the upper parts. These three portions which are thus put together, and all their exterior surfaces, are covered with pia mater; nor does it cover them loosely, but it makes its way deeply into every cavity and every recess, and there it presses around and closely invests them" (p. 7). "The shape of the cerebrum, especially with man, is somewhat globular or spherical. Its outer surface is everywhere marked by gyres and winding clefts, which are similar to the convolutions of the intestines. Each convolution, or the whole body of the cerebrum, consists of two substances, namely, the *cortical*, which is of an ashy colour and is outermost, and the *medullary*, which is underneath the other, and presents a whitish appearance. The cerebrum, which by these tortuous windings is almost ploughed through by furrows or sulci, is cleft in the middle, and as it were divided into two hemispheres. Both, however, are joined in the middle, and repose there as it were on a very white substance similar to that which lines the whole mass of the cerebrum interiorly, and as it were constitutes its vault. This substance [the corpus callosum] is harder than any other portion of the brain; since it is entirely medullary in its character, and is the recipient of the medulla of all the convolutions, and serves them in the place of a common base. This corpus callosum or this medullary substance, near the anterior parts of each hemisphere of the cerebrum, is thicker and denser than in any other place; and there it is attached on both sides to the medulla oblongata by apices or protrusions. From these apices, which are in a certain sense its origin, this medullary substance which lines and vaults the cerebrum extends towards the back, and diminishes gradually in thickness; at last the outer border of this expanse is drawn more closely together and is conjoined underneath with the body of the medulla oblongata by fastenings consisting of membranes and vessels. In order to strengthen this connection, a medullary process [the fornix] takes its origin at the anterior part of the corpus callosum near its apices or protrusions; this extends under the fissure of the cerebrum and passes to the extremity of the above body, and to this it is attached by two arms as it were stretching back; these same arms embrace the body of the medulla oblongata [*i.e.* the optic thalami], and thus attach to it more firmly this part of the cerebrum" (p. 10). "The principal reason why the mass of the human brain, which in itself is very large, is also very much denser and furnished with many sulci or anfractuosities, is this, that it cannot be inverted so easily as in a calf or a sheep, and spread out on a large surface; and nevertheless at its border it can be so raised and expanded that the interior recesses are everywhere rendered visible" (p. 12). "In some animals, on the other hand, the structure of the cerebrum is divided into two parts or hemispheres almost throughout the whole of its thickness; that is, all the way down to the corpus callosum, which is in the place of a base; and, as in all the organs of sense and in most other organs which perform necessary functions, there is obtained as it were a double organ, so that when the cerebrum of one side fails, that of the other is able to supply its place. Besides, in man, whose cerebrum is more capacious and larger than that of the remaining animals, each hemisphere is again subdivided into two lobes, namely, an anterior and a posterior one, between which, on either side, a branch of the carotid artery runs, like a brook between two boundaries, dividing them each as it were into two provinces. This secondary division of the human cerebrum seems also to be intended for a greater protection of the same; so that in case a certain consumption attacks one or both of the anterior lobes, the posterior ones, disconnected from them in a certain measure, may escape the neighbouring injury and the spreading contagion. The cerebrum is thus like a citadel divided into several bastions and bulwarks, and rendered safer and more difficult against an attack. Nay, the entire structure of the brain, within each of the above partitions, appears still more divided and individualized; for its whole external surface, by gyres and convolutions, similar almost to those of the intestines, is rendered everywhere unequal and filled with rifts. These gyres, which progress from the anterior part of the cerebrum towards the posterior by sinuous windings and almost in a spiral circuit, encompass each of the hemispheres, and by degrees all the convolutions pass over into one another. In a moist cerebrum, or in one which has been macerated for some time, the pia mater, which lines all its parts and connects them together, is easily separated; and then the gyres or convolutions being opened and drawn apart, the substance of the cerebrum appears as it were ploughed into furrows or sulci. Thence the convolutions arise not in a direct series, but crosswise (*decussatim*), thus in a wonderful manner, as in the bottom of each convolution that which arises on the right side is carried to the left, then the other, which follows it immediately, is sent out from the left side, and passes thence to the right; and thus in their turn the inequalities of the whole cerebrum alternate in this order" (pp. 64, 65). "The cerebrum filled with sulci, and, as is the case in its base, scattered over with little eminences and hills, is much greater in extent than if it had a smooth and even surface. Besides, the sulci of the cerebrum conceal blood-vessels, which are extremely small and tender, and interlaced with one another so as to form various plexuses, and in this wise to protect them. If these were distributed publicly in the exteriors, they would be too much exposed to harm and damage" (p. 66). See also his plates.

11. VIEUSSENS.[1]—"The brain, which is formed of two substances, is divided into the cerebrum, cerebellum, and medulla oblongata. These are as it were three contiguous provinces of one and the same kingdom whose limits are distinctly defined. . . . The cerebrum is that portion of the brain taken in a larger sense which overhangs the medulla oblongata like a tuber or an apophysis, and which by the intermediation of the tentorium is separated from the cerebellum. By the interposition of the falx cerebri it is divided into two hemispheres which fill the greater part of the interior cavity of the cranium, and which from the posterior region where they rest upon the cerebellum tend toward the anterior region. Here lie the bulbs of the olfactory nerves, which by the intermediation of the falx, and also of the process of the crista galli, are separated from one

[1] *Raymundi Vieussens Neurographia Universalis*, Lugduni, 1685, lib. i. cap. xi.

another. See Plates ii., iii., iv. The convex part of the cerebrum approaches somewhat to the spherical figure. Its lower part, however, is divided by two prominent branches of the carotid arteries into four lobes; namely, into two anterior ones which are smaller, and two posterior ones which are larger; see Plates iv. and v. Its external surface appears marked by a great many oblique furrows or sulci; whence it is that it bears some likeness to small intestines, which are placed near one another, are rolled about without any discrimination, and are arranged in an oblique series" (pp. 56, 57).

12. RIDLEY.[1]—"Outwardly the cerebrum is convex and cortical, exactly divided into two hemispheres by the falx cerebri, from the bony process called crista galli forwards to the very hindermost part of the cranium, where these two divisions are stretched over the cerebellum, from which part also it is perfectly separated by the tentorium to the end it may not cause any prejudicial compression upon that part, either by its weight or pulsation. The anterior division is made only as deep as the corpus callosum, the latter to the very medulla oblongata itself. It is further imperfectly divided into four lobes, two whereof, which are the less, are anterior, and two, which are much bigger, posterior. These divisions appear best in the inverted or Varolian dissection, being marked out as it were by four branches of the carotid artery, two before, and one on each side. These I call imperfect divisions of the brain, because though the pia mater runs between them, together with the aforesaid branches of the great artery, yet they adhere by several fibres, both of that membrane and the blood-vessels themselves" (pp. 113, 114). "The brain is that large and almost spherical body which comes first to sight in the old way of dissection, filling the greatest part of all that space contained in the cranium, consisting of two substances (first taken notice of by Archangelus Piccolominius) different both in colour, consistence, and office, the

[1] H. Ridley, *The Anatomy of the Brain*, London, 1695. The whole of this work, in the Latin language, was inserted by Manget in his "Theatrum Anatomicum," vol. ii. pp. 294-331. Thence it was probably quoted by Swedenborg.

one being more compact, white, medullary, or fibrous, the other softer, greyish, and glandulous" (pp. 87, 88).

13. WINSLOW.[1]—"In general the name of brain is given to all that mass which fills the cavity of the cranium, and which is immediately surrounded by the two meninges, the dura, and the pia mater. . . . This general mass is divided into three particular portions; the cerebrum or brain properly so called, the cerebellum, and medulla oblongata. To these three parts contained within the cranium a fourth is added, which is called the spinal marrow, and fills the great canal of the back; it is a continuation of the medulla oblongata" (sec. x. nos. 3, 4).

"The cerebrum properly so called is a kind of medullary mass, of a moderate consistence, and of a greyish colour on the outer surface, filling all the superior portion of the cavity of the cranium, or that portion which lies above the tentorium. The upper part of the cerebrum is of an oval figure like half an egg cut lengthwise, or rather like two quarters of an egg cut lengthwise, and parted a little from each other. It is flatter on the lower part, each lateral half of which is divided into three eminences called lobes, one anterior, one middle, and one posterior. The substance of the cerebrum is of two kinds, distinguished by two different colours; one part of which is softer, being of a greyish or ash colour; the other, which is more solid, is very white. The grey substance lies chiefly on the outer part of the cerebrum like a kind of cortex, whence it has been called the cortical or grey substance. The white substance, however, occupies the inner part, and is named the medullary substance, or simply the white substance. The cerebrum is divided into two lateral portions, separated by the falx cerebri, or the great longitudinal septum of the dura mater. They are generally called hemispheres. . . . Each of these portions is divided into two extremities, one anterior and one posterior, which are termed the lobes of the cerebrum, between which

[1] Jacques Benigne Winslow, *Exposition Anatomique de la Structure du Corps Humain*, Paris, 1732; translated into English by Dr. G. Douglas under the title, "An Anatomical Exposition of the Structure of the Human Body," London, 1733.

there is a large inferior protuberance which goes by the same name; so that in each hemisphere there are three lobes, one anterior, one middle, and one posterior. The anterior lobes are enclosed and supported by the frontal bone, which also contributes to the formation of the orbits and of the frontal sinuses, commonly called the anterior fossæ of the base of the cranium. The posterior lobes, however, lie on the tentorium, or the transverse septum of the cerebellum; and the middle lobes in the middle or lateral fossæ of the base of the cranium. Each lateral portion of the cerebrum has three sides: one superior, which is convex; one inferior, which is uneven; and one lateral, which is flat and turned to the falx cerebri. Through the whole surface of these three sides we see inequalities or windings like the convolutions of intestines, formed by sulci or furrows very deep and narrow, into which the septa or duplicatures of the pia mater insinuate themselves, and thereby separate these convolutions from each other. Near the surface of the cerebrum these convolutions are at some distance from each other, representing serpentine ridges; and in the interstices between them the superficial veins of the cerebrum are lodged, between the two laminæ of the pia mater, whence they pass into the duplicature of the dura mater, and so open into the sinuses. These convolutions are fixed through their whole depth to the septa or duplicatures of the pia mater by an infinite number of very fine vascular filaments, as may be seen by pulling the convolutions a little asunder with the fingers. When they are cut transversely, we observe that the white substance lies in the middle of each convolution, so that there is the same number of internal medullary convolutions as of external cortical ones; the first representing white laminæ invested by others of a grey colour; but the cortical substance is in many places thicker than the medullary. The anterior and middle lobes of the cerebrum on each side are parted by a deep narrow sulcus, which ascends obliquely backward, from the temporal ala of the sphenoidal bone to near the middle of the parietal bone; and the two sides of this division have each their particular ridges and convolutions, which gives a very great extent to the cortical substance. This sulcus is termed the fissure of Sylvius, or simply the fissure of the cerebrum" (nos. 53-61).

14. In respect to the internal organization of the cerebrum, it consists of several members or organs, as well as of several cavities or ventricles, and likewise of septa. I shall not mention them here in their order, because they will be specially treated upon hereafter. I shall only mention here the corpus callosum, the fornix, the septum lucidum, the larger or lateral ventricles, and therein the thalami of the optic nerves, the corpora striata, the foramen commune anterius and posterius; besides the third ventricle, the aqueduct of Sylvius, the valve of Vieussens, the pineal gland, the corpora quadrigemina, the infundibulum, the pituitary gland, the cavernous sinuses, the rete mirabile. The rest belong more properly to the medulla oblongata.

[MODERN AUTHORS.

In order to enhance the use of the present work, and also to show that the facts on which Swedenborg based himself in his inductions, do not differ essentially from those professed by modern science, we propose to supplement his extracts from the anatomical authorities of his time, by a few typical ones taken from acknowledged representative works on anatomy of modern times.

14*a*. CRUVEILHIER.[1]—"The *cerebro-spinal axis* constitutes the *central* portion, whilst the *nerves* form the *peripheral* portion of the nervous system. The *apparatus of innervation* formed by the cerebro-spinal axis and the nerves together, and named the *nervous system*, is the most important part in the animal machine;

[1] *Traité d'Anatomie descriptive.* J. Cruveilhier, at the time when he published his work, was Professor of Anatomy to the Faculty of Medicine of Paris, and President of the Anatomical Society. We quote from the English translation of his work in the "Library of Medicine," edited by Alexander Tweedie, M.D., F.R.S., London, 1842.

it is the source not only of sensation and motion, but of the universal sympathy existing between the several parts of the animal economy; and that part of it called the brain performs the highest function allotted to organized beings, by becoming the immediate instrument of the soul in the exercise of the intellectual faculties.—The cerebro-spinal axis consists of that soft, pulpy, elongated, and symmetrical mass of nervous substance, which becoming enlarged at its upper part, occupies the vertebral canal and the cavity of the cranium, and forms the centre from which the nerves of all parts of the body take their origin, or in which they all terminate.—The structure of no other organ in the body excites so much curiosity, and unfortunately there is none whose structure is involved in greater obscurity. Notwithstanding the real advances that have recently been made in our knowledge of the anatomy of the brain, we must still acknowledge with Steno, that the human mind, which has carried up its investigations into the heavens, has not yet been able to comprehend the nature of the instrument by which its own operations are performed, and that its powers seem to abandon it as soon as it turns its attention to the organ in which it resides. . . . The central portion of the nervous system consists (1) of the *spinal cord;* (2) of the *tuber annulare* (the pons Varolii), the *peduncles of the cerebrum and cerebellum*, and the *tubercula* (corpora) *quadrigemina;* these together constitute a very constricted portion, which forms the bond of union between the other parts of the encephalon, and which I shall accordingly name the node or nodes of the encephalon—*le nœud de l'encéphale;* (3) of *the cerebellum;* (4) of *the cerebrum.*—The cerebro-spinal axis is surrounded by three membranes or coverings called *meninges* (from μήνιγξ, a membrane), which perform some important functions in regard to it" (pp. 908, 909).

"The *cerebrum* or *brain*, strictly so called, is that portion of the encephalon which occupies the whole of the cavity of the cranium, except the inferior occipital fossæ. It forms as it were the crown or summit of the spinal axis, surmounting it—*cerebrum* *superius*—and at the same time—*cerebrum anterius*—lying in front of the spinal cord, as the origin and termination of which it has been alternately regarded. By the pons Varolii and the anterior or cerebral peduncles it is intimately connected with the cerebellum and the spinal cord. The tentorium cerebelli completes the cavity in which it is enclosed, and separates it from the cerebellum, which is situated below its posterior lobes. The cranium, the dura mater, the arachnoid, and the pia mater form a fourfold investment of it.—The great *size* of the cerebrum is undoubtedly one of the most characteristic points in the structure of man: in several animals, as the canary-bird, the sapajou, the dolphin, the entire éncephalon is relatively as large, and even larger; but in reference to the size of the brain properly so called, *i.e.* of the cerebral hemispheres, even the most favoured animals are much inferior to man.—In the adult, the weight of the cerebrum, detached from the cerebellum and the pons by a section through its peduncles, varies from two to three pounds. I believe it to be impossible to construct a table of the comparative size and weight of the brain and of the body. . . . These remarks do not apply to the relative proportions between the cerebrum and cerebellum. According to my own observations, the weight of the cerebellum is from the twelfth to the eighth part of that of the cerebrum" (pp. 968, 969).

"The form of the cerebrum corresponds exactly to that of the cranial cavity, which is as it were moulded on it; it is therefore variable like that of the cavity itself, which during early infancy is capable of assuming all sorts of shapes from the application of external pressure.—If the entire cranial cavity, excepting the posterior occipital fossæ, be filled with plaster of Paris, an exact representation will be obtained of the general form of the brain which had been removed. The cerebrum, therefore, like the cranium, is of an ovoid figure, having its large end turned backwards, and its small one forwards. It is divided on its under-surface into *lobes*, which occupy the different compartments in the base of the cranium. The entire surface is marked by deep tortuous furrows, called *anfractuosities*, which occasion an appearance like that of the convolutions of the small intestines, and hence the term *convolutions* is applied to the eminences resembling folds by which the anfractuosities are bounded.—A *median vertical fissure* running from before backwards, called the *longitudinal fissure*, divides the cerebrum into two exactly similar lateral halves, which are improperly called *cerebral hemispheres*, for each of them resembles the fourth part of an ovoid; they would be more correctly designated the right and left brain, as was done by *Galen*. The longitudinal fissure divides the cerebrum in its whole depth, both in front and behind; but in the middle it is interrupted by the *corpus callosum*. There are two brains, as there are two spinal cords and two cerebella" (pp. 969, 970).

14*b*. QUAIN.[1]—"The *cerebro-spinal axis* is contained partly within the cavity of the cranium, and partly within the vertebral canal; it is divided by anatomists into the *brain* or *encephalon*, and the enlarged upper mass placed within the cranium, and the *spinal cord* contained within the vertebral canal. It is symmetrical in its form and structure throughout, consisting of a right and a left half, separated to a certain extent by longitudinal fissures, and presenting, in their plane of union, various portions of white and grey nervous substance which cross from one side to the other, and form the *commissures* of the brain and spinal cord.—Enclosed within the skull and the vertebral canal, the cerebro-spinal axis is protected by the bony walls of those two cavities; it is also surrounded by three membranes, which afford it additional protection and support, and are subservient to its nutrition. These envelopes are (1) a dense fibrous membrane named the dura mater, which is placed most superficially; (2) a serous membrane called the arachnoid; and (3) a highly vascular membrane

[1] *Elements of Anatomy*, 8th edition, edited by *William Sharpey*, M.D., LL.D., F.R.S.L. and E., Emeritus Professor of Anatomy and Physiology in University College, London; *Allen Thomson*, M.D., LL.D., F.R.S.L. and E., Professor of Anatomy in the University of Glasgow; and *Edward Albert Schäfer*, Assistant Professor of Physiology in University College, London. Eighth edition. Two vols. London, 1876.

named the pia mater, which is next to and closely invests the surface of the brain and cord" (ii. p. 489).

"The *encephalon* admits of being conveniently divided into the medulla oblongata, the cerebellum with the pons Varolii, and the cerebrum. The *medulla oblongata* is the part continuous with the spinal cord: it rests on the basilar process of the occipital bone, and on its superior or dorsal surface presents a groove continuous with the central canal of the spinal cord. The *cerebellum* occupies the posterior fossa of the cranium. By the mesial part of its anterior and inferior surface it forms the roof of a space, the floor of which is the grooved posterior surface of the medulla oblongata, and which is named the fourth ventricle of the brain. On each side of this the cerebellum is connected with the medulla oblongata and cerebrum, and also receives the fibres of the *pons Varolii*, which is a commissure, uniting the two hemispheres of the cerebellum, and passing beneath and between the fibres which extend upwards from the medulla oblongata. The *cerebrum* includes all the remaining and much the largest part of the encephalon. It is united with the parts below by a comparatively narrow and constricted portion or *isthmus*, part of which, forming the crura cerebri, descends into the pons Varolii, and through it is continued into the medulla oblongata, whilst another part joins the cerebellum. Situated on the fibres which extend up from the constricted part are a series of eminences, named from behind forwards, the corpora quadrigemina, optic thalami, and corpora striata; and springing from the front and outer side of the corpora striata are the large convoluted cerebral hemispheres, which expand from this place in all directions, concealing the eminences named; and occupying the vault of the cranium, the anterior and middle cranial fossæ, and the superior fossæ of the occipital bone. The cerebral hemispheres are united together by a principal commissure and smaller commissures; by means of which there is enclosed a cavity, which is subdivided into various ventricles, viz. the two lateral, the third, and the fifth" (ii. pp. 502, 503).

"The *cerebrum*, or brain proper, constitutes the highest and much the largest portion of the encephalon. It consists of the following parts, viz. the peduncular masses of the crura cerebri and processus a cerebello ad cerebrum; the series of eminences or cerebral centres or ganglia concealed from view, named corpora quadrigemina, optic thalami, and corpora striata; the cerebral hemispheres, which are by far the most bulky part of the cerebrum; various commissural structures, including the corpus callosum and fornix; and lastly, some smaller structures, viz. the pineal and the pituitary bodies, and the olfactory bulbs.—The *cerebral hemispheres* together form an ovoid mass, flattened on its under side, and placed in the cranium with its smaller end forwards, its greatest width being opposite to the parietal eminences. They are separated in the greater part of their extent by the great longitudinal fissure. Each cerebral hemisphere has an outer convex surface, in contact with the vault of the cranium; an inner or median, flat surface, which forms one side of the longitudinal fissure; and an irregular under surface, in which is a deep cleft, the fissure of Sylvius. In front of this cleft the under surface rests in the anterior fossa of the base of the skull, and behind it in the middle fossa, and farther back still, on the tentorium cerebelli.—The *great longitudinal fissure* seen upon the surface of the brain extends from before backwards throughout its whole length in the median plane, and thus separates the cerebrum, as already stated, into a right and left hemisphere. On opening this fissure it is seen, both before and behind, to pass quite through to the base of the cerebrum; but in the middle it is interrupted by a large transverse mass of white substance, named the *corpus callosum,* which connects the two hemispheres together. While the brain is in its natural situation, this fissure is occupied by a vertical process of the dura mater—the falx cerebri—which dips down between the two hemispheres, not quite reaching the corpus callosum.—The *surface of the hemispheres* is composed of grey matter, and is moulded into numerous smooth and tortuous eminences, named *convolutions* or *gyri,* which are marked off from each other by deep furrows, called *sulci,* or *anfractuosities.*—The *lobes of the* *cerebrum* are five in number, termed respectively, *frontal, parietal, occipital, temporo-sphenoidal,* and *central.* The three former are in contact with the bones after which they are named, though their limits do not correspond to those of the bones; the fourth occupies the middle or temporo-sphenoidal fossa in the base of the skull, while the central lobe, or island of Reil, lies within the fossa of Sylvius. The divisions between these lobes are marked by certain conspicuous fissures and by artificial lines connecting these fissures. . . . Formerly it was customary to divide each hemisphere into three lobes: an anterior, in front of the fissure of Sylvius; a middle, behind that fissure and resting in the temporo-sphenoidal fossa; and a posterior lobe behind it, resting on the tentorium cerebelli. The division into five lobes, now generally adopted, was first made by Gratiolet.—The *Convolutions* are covered closely throughout by the vascular investing membrane, the pia mater, which sends processes down to the bottom of the sulci between them, while the serous covering, the arachnoid membrane, passes from one convolution to another, over their summits, and without dipping between them. In general the depth of a convolution exceeds its thickness; and its thickness, near the summit, is somewhat greater than through its base. Since the external grey or cortical substance is continuous over the whole surface of the cerebral hemispheres, being found alike within the sulci and upon the gyri, a far greater extent of grey matter is thus exposed to the vascular surface of the pia mater with a given size of the brain, than could have been the case had the hemispheres been plain and destitute of convolutions.—The *fissures* between the convolutions are generally from half an inch to an inch in depth, but vary in this respect both in different brains, and in different parts of the same brain. In all brains certain primary fissures can be recognised, on which the division into lobes has been founded" (ii. p. 523).]

B. *The Motion of the Brain.*[1]

15. Th. Bartholin.[2]—"The motion of the brain consists of a systole and a diastole, and it is continuous, as may be seen from wounds in the head, from recently born infants, and from vehement headaches; we have also, not unfrequently, seen this motion in wounded persons. It is surprising, therefore, that some of the learned feel inclined to deny this motion. It is, nevertheless, extremely difficult to point out the true cause of the motion. Some attribute it to the dura and pia mater; others to the arteries; and still others to the substance of the brain. It is, however, not well ascribed to the meninges, or to the dura and pia mater alone; for on the removal of a large portion of the cranium, and even of the dura and pia mater, the motion of the cerebrum was, nevertheless, observed in a living sheep by Riolanus. Those who ascribe the motion of the brain to the arteries are better advised; for this motion coincides in its periods with the motion of the arteries, as may be observed in the heads of infants and in cases of fractures of the skull. Nay, Valæus even noticed that in the cases of such as suffered from wounds in the head down into the substance of the brain, certain conspicuous arteries did not move the brain; and that on the return of the strength, the motion of the brain evidently returned of its own accord. Coiter again noticed in lambs, kids, and living dogs, not a motion of the brain itself, but of the arteries. Olhasius agrees to this, because the motion principally

[1] The experience which is collected under the head of "Motion of the Brain," as mentioned above, is supplied from chapter i. of Codex 55. Of this Codex, however, several leaves are missing, and it begins on page, or rather leaf vi, with the latter part of a quotation from one of the older anatomists on the subject of the motion of the brain. After a careful examination it was found that this quotation is from a paper of H. Ridley read before the Royal Philosophical Society on September 20, 1703. (See "Transactions," etc., vol. 23, pp. 1480-1484.) We therefore translate from this paper what bears on the present subject. After leaf viii, an extract from Bartholin is bound up in the original Codex, marked "page v," from which it follows that the author intended the quotation from Bartholin to precede that from Ridley. We accordingly begin the anatomical quotations with that from Bartholin.—Editor.

[2] *Anatome*, etc., lib. iii. cap. ii.

displays itself around the sinuses of the dura mater, where there are a number of arteries. It does not therefore seem that we are obliged to have recourse to the substance of the brain; besides, this substance is soft and flaccid, and quite unfit for motion. A peculiar motion, however, is remarked when the moon is full, from the turgidity of the humour. . . . I am not able to see a sufficiently urgent indication that the motion of the brain corresponds to the motion of the lungs" (p. 459).

16. RIDLEY.[1]—" On meeting a short time ago in a tract on the motory fibre by Professor George Baglivi of Rome, with a new theory on the reciprocal motion of the dura mater exhibited to the eye in wounds of the brain, or in the vivisection of animals; which theory differed altogether from that which some time ago I set forth in my 'Anatomy of the Brain,' chapter vi., I considered it my duty, for the sake of those who have hitherto acquiesced in my theory, to submit the same to a renewed examination—so that I might either extricate them from an error into which they might have fallen through my fault, or else guard them against the errors of others.

" The idea of Baglivi, which is besides stated in several other passages in his work, is set forth on p. 20 thus: 'This boy having been seen, we at once began to suspect that the dura mater accomplishes these strong and orderly pulsations not by arteries which are disseminated through it, but chiefly by virtue of its own texture, which emulates with the structure of the heart;' on this account also he styled the dura mater the 'heart of the cerebrum.' Afterwards on p. 29 he says as follows: 'Wherefore the cause of the pulsation of the dura mater lies within its own mass, and in its own substance, and must not be looked for without.'

" What I put forth on this subject in my work which was printed in the English language, and on what authorities I there based myself, and by what experiments I supported

[1] Swedenborg quoted this paper from Manget's "Theatrum Anatomicum," vol. ii. pp. 290, 291. As Manget, however, cited simply the substance and not the exact language of Ridley's experiment, we translate it immediately from the "Transactions of the Royal Academy."—EDITOR.

myself, appears from the following extract: 'To these sinuses most of the ancients, and also some of the moderns, especially Willis and Vieussens, have ascribed pulsation, after the manner of arteries, by reason of some arteries from the dura mater terminating in them: of the truth whereof being somewhat doubtful, I resolved to make use of such an experiment as might remove all future scruples, and most satisfactorily put an end to the controversy. The experiment was as follows: I took off the upper part of the skull of a dog alive, by which means the dura mater with its third longitudinal sinus lay bare to the sight and touch, to neither of which senses, at first, either any beating of the membrane in general, or of the sinus, was the least discernible. After some pause, by chance the sinus itself, which I designed to have opened with a lancet, being touched with a cauterizing-iron (which in making the experiment there was occasion to make use of), poured out the blood very violently, and at first without any very remarkable pulsation, but after some time discernible enough, both as to the blood and membrane too. I cut this sinus through almost the length of it to see whether any arteries (whereof many, according to Vieussens, which was also long afore affirmed, and that upon experience too, by the learned Wepfer, did terminate in it, and so occasion its beating) would discover themselves by throwing out their salient blood; but no such sign appeared. After all which it is manifest the sinuses themselves have no pulsation, other than what is communicated to them from the subjacent brain, which, contrary to what Bourdon affirms, has an evident pulsation through the multitude of arteries dispersed through it so forcible as to create a sensible systole and diastole in its outward coverings; as was formerly stated by Fallopius and others.'

"In order that I might either more thoroughly embrace my theory or abandon it (for I reverence only the naked truth), I was willing to make the following experiment in order by the same to scrutinize the subject still more.

"The upper part of the skull of a dog having been perforated, I laid bare the dura mater, not without some loss of blood.

The hemorrhage having been stanched by the application of some lint, and the blood having been washed off, the systaltic motion of that membrane and of its longitudinal sinus, which ran along the edge of the aperture, was made apparent, which motion was like that of the pulsation of the heart, only quicker than usual, and exactly corresponding to it in point of time.

"This pulsation was observed by those that stood near me for nearly a quarter of an hour. After this time had elapsed, I tried to seize the membrane with a little hook, so that being suspended by the same, and divided with a knife, we might explore the motion of the brain underneath. This perforation having been accomplished, which seemed to cause the dog acute pain, but did not produce any convulsion, a hemorrhage ensued which was, however, quickly stanched as before. After the blood had been washed off, especially from the little opening made by the hook, the systaltic motion of the brain appeared, expelling the small quantity of the blood which was still contained in it. After cautiously introducing into the aperture of the wounded membrane one blade of a blunt pair of scissors, I slit it across, in the part which was furthest removed from the place where the longitudinal sinus passed. After this incision had been made the cerebrum covered with the pia mater protruded through this aperture, its motion still continuing strong to the touch, yea, the membrane itself, on account of the recuperating power of its fibres being diminished by reason of the wound received, seemed to the eye to vibrate obscurely. During the whole of this time the dog appeared to be brisk, but its whole body seemed nevertheless shaken by slight tremors accompanied with some feeling of horror. After the dog had thus been treated for several hours, and had lost much blood, so that almost all pulsating force which may have been supposed to exist in this membrane, or to have been derived to it from other sources, had ceased, I smeared it gently over with a few drops of oil of vitriol, so that it assumed a black colour, and that none, or at least only a very slight and obscure vibration could be observed in it; but on applying the finger the pulsation of the brain could be distinctly felt. Afterwards I introduced the point of a knife into the substance of the brain to the depth of about an inch, when the dog, who had remained up to that time still brisk, became violently agitated, it tossed the body frightfully about, and the feet both in the front and rear became seized with spasms. When the blade was introduced still more deeply the animal gave signs of the most acute pain; but when the knife was passed through to the opposite side of the skull, horrible spasms were the result, and during all this time the systole and diastole of the brain took place with the greatest impetus—which was observed by myself and some of the by-standers."

[The author sums up Ridley's first experiment in his "Anatomy of the Brain" as follows:] "The dog's cranium was laid open in order that the dura mater and the longitudinal sinus might be exhibited to the sight, when no pulsation was observed anywhere. After the sinus had been touched with a cauterizing-iron, there was a violent discharge of blood, at first without any notable pulsation; but this by degrees became quite conspicuous, both in the blood and in the membrane. It hence follows that the sinuses themselves have no pulsation, except what is communicated to them by the subjacent cerebrum; as long as the vessels were filled with blood there was no visible pulsation, but when they were depleted the pulsation became visible both in the sinus and in the membrane."

17. VIEUSSENS.[1]—"We assert that the whole mass of the brain, especially when it is at some distance from the bones of the skull, has a natural motion of intumescence and detumescence, and we prove it by the single fact, that on opening the head of a dog, or of any other animal, traces of the several external convolutions of the brain are found accurately and deeply engraven upon the bones of the skull. Such traces of the exterior figure of the convolutions of the brain could never be imprinted upon the inner surface of the skull, if the brain were entirely destitute of motion; for no one, we presume, will affirm that the dura

[1] *Neurographia*, etc., cap. vi.

mater, as it lies between the skull and the brain, is capable of producing depressions in the skull" (p. 41). Vieussens, however, deduces the motion of the brain from the pulsation of the arteries.

18. Where the crista frontalis and the crista galli descend into the lower or more level parts, they receive the front parts of the frontal bone, which with their surface turned towards the concavities of the cerebrum and its lobes, are so moulded and furnished with depressions as to receive and store away fitly in themselves the gibbous protuberances of the anterior lobes of the cerebrum. These depressions are visible on the external surface of the forehead, where they frequently protrude in the shape of two promontories between the middle portion of the forehead and the temples. In these depressions or cavities, as well as in all the surrounding parts, appear little grooves for the arteries of the dura mater, as well as other impressions more vague and meandering, all of which fit into similar vessels in the cerebrum. The same is the case in the large bones on the side, where in addition to little grooves for the longitudinal sinus and the two lateral ones, the effigies of smaller vessels also are imprinted more deeply for the use of the arteries of the dura mater, which sometimes adhere to them, presenting the appearance of little trees and branches. Here also there are some vague and scattered impressions of grooves, which are more marked towards the temporal bones, but which are more evanescent as they approach the suture; for they seem to be obliterated in proportion as they ascend to the crown. They are more marked where there is less open space between the dura mater and the cerebrum, or where the cerebrum is able constantly to superadd of its own force to the dura mater, and thus impinge the arteries of this membrane (which are in themselves capable of being elevated) against the walls of the cranium from tender youth or infancy. Most marked impressions of this kind of grooves in the cranium are exhibited in the anatomical illustrations of Bidloo and Cowper. "That person," says Cowper, "the impressions of whose cranium are here

delineated, died of apoplexy, and with him the cranium protruded like a horn."

19. WEPFER.[1]—"I do not venture to assert that the brain is moved by arteries—although it is provided with many, and most important ones lie under its base—in view of the inadequacy of the arterial pulse to elevate so large a mass as that of the brain in man" (p. 44).

20. BAGLIVI.[2]—"Although man's life is dependent upon the incessant, regular, and equipoised motion of solids and fluids, nevertheless, lest this should be subverted, man is furnished with two principles or beginnings of motion, namely, the heart and the two membranes of the brain, which on account of their superior structure, by virtue of their nerves, membranes, and other parts, make of the brain the image of a second heart. . . . Let us examine the dura mater, upon whose motion—we scarcely dare to maintain it—depends the motion of the heart, and to which it is altogether subordinated. On the ground of the many experiments which Pachioni instituted in respect to the cerebrum and the dura mater, he often asserted that the dura mater is not a simple membranous texture, but is composed of three diverse orders of fibres, of which one is stretched out with great skill over the other, and which mutually intersect one another; and of these orders or series one is noticed on its convex, and the two other on its concave side" (p. 272). "After thus considering in the dura mater in particular this structure of fibres and muscles, which seems to be formed entirely for the purpose of contracting and expanding, like the fibres of the heart, and after considering also its sinuses, cavities, and the manner in which it embraces and presses upon the brain, it follows that it can be justly called the heart of the brain, composed of membranous filaments; which filaments, when they curl up and contract, squeeze and compress the whole of that with which they come into contact.

[1] Wepfer (J. J.), *Observationes Anatomicæ ex cadaveribus eorum, quos sustulit apoplexia*," Amsterdam, 1681.

[2] Giorgio Baglivi, *De Fibra Motrice et Morbosa*, in his *Opera Omnia*, Lugduni, 1733, lib. i. cap. v.

For this reason also we rather call it the heart than with Mayow the diaphragm of the brain. But what induces us to call it the heart of the brain, in addition to the considerations based on its structure, is also the continual and strong systaltic and diastaltic motion which prevails in it more than in other parts, and which can be descried most palpably even by the naked eye. But if any one desires to have additional confirmation on the subject, let him inspect the anterior part of the cranium in a new-born child and ponder over it; for while his bones are still very soft, on applying the palm of the hand to them, he will observe there a strong and regular systaltic and diastaltic motion which is caused by the dura mater underneath. With much surprise we noticed this motion some years ago in a boy recently born with a hydrocephalus; and on seeing this boy we immediately began to suspect that the dura mater caused this strong and orderly motion not by the arteries which are scattered over it, but by virtue of its peculiar texture which emulates that of the heart. . . . If any one, however, desires to perceive the systaltic and diastaltic motion of the dura mater, throughout its whole extent, still more clearly, let him observe, if he please, wounds in the head accompanied by fracture of the skull, and penetrating to the cerebrum; such as we had occasion to observe in many hospitals in Italy, and he will see that the whole mass of the dura mater which is laid bare by the wound, pulsates equally and forcibly; and not only in those little branches and furrows that are hollowed out by the little arteries distributed through it—which would not be the case if the motion of the dura mater was due to these little arteries. And if convulsive motions supervene from the wound, it is wonderful what a strong and manifest pulsation in this case is manifested throughout the whole dura mater; which pulsation occurs at stated intervals and spaces, so that in reality you seem to see a pulsating heart. This has been repeatedly witnessed by myself as well as by others. But in order that I might observe these regular motions of the dura mater still more manifestly, I made many experiments on recently-born lambs, removing their skulls with a very fine knife;

when I not only beheld in the dura mater a regular and continuous series of pulsations, but by pricking it in various ways by very thin needles, and by introducing into it corrosive liquids, I also obtained thence most useful observations. If the dura mater was pricked on the right side, convulsive motions were caused in almost all the parts, and these were most violent especially in that part which was pricked. The same happened if it was pricked on the left side. Generally, however, after the tension of the meninx became weakened by pricking, there arose an indescribable confusion in all the lower parts of the body, both in those which were subservient to sensation and in those which contributed to motion; first, however, this took place in the head, and afterwards in the remaining parts" (pp. 272-275). "On applying the right hand to the heart of such persons as were wounded in the head, and where the dura mater lay exposed, I noticed that the pulsation of this membrane in the cerebrum kept exactly the same time as the heart which was beating against the hand; nor could the least difference in the time of these pulsations be discovered. . . . If any one examines the motion of the dura mater in living animals, he will notice that while it undergoes its systaltic and diastaltic motion, it is in a state of commotion as to its whole body, and the motion is not continued from part to part. . . . It seems probable to me that this pulsation depends upon the peculiar structure of this membrane, and upon a wonderful elasticity which lies hidden in its fibres, and also upon the peculiar equilibrium of the fluids circulating through it, as well as upon the above said elastic fibrillæ" (p. 280).

21. PACCHIONI.[1]—"When the arterial blood, the air of the blood, and the pure air reach the brain and its cavities, the air which carries with it particles of a dissolving menstruum and also elastic particles, will actuate not only the fluid portion of the blood and of the lymph within the ventricles of the brain and

[1] *Antonii Pacchioni Opera*, edit. quarta, Rome, 1741. Swedenborg seems to have had access only to a portion of the writings of this scholar, namely, to his *Epistolæ Physico-Anatomicæ*, which were reprinted by Manget in his "Theatrum Anatomicum." The references are made to the edition of his works published in Rome in 1741.—EDITOR.

of the spinal marrow, by [further] dissolving and fermenting them, but will also distend and inflate the particles of the ventricles and of other cavities to an immense extent; so as necessarily to cause the body of the cerebrum and cerebellum to fill a greater space, and in a manner to be thrust outwards. . . . Wherefore from this effort and its intermission results a motion which is not unlike that of a systole and diastole, and which corresponds as a whole to the systaltic and diastaltic motion of the arteries of the brain. This is in fact the true and genuine systaltic and diastaltic motion of the brain which has been so much talked about by the anatomists. . . . Wherefore it is not at all wonderful that Pliny should have related of a certain Zoroaster that he laughed on the day on which he was born, and that his brain palpitated in such a manner as to repel a hand which was laid against it" (pp. 91, 92). "The motion of the dura mater is not simply pulsatile, as Mayow and others have thought, who endeavoured to prove that kind of pulsation of the dura mater by autopsy; since they declare that after the cranium had been perforated, a part of the brain became visible, which appeared to surge in a swelling, and then again to subside, and which motion of the brain seemed to be very much like the pulsation of the heart. From this it is quite evident that this pulsatile motion is not the genuine motion of the dura mater, but is owing rather to the brain and to the arteries of the pia and dura mater; which motion also impresses marks on the tender cranium, which after it has been hardened can no more be effaced from it" (pp. 152, 153).

22. FANTONI.[1]—"Nothing in the brain is more conspicuous than its alternate swelling and subsidence, or dilatation and contraction: these motions are visible in cases of wounds of the head, and in the vivisection of brutes. . . . We find it recorded of Zoroaster, the celebrated King of the Bactrians, that on the

[1] Joannes Fantonus, *Epistola ad Pacchionum* in *Pacchioni Operibus;* it is also contained in an edition of Fantoni's works published in Geneva in 1738, under the title, Joannes Fantonus, *Opuscula medica et physiologica.* The references are made to his letter as printed in the works of Pacchioni.—EDITOR.

very day that he was born his brain palpitated to such a degree as to repel a hand when placed upon it. . . . To state a general opinion, not a particle of the brain is destitute of this motion, all the glands and all the little tubes enjoy an alternate and regular compression. . . . It is well known that in living animals, when the brain is wounded, and the finger thrust well into it, a very strong diastole and systole of its substance is perceived. . . . The mass of the brain is large; the force of compression operates in its whole circumference; and not only in the circumference, but also in its inmost substance, and in its core. . . . In proportion as a part of the brain is higher, and more distant from the medulla oblongata and the emissary ducts of the nerves, it seems to require a greater force of compression, and there also the energy of the motions is greater. . . . The dura mater undergoes the same changes, which are caused partly by the brain and partly by its own arteries; wherefore I conjectured that the return of the membrane into its original state contributed to the compression of the brain: yet this cannot contribute anything at all towards this purpose; since the brain subsides sufficiently by its own weight and effort; and since by subsiding equally in every part, and thus by contracting itself as it were, it exercises a pressure upon itself. Besides, the mass of the brain is not encompassed by a membrane in a state of tension, but by one which is very loose" (pp. 171, 172).

23. *Bellini* treats occasionally in his *Opuscula*[1] on the systaltic motion of the brain, and on the natural power of the spinal marrow of contracting itself; and on approaching his subject more intimately, he says that this is due to the structure of the pia mater, and the dissemination of arteries throughout the whole depth of the brain, which causes every part of the brain to be situated between two arteries, by which it is alternately compressed and freed from pressure. And each time when it is released from pressure, it is filled by a liquid secreted by the arteries; and this release from pressure takes place when the

[1] Bellini (L.), *Opuscula aliquot ad A. Pitcarnium, de motu cordis in et extra uterum, ovo, ovi aere et respiratione*, etc., Leyden, 1714.

arteries are constricted; but, on the other hand, when every part of the brain is compressed, the liquid secreted by the arteries, and which is derived to every particular part, is further propelled through the cerebrum and the nerves; and this takes place at the time when the arteries are dilated. The result of this is that the whole mass of the brain is moved, and indeed by a motion of expansion and constriction, and in an inverse order to that motion by which the arteries are dilated and constricted. For when these are dilated, the brain which is contained within them is constricted, and the liquid contained therein is propelled further; but when the arteries are constricted, the cerebrum is dilated, and then there is derived to it that liquid, which is secreted from the arterial blood.

24. Realdo Colombo.[1]—"When the head of a living dog is stripped of its skin, the skull broken, and the hard membranes divided, you may see the motion of the brain. For the brain moves in the same manner as all confess that the heart itself moves, namely, with a motion of dilatation and constriction."

25. Malpighi.[2]—"At the end of six hours from the beginning of the incubation of an egg the rudiments of the carina and head of the chick were seen as a zone, swimming in a colliquamentum of a leaden colour which was bounded by a circle that served as a kind of a dam" (*De formatione pulli in ovo*, p. 3). "I have often remarked, as a usual piece of nature's play, a motion present in the zones, by the coming and going of which the areas and cavities of the carina were either enlarged or obliterated" (*De ovo incubato*, pp. 2, 3).

C. *The Cortical and Medullary Substances of the Brain.*

[The experience of the anatomists on the cortical and medullary substances of the brain which the author desired to introduce here, will be found in Part II. chapters i. and ii.]

[1] Matth. Reald. Colombo, *De Re Anatomica libri xv.*, Venice, 1559. See *Lib. xiv. De viva sectione.*

[2] *M. Malpighii Opera*, London, 1687, fol.

ANALYSIS.

A. *The Cerebrum.*[1]

26. The cerebrum, properly so called, consists of two substances, the cortical or grey, and the medullary or white. The great mass of the former, divided into convolutions, and these again into gyres, clusters, and as it were into grapes, occupies the surface; and in some places it enters into the interior in the form of streaks, and in other places in the form of rays. The latter substance, that is, the medullary or white, begins where the former ceases, and it constitutes a certain nucleus, which is divided into various organs. This substance consists not only of fibres which have sprung from the former substance, but also of arterial and venous vessels, and their capillary prolongations; which seem introduced among the fibrillæ, as passive among their active forces.

27. The cerebrum is clothed with its own membranes; more immediately with its pia mater and the arachnoid membrane, and afterwards at a somewhat greater distance with a grosser membrane which is called the dura mater; and finally with the bones of the skull; so that it is most guarded against external injuries.

28. It is also furnished with its own sinuses, namely, the two longitudinal. To the cerebrum belong also the sinuses of the base, both the superior and the inferior petrosal. It is likewise provided with its own arteries, which are called the internal carotids.

29. The cerebrum is entirely separated from the cerebellum; for there is a curtain between them which is formed of the interior lamina of the dura mater; nor is there any communication between them except by the superior [or interior] lamina

[1] This sub-section of chapter i. is translated from Codex 58, vol. vi. of Photolithographed MSS.

of the same mater, by the pia mater, and likewise by the fibres in the medulla oblongata: for the meninges and the fibres are brought more closely together in the region of the corpora quadrigemina, and anteriorly near the beginning of the pons Varolii. They also communicate in a similar manner their arterial and their venous blood; for the arterial blood of the cerebellum, which is conveyed to it by the vertebral artery, flows into the carotid of the cerebrum, and the venous blood of the cerebrum through the longitudinal and the basilar sinuses flows into the venous blood of the cerebellum; inasmuch as the lateral sinuses at first are common to both, but afterwards decline towards the cerebellum and submit themselves to its jurisdiction and power. A communication is also effected through the straight sinus, which is likewise common to both.

30. The proper termini of the cerebrum are as follows: in the fore-part of the head it terminates near the crista galli, where it is attached to the lamina cribrosa by the fibres of the olfactory bulbs, and the dura and pia maters; below or behind it terminates almost in the middle of the occiput, where the longitudinal, the two lateral, and the straight sinuses meet at a certain bony bulwark. Besides, it terminates also in the middle of the sphenoid bone, and in its sella turcica, on which the pituitary gland is situated.

31. The above is the proper sphere of the cerebrum. As an appendage, there is as it were added to it the upper part of the medulla oblongata, which bears the name of the upper corpora striata; for these bodies meet the fibres of the cerebrum, and add thereto those which spring from their own grey matter; and thus in conjunction they give birth to the sensory and motory fibres of the body. By this royal road, therefore, which is as an appendage to the cerebrum, the sensory and motory fibres of the cerebrum take their departure; and in this respect the last terminus of the cerebrum is around the head of the pons Varolii; for there a meeting is effected with the fibres of the first process of the cerebellum—middle peduncles or crura ad pontem—. Another meeting-place is near the corpora quadrigemina, where the fibres of the second process of the cerebellum—superior peduncles or

crura ad testes—are encountered. In this wise the two brains form a common appendage or medulla, which as long as it tarries within the cranium is called the medulla oblongata, but when it leaves the cranium, enriched by the fibres of the third process of the cerebellum—inferior peduncles or crura ad medullam—it is called the spinal marrow. In this neighbourhood the motory nerves of the eye take their origin.

32. By means of the corpora striata the cerebrum extends its termini even to the orbits of the eye, and finally in conjunction with the cerebellum it reaches to all the foramina, through which the consociated fibres leave the cranium, the lowest or corporeal sphere of its organization.

B. *The Fabric of the Cerebrum.*[1]

33. Viscera and organs constructed according to the measure and pattern of nature have within them most pronounced determinations, both on their surface and in their interior globular mass; and the determinations on the surface likewise extend thence into this globular mass. These determinations[2] are general, particular, and singular. That determinations may be, they must have respect to centres, where they must end; centres, again, require intermediate axes, and axes poles; and then they have the power of displaying their forces, and of producing effects.

[1] This portion of chapter i. is likewise translated from Codex 58, contained in Photolithographed MSS., vol. vi. pp. 66-68. On p. 65 is the first draught of this article, which, however, is crossed out. On p. 63, where the author lays down the general order in which chapter i. is to be treated, he says in respect to the present subdivision, "The Fabric of the Brain, see chapter vii. of our first projection"—from which it would seem that at first he had not intended to rewrite this portion of chapter i.; but subsequently he changed his mind, and superseded chapter vii. of Codex 55, Photolithographed MSS., vol. v., which is added as appendix i. to the present chapter.—Editor.

[2] A *determination*, according to Swedenborg, is an activity exerted by a viscus or organ in a certain direction, either within its own sphere or upon adjoining organs. A determination may also be organic, in which case it consists of a vessel together with the fluid or essence circulating through it. Of such organic determinations, all tending towards the production of one general result, consist the various organs and viscera of the body.—Editor.

34. [In the cerebrum] the determinations on the surface are cortical; for the cortical substance occupies the whole exterior of the cerebrum, and constitutes its surface. The greatest determinations are into hemispheres; which, again, are determined into lobes. Smaller determinations are into convolutions which creep along in a serpentine manner; and again into smaller masses, glomes, and clusters. The least determinations, however, are into the so-called glands, or vesicles [ganglionic cells]; these are the units of which the cerebrum is composed, and whence it derives its esse, such as it is.

All these determinations are separated from one another by the productions or prolongations of the dura and pia maters, through fissures, sulci, and finally through imperceptible clefts or rifts; for in this wise the anfractuosities ramify, as is even the case with the cortical convolutions and gyres.

35. The determinations on the surface have mainly respect to the blood-vessels, venous (*i.e.* sinuses) as well as arterial. The hemispheres, or the large division backwards, has respect to the superior longitudinal sinus. The determinations, like the convolutions themselves, increase according to their action upon the sinuses, thus according to the capacity of the sinuses, and the resistance of the blood. The greatest determination takes place towards the straight sinus or the torcular Herophili; and finally from the edges of the cerebrum towards the lateral sinuses; the action of the cerebellum concurring likewise in these determinations. The smaller determinations have respect to the carotid arteries, which pass through and are extended through the fissures of the lobes, and at last pass over the corpus callosum. Still smaller determinations encompass or enclose the branches of the carotid artery; afterwards the lesser branches, and so on. Finally also, but on the reverse side, the determinations on the surface have respect to the fibres which they produce, and project into the medullary globe.

36. The determinations on the medullary globe or mass are most distinct from those on the surface. The greatest among them is the so-called corpus callosum, which reunites and con-

sociates the two hemispheres. From this the determinations run out through the body of the fornix[1] into the ventricles; these they also distend in a vault-like manner, and diversify in various ways. In addition to this they also push forward in the direction of the infundibulum. The medulla of the cerebrum is determined likewise in the direction of the corpora striata, and through these into the olfactory, as well as into the optic, nerves, and also into the remaining nerves which run out of the medulla oblongata, and finally out of the spinal marrow. There are thus as many particular determinations as there are nerves, and indeed for this purpose, that they may be subservient to motion and sensation.

37. Again, there are two centres or focuses of the substance of the brain; one of which must be called the centre of the cortical substance, and the other the centre of the medullary substance. The centre of the cortical substance, or of the surface of the brain taken at large, is the isthmus, or that medullary substance which is between the cerebrum, the cerebellum, and the medulla oblongata, on which are placed the corpora quadrigemina and the pineal gland; the centre of the isthmus again is this very gland; for all determinations which flow together in the direction of the straight sinus are finally concentrated there, as in their most tranquil spot. The medullary centre of the cerebrum, however, is the body of the fornix; for there the fibre of the corpus callosum is concentrated,[1] and thence it is again ramified, in order that it may perform its functions. For nature is wont to collect the scattered determinations into one centre as it were, or into one central axis, whence they run out again to their termini. The medulla of the posterior and lateral cerebrum is thus gathered up in the body of the fornix; the medulla of the cerebellum in its peduncle, and it is thence continued into the processes, namely, into its three pairs of crura or peduncles; and the fibre of the cerebrum, cerebellum, of the medulla oblongata and the spinal marrow is collected into nerves; the nerves are collected into ganglia, and

[1] See Sub-section C in Note iii., entitled "The Chemical Laboratory of the Brain."—Editor.

so on, so that from a certain centre previously formed a new field for its determinations is surveyed. There [that is, in the centres] is the most tranquil region of the whole medulla.

38. The cerebrum has two axes; a longitudinal and a transverse one. The *longitudinal* axis is the cleft which proceeds from the septum lucidum through the third ventricle, and finally through the isthmus or aqueduct to the valve of Vieussens. Thence a similar axis is continued through the fourth ventricle, the calamus scriptorius, and lastly through the fissures of the spinal marrow to the cauda equina. This axis, however, is repeatedly interrupted or obstructed by serosities. The middle of this axis is occupied by the third ventricle, on either side of which are the two centres, namely, the pineal gland and the body of the fornix. The *transverse* axis, on the other hand, extends from the straight sinus towards the pineal gland, and after bending there a little it is continued through the infundibulum towards the pituitary gland. This axis is also hollow, and forms an oblique angle with the longitudinal axis.

39. The poles, however, are at the beginnings or at the ends of the axes; they are like centres in the middle of the axes, where they intersect one another. The highest pole is where the crista frontalis and the crista galli meet; for there the longitudinal sinuses and the falciform process of the dura mater begin. There the medulla of the cerebrum terminates after passing over the bulbs of the olfactory nerves; and if the hollow axis of the cerebrum is continued through the septum lucidum, it terminates in this pole. An opposite pole to this, properly so called, does not exist in the cerebrum, unless you choose to designate the pineal gland as one; but as this axis is prolonged into the spine, the above pole seems to have respect to an opposite pole in the ultimate apex of the spine or in the coccyx, where the remaining portion of the fibre at last bursts out.

The poles of the transverse axis, however, are conspicuous. The one exists where all the posterior sinuses of the dura mater are concentrated, and where there is a sufficiently marked protuberance. On the opposite side, or at the other extremity of this axis, is the pituitary gland, which is placed on its sella turcica. These three points outside of the cerebrum are the most tranquil—namely, the point of the crista galli, the sella turcica, and a point almost in the middle of the occipital bone—because there is a meeting-place of opposite determinations there.

The cranium has likewise its determinations, which are pointed out by the sutures and other indications.

40. All the viscera and cavities of the cerebrum, as well as the remaining viscera or those of the body, have likewise their definite determinations, focuses, axes, and poles. Likewise all the larger and smaller divisions of the cortical and medullary substances of the cerebrum; nay, even every least substance or spherule. The determinations of these have a mutual respect to one another; and at the same time they have respect with all their eyes [as it were] to the general determinations, or to those of the whole. There prevails thus a sublime and wonderful order and a mutual respect in all things, from the least singulars to their generals, and again from these to the most general.

C. *The Motion of the Cerebrum.*[1]

41. The ancients and some of the more recent anatomists and philosophers have thought that both the cerebrum and the cerebellum are quiescent; and that the lymphs and animal spirits pass through them just as through the trunk of a tree, which while it stands still is permeated by the sap from the root to the branches. They, nevertheless, admitted a slight raising above the outer circumference (*liber*) of its surface, caused by the pulsation of the arteries. The learned of our times, however, better instructed by experience, which is now in its bloom, have observed that the cerebrum is expanded and constricted like the heart and lungs, and that it performs a systaltic and diastaltic motion, which in the following pages we venture to style the animation and respiration of the cerebrum.

42. By the observations made by the most celebrated men,

[1] This portion of chapter i., in compliance with the author's instruction given in Codex 58, Photolithographed MSS., vol. vi. p. 63, we supply from chapter i. of Codex 55.—Editor.

we have been convinced that the cerebrum is stirred to its very base by alternate motions; and if such is the case with the cerebrum, it follows of a necessity that such must also be the case with the cerebellum, the medulla oblongata, and the spinal marrow; for the connection of parts, the continuation of membranes, the consociation of fibres, and the passage of the arteries among them, is such that it is impossible for one to be moved without the other; and, besides, the same causes and the same effects which prove this motion in the one case, prove it also in the other.

43. There exist also clear evidences of a motion in the two brains, and likewise in the medulla oblongata and the spinal marrow, namely, in the bones of the cranium, in the dura mater, and also in the pia mater and the arachnoid membrane; in the spaces and sulci between the convolutions and gyres of the cortical substance, and also between the fascicles of the medullary substance; in the larger cavities or ventricles; nay, even in the individual members and organs. When these are thoroughly scrutinized, we cannot help seeing that motion has imprinted as it were its own marks upon them, and we see also traced out in them the form of this motion. For the *dura mater* again and again retreats to some distance from the cerebrum, thus affording it space for swelling and subsiding; it is furnished with fibres of a double and threefold order, and besides with muscular bands which are placed near the larger sinuses; the fibres run out in a semicircular form; those which constitute its lower lamina in a different way from those which compose the upper one. Its muscular bands also are folded up in a like direction: its blood-vessels tend in a sure course from their origins towards the common centre of the motion, or towards the concourse of the sinuses; and traces of the largest of them are impressed upon the tables of the cranium: the lesser vessels, however, are inserted in an oblique direction and in proper order into their sinuses. All these things would not be arranged thus, unless in every one of them there was a perpetual motion as long as life remains. The same also is proved, and as it were dictated, by the *pia mater* with the *arachnoid membrane* spread

over it; for it is folded and duplicated more than a thousand times, so as to be first unfolded and then again folded together in conformity with every motion of the cerebrum underneath. Besides, the most refined lymph is poured over the pia mater, and by little lakes and continuous ducts is expressed over the arachnoid membrane during the intumescence of the cerebrum, and is collected again during its subsidence. Moreover, the continuous *anfractuosities* and sulci between the convolutions or gyres of the cortical substances are lined with pia mater and arterial villi; and likewise more deeply in the interior of the cerebrum, between the fascicles of the fibres: all of which goes to prove that the cerebrum in every part of its organism is capable of being unfolded and compressed. The cavities or *ventricles* also are so formed as to be contracted when the cerebrum is expanded, and to be dilated when it is constricted. But why should I specify all these particulars? For we cannot meet with anything whatever in the fabric of the brain which does not declare that both the cerebrum and the cerebellum are in constant motion, and are formed for such a constant motion; and that there is no part, that is, no artery, vein, or fibre, and still less an aggregate of parts, which is not placed in the very current of the motion of the brain. The following also occurs as a wonderful arrangement; namely, that every single part, and every compound of parts, has inscribed upon it as it were the very form of motion; for poles are there, or are represented there; and between the poles are axes, and around the immovable axes there are greater and smaller circles, like equators and ecliptics, which are capable of circumvolution, scarcely otherwise than in the large hemispheres of heaven. All have as it were a spiral fluxion and contortion, and hence a free power of expansion and contraction.

44. From the longitudinal sinus which is contained within the duplicature of the dura mater; and from its cords, muscular glandules—Pacchionian corpuscles—and muscular bands; and likewise from the remaining sinuses, their coatings, folds, ligaments; and from their fluxion and connection, it is seen manifestly how

the motion of the cerebrum is communicated to the dura mater, and the motion of the dura mater to the cerebrum. The same is noticed in the cerebellum, and likewise in the medulla oblongata and the spinal cord; but because these are to be specially treated upon below, I refrain from collecting and quoting here any further proofs drawn from their consideration.

45. The alternate motion or that of expansion and constriction of the cerebrum, the cerebellum, the medulla oblongata, and the spinal marrow, is proved still more ostensibly by other phenomena; namely, by diseases, especially those of the head; as from apoplexy, epilepsy, catalepsy, and other convulsive diseases, also from dropsy and hydrocephalus; from cases of hypochondriasis and melancholy; likewise from vertigo, fainting fits, syncope, phrenitis, delirium, catarrhs, and also from coma, asphyxia, lethargy, and other diseases originating either in the brain or in the body. For the diseases which are of the blood, that is, of the body, attack the brain, and those which are of the animal spirits invade the body. On opening the brains of such persons as have died of these diseases, the dura mater appears either rigid or inflamed, or else relaxed and suffused with humours; the same also is the case with the substances belonging properly to the brain, namely, the cortical and medullary. Frequently also the spaces between the dura and pia maters, the sulci and passages between the simple or composite parts of the encephalon, or even the ventricles themselves, have been found obstructed by malignant humours, by a sluggish phlegm or pus; again, very often suffused swellings or scirrhi have been found to exert a pressure, or else fragments and splinters of bones had torn the membranes or fibres of the brain. By such causes the motion is partly stopped, and the power of expansion and constriction interfered with, so that the brain is only with difficulty enabled to animate. When the alternate animation of the brain is thus obstructed, the senses are blunted, the muscles grow torpid, the animal mind languishes, the memory is shaken, the understanding obscured, and the will is at a standstill, and in the same proportion animal life is rendered difficult.

46. But what is the use of adducing confirmations from the anatomy of the brain and the history of its diseases? For all inductions made from such marks or signs are nevertheless regarded as so many conjectures—still autopsy, and thus the testimony of men worthy of faith, ought to suffice. By their experience, however, it is proved that this motion actually exists; nevertheless, the quality of this motion, its origin, progress, determination, and use have to be learned from the above-mentioned phenomena and sources of information. The first thing, however, which must be proved is this, that not only the whole mass of the brain or one of its hemispheres, but also that every one of its organs and members—nay, what is even more worthy of being mentioned, that every one of its least parts is movable by itself or individually; and that in a like manner it is also capable of undergoing animation: for the universal brain is encompassed by its own space, each of its hemispheres by its own, each glome of the cortical substance and also each fascicle of fibres by its own; further, each gland and each protuberance, nay, each cortical part, each fibre, artery, and vein is surrounded by its own particular space. Each of these parts, therefore, has granted to it the power of expanding and contracting in the greatest freedom; and hence arises the universal power of all, that is, the general or common power of the brain. Concerning the power, quality, and determination of this motion, however, we must judge from the connection, form, and unanimous consent of all the individual parts in the production of a general effect. For nature in its kingdoms is so circumstanced that it is the more perfect in its general sphere, the more distinct it is in its particular spheres. The brain acts most distinctly in its first infancy, less distinctly in adult persons; but indistinctly in old and decrepit men: for as age advances, parts coalesce, and the motions of the parts are condensed; and at last the parts grow together, whence there results a hardness and slowness of action, and finally impotency and death.

47. The quality, power, and determination of motion are judged

from the connection and form. Connection will be treated of in the following chapters; but in respect to form, there is no more perfect form in nature than that of the cerebrum; for this organ is divided into hemispheres, and these again are subdivided into convolutions, larger and smaller; in the middle it is traversed by a certain axis, which is continued even to the very apex of the spinal marrow; and around this axis flow perpetual circles drawn in a spiral form. Poles, axes, larger and lesser circles, are thus seen to be marked out not only in the brain, but also in its convolutions, glands, and organs, nay, in its least parts; and these scarcely differ from those in the large hemispheres of heaven. Such is the most perfect form of nature and of its motion; and hence results a harmony of all things, a mutual respect and dependence. And because the form of simple parts in its nature is more perfect than the form of composite parts, it follows that the motion of the brain in general is most perfect if it depends in greatest fulness and in due order upon more simple forms and parts, and finally upon the most simple. As is the form of the brain and of its parts, such also is its motion.

48. Still, however the cerebrum is divided into serpentine and almost vermicular gyres, and however in its form it emulates that of an individual snail, nevertheless its periods of expansion and constriction are simultaneous, and not successive. It performs this motion in the same way as the large muscle of the heart, which also undergoes its systaltic and diastaltic motion by simple expansion and constriction; for its fibres near the core are also curved in spiral flexions. We are familiar with these spiral inflections in many other little bodies in the same kingdom. It is only the spiral fluxion and form which furnishes an easy power of expansion, and which causes one part not to be in the way of another; it likewise induces a gyre to commence its fluxion anew where it ceases, and it thus perpetuates the same by a certain spontaneous effort. Mechanical art also has been able to demonstrate this by twine wound in the form of a screw.

49. The cerebrum, besides, is so partitioned and convoluted that it may be moved, *i.e.* unfolded and refolded as a whole, and also as to its component parts; or in other words, the entire cerebrum may either be moved as a whole, or one of its hemispheres may be moved by itself or separately; or again, a single convolution of the cortical substance, or even one least cortical substance may undergo a motion by itself—for there is nothing in the cerebrum which is not encompassed or surrounded by its own space, and in this manner connected with the neighbouring parts, so that it may be expanded either in conjunction with them or separately. As is the case with the convolutions and cortical substances, so also is the case with the fascicles and the medullary substances of fibres, which are cortical appendages. This is the reason why, upon one part of the cerebrum being obstructed, the remaining parts nevertheless perform their vital functions, and continue unimpaired and living; and likewise why the cerebrum at its good pleasure, and also from necessity, is able to control the single fibres and muscles; whence result special and individual actions.

50. The cerebellum, however, is differently formed and articulated. From its little parallel circles which finally converge; from the insinuations of the pia mater and the arteries; from some protuberances in its anterior part which fold and unfold in conjunction; from the figuration of its substances, and the determination of its superficial parts towards general centres and bosses, and of the substances of its globe towards a common peduncle which is rooted in the border of a certain cavity [the fourth ventricle] sculptured into the stem of the medulla oblongata,—from all this it may be judged that the cerebellum undergoes an alternate intumescence, just like the cerebrum, with this distinction, however, that it is expanded in a simple and almost a single manner; and that by such an expansion it provides for its fibres in a general way. Besides, it appears from the medulla oblongata, in which the fibres of both brains meet, and also from the tentorium and sinuses, and likewise from the fourth ventricle and other connections, that the

cerebellum undergoes its intumescence at the same time as the cerebrum, yet in such a manner that the cerebellum may rise up high, and may thus reciprocate this motion, when the cerebrum does so placidly and tranquilly. It is different in brute animals; and the difference is still greater in insects.

51. The spinal cord, which is stretched out in the form of a long reed in the interior of a certain bony articulation, is extended and contracted, expanded and constricted in a similar manner. This may be concluded from its middle axis, which is purely cineritious or formed of grey matter; from its circumference, which is medullary; from the fluxion of the fibres, the determination of the roots of the nerves; from the mode in which the arteries and veins are emitted in its anterior and posterior parts; from the continuation of the meninges [the dura and pia maters]; and finally from the interposition of cavities,—from all this, and from some other proofs, it may appear that the general systaltic motion of the spinal marrow depends upon the motion of the cerebellum, but all its individual or least motions, which are many, upon the cerebrum. For the cerebrum by means of the spinal marrow acts upon the individual motory fibres of the body, which are determined into action by previous volition.

52. The cerebrum may be expanded outwardly or as far as the dura mater, against which it impinges lightly. Its mass may also be expanded, or may swell, inwardly; for the larger and smaller cavities, that is, the ventricles and the little spaces by which its continuity is interrupted, impart this power to it. This twofold power of determining its animations was granted to it for this purpose, that its motion may never cease and expire, no matter how much the spaces without or within its surface may be obstructed by humours.

53. That the times of the animatory motion of the cerebrum, cerebellum, of the medulla oblongata and the spinal marrow, coincide with those of the respiration of the lungs in adults; but with the times of the pulsation of the arteries and of the heart in embryos, and in persons not breathing, this has been shown in

a particular work;[1] likewise that the dura mater is the uniting medium of the motions of the heart and of the brain, because it is excited partly by its own arteries, and partly by the brain.[2]

54. The brain, besides, while in a state of wakefulness, frequently changes its states; for at one time it rises higher and is swollen, and at another time it is lower and compressed; this being entirely according to the various motions of the animal mind. It is borne upwards and swells, when a man is angry, proud, or joyful; but it subsides and is compressed in states of grief, sadness, fear—yet even then it undergoes its alternate motion of animation, but with a difference according to the states that have been induced.

55. From all the above-mentioned phenomena it appears clearly that the motion of the brain does not arise from the pulsation of its arteries, or that the heart does not extend the sphere of its activity into this illustrious court of the whole kingdom, *i.e.* into the brain; for the brain acts from the beginnings or principles, and it presides over the causes of the effects; consequently it presides also over the heart, and its arteries and veins, by which the effects are immediately produced. The brain, indeed, furnishes the blood-vessels with fibres derived from its own body; from these fibres also the muscles are woven together, whence there arise actions. The brain in time, and also by virtue of its action, is first; wherefore it will not consent to be governed by the heart, which is generated afterwards; it also occupies the supreme place, and resides as it were in the heaven of the body. The heart, on the other hand, occupies a lower place, and inhabits a kind of earthy body. The brain acts at the same time from nature and from the will; but the heart only from instinct and a blind influx; for while ruling the blood, it is also ruled by it in return. To attribute therefore the

[1] *Œconomia Regni Animalis Transactio II., Paragraphus primus.* Concerning the motion of the brain, and that its animation coincides with the respiration of the lungs (pp. 1-34); Engl. edit., vol. ii. part ii. chapter i. pp. 59-111. For the sake of convenient reference this article is reprinted as chapter ii. of the present work.—Editor.

[2] This subject is discussed in sub-section x. of chapter ii.

motion of the brain to that of the heart, would be to assign the efficient cause to the effect itself, the origin of the fountain to the rivulet flowing from it; and the judgments of the mind to the coarse blood. That the state of things is not so perverted is taught by anatomy, when it is examined not only by the sight of the eye, but also by that of reason. For as soon as the arteries of the body reach the first threshold of the head or the cranium, they renounce the government of the heart, and subject themselves to the cerebrum and cerebellum. There are two arteries which ascend from the kingdom of the heart, that is, from the body; they are the carotids and the vertebral arteries. As soon as these touch the bony threshold itself, they twist and bend themselves in a wonderful manner, and untwist again; they also lay aside their motory coating, beyond which the heart of the body cannot act; moreover, they are dilated against the customary use, and at last after repeated decussations they insert themselves into the pia mater, and after being ramified into least threads, they enter into the cerebrum and cerebellum without blood, and submit themselves entirely to their orders. Wherefore the origin and cause of this motion must be sought for in the brain itself; for since the brain exists in the principles, whatever it has it has from itself.

56. It is the cortical or grey substance which is expanded and constricted, or from which the cerebrum has its animatory motion; for its parts are globules of a roundish shape approaching the oval; they are engirded by a thin or most delicate meninx or membrane; they are distinctly separated from those parts to which they are related, and which are in their confines, so that each single globule is movable, and capable of expansion and compression within its own space. The impression given by their form is, that they are least hearts (*corcula*) and least brains (*cerebellula*) of a purer nature. Little arteries flow into them with their ultimate and least ramifications, and fibres proceed from them, as many as ever appear in the brain, in the nerves, and finally in the body. These grey particles constitute the circumference of the cerebrum; they penetrate into the

cerebellum in the form of a little tree; they interline the medulla oblongata in the form of striæ, and they constitute the entire axis of the spinal marrow; so great is their number. Moreover, they also occupy, here and there, in various forms the interiors of the cerebrum, that is, its [fibrillary] texture, its glands and corpora. We must not look for the origin of the motion of the brain anywhere else than in these its organic parts; for only in these does the brain begin to be a brain; from these it takes cognizance of the arteries about to enter into it from the body, and likewise of the fibres that are about to depart into the body; and thus as it were from so many centres it contemplates whatever is done in the rays and circumferences of its kingdom.

57. Their number also is so great that while each single particle expands itself, the whole mass of the brain is expanded from its bottom and from all its depths. Their connection also is such that all are able to have their systole and diastole in the brain in conjunction, or some separately; and that they are thus able to inspire their fibres, and to excite the motion of their fibres, almost as is the case with the arteries which depart from the large heart. There are thus myriads of origins of motion in the brain which cannot in any way be derived from the one only source of motion in the body, namely, from the heart; this, on the contrary, is compelled to live under the auspices of the motion of the brain.

58. The very principles of motion, however, are hidden still more deeply; and we must look for them in the interiors of these same organical parts. But as these parts cannot be pierced by the eye, therefore we need for their exploration an acute intellectual vision furnished with sciences instead of microscopes. From many considerations we are allowed to conclude that the least cortical substances are each like a brain in miniature; if, however, they are cerebellula or corcula of a purer nature, they would seem also to consist of substances which are similar or analogous to those of the larger brain; namely, of a purest cortex, a purest medulla, and likewise of exceedingly small cavities. By means of these there is conceived and born a most

refined liquor which is called animal spirit or nervous essence; and this liquor, by the fibres which descend thence, is sent out even into the motory fibres of the body. After this animal spirit has accomplished its circle, it is received back again from the blood, and again sent out. There [in the animal spirit] we must seek for the origin of the motion of the brain. If it is asked, but where is the origin of the motion of the animal spirits? we reply that this follows from the series of the same reasons; namely, that this motion derives its origin from the same source whence the above spirits derive the force and power of their activity, namely, from the soul. This issues its orders like a queen, and the animal spirits like servants obey its behests, and at its beckoning they run whither they are commanded. It hence follows that the animation, or the expansion and constriction of the brain, is both natural and also subject to man's will.

59. Of what use, however, is the knowledge of the motion of the brain? Without it, we are not able to perceive anything in the anatomy of the brain; for unless we behold it as it were set into motion, all things appear, so to say, closed and dead; if then we look for the brain in the brain, we examine simply its dead body. But the uses of all the parts begin to lie open before us, as in the light of the rising sun, as soon as we represent to ourselves that the brain in general, and also each of its members and parts, is expanded and moved, and thus as it were lives.

Without a knowledge of the motion of the brain we inquire in vain for the principles, the causes and origins of the motions of the senses, and also for those of the remaining effects and phenomena in the body; for the universal body, with its powers, forces, and actions, lives entirely or chiefly under the motion or the auspices of the brain. Without this knowledge we neither know whence come the so-called animal spirits, nor by what principle they are determined into the fibres, how they produce actions, nor finally how they circulate. Everywhere, then, the whole of that chemical, physical, and mechanical science would fail us, which is as it were implanted in the animal kingdom, and which is far above the common facts of men.

Without a knowledge of the motion of the brain we should remain in doubt as to the various diseases, especially of the head, and we should not know how to point out their causes, and on seeing and observing the changes in the opened brains we should stand agape and wondering, as a donkey before a machine set in motion by the wind or water. Without this knowledge also we should know nothing whatever in psychology; we should not know what the soul is, what the mind, the understanding, the will, and what the exercises of each are; for in order that the soul may live corporeally or by a body, the brain or everything organized must be moved or animated in alternate periods; but in order that the soul may live spiritually or in its spirit, the brain, or that which is an organism, must be quiescent.

D. *The Functions of the Cerebrum in General.*[1]

60. *The cerebrum is the general maintainer and regulator of the internal sensories, or of the [least] organic substances which are in a spherical form;* for it is the subject which contains them, and it is a globe formed of these substances and their determinations. By the influence of the cerebrum the order, situation, and respect which these least parts have to one another is caused and preserved.

61. *The cerebrum also is the common moderator of their states and operations;* for whoever or whatever directs the order, directs also the states of all among one another; as may be seen from an infinite number of phenomena; consequently the cerebrum is the efficient cause by which the inmost sensories are able to perform aright their offices in the communion.

[1] This article is translated from Codex 58, Photolithographed MSS., vol. vi. pp. 75-81. It is preceded by another article on the same subject which is not crossed out, wherefore a translation of the same is given as appendix ii. of the present chapter. The above article the author introduces by the following words : "This is the order which must be observed in laying down the functions of the cerebrum, for I have become better instructed on this subject."—Editor.

62. *The cerebrum is the common bond connecting the organs of sense of the body with the sensories of the soul;* for all fibres after having passed through the brain terminate in the cortical substances.

63. *The cerebrum also is the common or general vehicle of the external sensations to the soul;* for all sensory modifications are excited throughout this way until they are perceived in the inmost sensories.

64. On this account the cerebrum is called *the common or general sensory;* for all the generals belonging to sense are proper to the cerebrum; consequently, as is the order and government, so is the copula and uniting medium which conveys the modes of the body to the soul. For it is the office of the cerebrum [to provide] that the internal sensations shall flourish, and, as behoves in a regular system, that they shall live harmoniously among one another; and therefore it is its office to provide that the inmost senses shall be able to perceive, think, judge, and will; thus to contemplate ends, or to see whether a thing be true or false, and to insert it among its analytical conclusions. Upon the cerebrum therefore depend the faculties of remembering, imagining, craving, desiring, willing, etc.

65. The cerebrum also is *the efficient cause and general determiner* of the power of the soul, of the conatus of the rational mind, and of the active forces of the animal mind, into effects; or of ends by means of effects and actions into uses: consequently it is the determiner of the will and the desires of the mind into ends having respect to the election of good and evil, and into ultimate acts. Wherefore *the cerebrum is the general voluntary organ of motion.*

66. The highest court (*curia*) of the cerebrum is among the topmost protuberances, or in the crown, where the highest lobe is. The middle court, which is adjoined to the former, is the middle lobe; and the lowest court is the third lobe. Thither all sensations aspire; and the sensories of the highest court are in a state of the greatest expansion, intentness, and vigilance;

the rest also in their order, yet in subordination to the highest. There is a diversity in the state of every one of the interior sensories; the most expansile are the highest, and they become less so in proportion as they descend from the crown. The faculty of expansion depends upon the anfractuosities and sulci, and upon the faculty of expanding derived thence; that this is so appears from the very connection of things. These sensories scarcely extend beyond the great fissure towards the back [of the cerebrum].

Where the faculty of perception resides, there also is that of volition and determination; thus as the very sensory resides in the above places, so also the very motory faculty must have its place there; for the most perfect faculty of expansion and animation is there, generally, specifically and also individually; thence is every determination.

67. The royal road of the sensations of the body up to the soul which resides in its sensories, is through the corpora striata, which are most immediately subject to the above courts and communicate therewith. For these corpora disperse or distribute every mode in all directions, but especially towards the crown, where the acutest internal contemplation resides.

All determinations of the will also descend by that road; for the fibres of the cerebrum adjoin themselves to the proper fibres of these corpora, and enjoin upon them duties which they must perform in the body. This appendage is therefore in a certain sense the Mercury of the Olympus; it announces to the soul what is happening to the body, and it bears the mandates of the soul to the body. This is the reason why this appendage must be adjoined to the cerebrum; namely, that it may act as a conjoining medium between the body and the cerebrum in respect to man's sensitive and motory life.

68. Order also seems to be so disposed that the corpora striata carry into effect what the cerebrum determines, and the rational mind orders; nay, even in such a manner that the muscles and actions which are in the ultimates of the body or in the soles of the feet depend more immediately upon the

highest parts; upon the middle lobe the muscles which belong to the abdomen and thorax, and upon the third lobe those which belong to the face and head; for they seem to correspond to one another in an inverse ratio. It hence follows that the office, function, or effort of the corpora striata consists *in conveying the sensations of the body to the courts of the cerebrum;* but that of the cerebrum in conveying them to the soul, so as to reach our consciousness. In like manner it is the office of these corpora *to determine the mandates of the cerebrum into the acts of the body;* for it is the duty of the muscles of the body to execute them just so as they have been determined. The power of the soul, the conatus or the will of the rational mind, and the active force of the animal mind are thus determined by the corpora striata, not into act, but for act in the body.

69. The cerebrum, besides, acts as an intermediate cause between the animal spirits and the blood; for it supplies a most refined lymph with which the volatile spirit is mixed, and it thus enables the same [*i.e.* the animal spirits] to enter the organic parts of the blood or its globules. This is the purpose for which the organs of the cerebrum are intended; wherefore *the cerebrum is a gland by way of eminence,* or *the model of conglomerate glands.* From the fabric and connection of these members or organs appears most manifestly of what nature are the operations of the gland; the cerebrum is consequently *the general chemical laboratory of the blood.*

The above lymph is conveyed into the pituitary gland, which is by right an *illustrious model of the conglobate glands;* for every liquid elaborated in the conglomerate glands is afterwards passed out by conglobate glands; thence by three ways that lymph is consigned to the jugular veins, in order that it may meet the chyle of the body, and that the spirit of the brain may celebrate its nuptials with it. There is a general laboratory, but there is also a universal one scattered over the whole body; wherever there is fibre there also is spirit; that spirit which is intended for the blood-vessels, is again collected by the lymphatic vessels and the conglobate glands, and is led back into the thoracic duct, in order that it may return into the blood. In this manner the cerebrum also vivifies and animates the torpid and sluggish blood, lest by its obstruction it should interrupt and stop the animal functions.

70. The corpora striata contribute their share also to this work; for they constitute the bottom of the lateral ventricles; they excite the choroid plexuses to action, and allow the infundibulum to pass through them; so as to control and accommodate its action. *The corpora striata, or the appendage to the cerebrum, thus excites to action and to a proper operation the cause belonging to the cerebrum.* The cerebrum simply pours out the spirit, but the corpora striata express from the choroid plexuses a lymph to which the spirit is being coupled (*copulatur*). This lymph must be called the purer blood; for the animal spirit is attached to it, as the blood-globule to its serum.

71. Because the office of sensation and volition is assigned to the anterior face or province of the cerebrum, therefore the above office has been allotted to the posterior part of the cerebrum, or to that region of it which is around the longitudinal sinus, as far as the extension of the large fissure, or the boundaries of the division of the cerebrum into lobes. Here also is a lesser faculty of expansion, consequently a lesser faculty of changing its states; the changes producing thoughts. It cannot, indeed, be denied that sensations reach even thither, yet our mind does not become conscious of them to the same degree as it does in the anterior part of the cerebrum, in the very courts. For the fibre of this [posterior] region does not pass into the corpora striata, but into the corpus callosum, and thence towards the chemical organs or members of the cerebrum.

72. The soul designs and forms the whole of its body, or of its animal world, by means of the cerebrum; for there is nothing but the fibre of the cerebrum which reigns in the whole bodily system, *i.e.* in its circumference, where are situated its muscles and organs of sense; for these are immediately subjected to the

auspices of the cerebrum, because to its knowledge and will. The viscera enclosed in the body, however, are from the fibre of the cerebellum; and by its action they are not committed to the dominion of the will, but of nature; wherefore in the egg first of all exists the cerebrum, afterwards successively the cerebellum and the heart. The cerebrum first of all determines the fibres of the principles, and then concentrates them; afterwards from its centres it designs the circumference; thus the medullary fibre passes over into the nervous fibre of the body; and by the nerves, according to the representation of the body in the soul, it determines individual things. This also takes place by means of the corpora striata, which are auxiliary forces of the cerebrum. This is the reason why the cerebrum feels and determines thus according to the state of these bodies, and according to the connection of its own fibres with theirs.

73. *The cerebrum therefore first represents in itself the idea or ideal of its soul, into the form and nature of which, and into the intuition of the ends of which,* the body as its image is formed; namely, both in respect to its organism and to its operations and their uses, to every one of which in the soul the body corresponds. For the soul weaves and forms its body or organism by means of the cerebrum; by means of the cerebrum also it imprints upon it its own image; yet, nevertheless, not as the greatest has reference to the least in a type, but rather as our rational mind in itself and in its own idea beholds the forms of actions and the efficient causes and effects adjoined to them, and as in them it beholds the ends. It is thus that the external man is assimilated to the internal, not as a type to a type, but as the type to the ideal. This also is the reason why the animal mind (*animus*) and all its affections, nay, why also the desires of the intellectual mind (*mens*) are represented to the life in the very expression of the face, nay, of the whole body, and likewise in all the forms of its actions, so that thereby they become known to every one. For when the principle through the causes produces effects,

it cannot do so otherwise than according to the idea or ideal in itself; if the individual determinations flow according to the order of nature from the first to the last. This also takes place by means of the corpora striata, and afterwards by means of the medulla oblongata and the spinal marrow.

74. The cerebrum joins *the first determinations or fibres with the last determinations or the blood-vessels,* and *vice versâ* the blood-vessels with the fibres. The fibres enter the blood-vessels of the body; but these, after returning by the carotids into the cerebrum, with their least ramifications enter the cortical substances, and finally they clothe the fibres and their fascicles.

75. As the cerebrum transmits the vessels of the body to the origins of the fibres, or to the cortical glandules, so also it *sends back to the fibres the spirit of the blood;* and in this wise institutes a certain perpetual circle, which may justly be called *the circle of life.* For the fibre transmits its spirit into the blood, and the blood reciprocally sends its spirit back into the fibres; and so on continually—without my mentioning here *the lymph conveyed thither by the eorporeal fibres, by means of which the animal spirit is generated;* for that lymph with its purest elements contributes to that spirit its elementary or corporeal nature, but the soul its spiritual nature or its life.

76. From all of this it follows that *the cerebrum elaims to itself the right over its blood, and over its arterial and venous vessels* as soon as ever they approach the threshold of the cranium. On this account it receives the carotids between the fissures of the lobes, and their branches and shoots between its convolutions, in its anfractuosities and sulci; and for this reason it distributes the capillaries with the blood extracted from them around the fascicles of the fibres, under the form of coatings, so that they exist altogether in the stream of the motions and determinations of the cerebrum. This also is the cause of the anfractuosities of the cerebrum; namely, that each least branch of the blood-vessels should be led distinctly to its own gland, and that thus the cerebrum should institute a universal circle or circle of life. In a similar manner

the cerebrum also rules the veins, and the venous troughs or sinuses; these it encloses in its largest fissures, or between the hemispheres; in a like manner also the remaining sinuses are governed by means of the cerebellum.

77. As the cerebrum concentrates its medullary fibres into the nervous fibres of the body, and transmits them to the muscles, so also *it lends a ministering aid to the juice, which effects a distinction between the fibres and the fascicles of fibres, and interposes an interval between them.* The grosser humours, however, it directs by determined ways into the bulbs of the olfactory nerves, and thus casts them out by the lamina cribrosa; there is thus [appointed] a place of purgation, so that nothing may interrupt, obstruct, and impede, and that all functions may progress and thrive in an orderly manner and according to the law of nature.

78. As the cerebrum weaves and forms the individual parts, and provides that they shall perpetually subsist, even as they exist, and that all things shall live by acting, and shall act by living, therefore by its expansions and constrictions it excites all things below into an animatory or universal motion, and thereby continues perpetually the circle of life which the soul begins and institutes from its ends.

79. It appears hence that it is the cerebrum which imparts life and motion to the organs of sense and to the muscles of the body, and which also deprives them of life and of motion; wherefore it is the *cerebrum which induces wakefulness according to the degree of its intension, and also sleep according to the degree of its relaxation.* This takes place by a collapse of the cerebrum in itself, or by a folding up and a gluing together of its folds and commissures. The state of wakefulness is one of expansion of the cortical substances; but the state of sleep one of constriction of these substances; their connection is thereby broken, and the determinations of the body, that is, the vessels with their blood and spirit, do not enter into these substances, but only the corporeal fibres with their elements or with the aliment of the spirit. During that time all purer nutrition and all chemical

operations thrive more perfectly; for there is nothing on the part of the body to excite and disturb the lower animal and higher intellectual minds. The cerebrum therefore is the seat of wakefulness and of sleep; because thence come sensation and determination of actions. The sceptre by which this kingdom is to be ruled is then handed over to the cerebellum.

80. It appears hence that it is the cerebrum which *institutes the intercourse* between the soul and the body, or between the highest or the celestial sphere and the corporeal; just as between the animal spirit and the blood. In order therefore to explore the intercourse of the soul, it is necessary to explore the cerebrum; yet it cannot be understood precisely how this intercourse is instituted, unless we know also what the soul and what the body are; since from its principles the cerebrum derives the faculty of being the sphere of causes, and the body from the cerebrum the faculty of being the sphere of effects. For as the body derives effects from its causes, so the cerebrum derives causes from its principles; the causes being effects in respect to the principles, if these are assumed for causes; for the effect is continued from the causes, just as the cause is continued from the principles.

81. After this we may inquire of what nature, and how wonderful, the nexus is of this system; and then what is the nature of the nexus, of the chain and of the circle of uses; for uses follow the same chain, as causes and effects. This we shall not discover unless we know how the soul acts upon its body, and how the body *vice versâ* reacts upon the soul; the medium of which action and reaction is the cerebrum.

E. The Soul.[1]

82. *The soul is properly the universal essence of its body.* The soul is the only thing substantial and essential in its body. From it are derived and born all the substances and essences which are called composite and corporeal. For what can truly

[1] Codex 58, Photolithographed MSS., vol. vi. pp. 81, 82.

be, unless it be from a thing prior, more simple, and more unique, which is the beginning of the rest? That which gives to others being and existence, must itself be. It cannot be produced from modes, accidents, and qualities without a subject and form, and consequently without a real essence and substance. The soul also is peculiar or proper, and there is not one universal soul for all; so that the soul of one cannot belong to the body of another; for, what is to be demonstrated, namely, the very form of the body is the result of its essential determination, or the body itself represents the soul as it were in an image. That the soul is peculiar or proper follows from the diversity of the state of each person. In general, souls are similar, but in particular they differ as to states. These differences arise from the variety of ends or principles in human minds, consequently they are due to the information of minds *a posteriori*. All this will be demonstrated in our psychology.

83. *From the soul, as from the end or principle of the body, flow forth all essential determinations, consequently all dynamical forms.* In order that any series may be determined to the termini of the ultimate world, or in order that it may be derived from its universal essence, it is necessary that there should be several universal essences in the series; namely, the higher, the lower, and the lowest universal essence. The higher or highest universal essence is the soul, the lower is the animal spirit, and the third the blood. The highest essence imparts being, the power of acting and life to the lower, this imparts the same in a like manner to the lowest; the lowest, consequently, exists and subsists from the first by means of the middle. There are just as many essential determinations as there are essences; for essences without determinations form nothing. The very essences also must be determinant, in order that there may be determinations. The determinations of the highest universal essence of the bodily system are those fibres which are the simplest of all, and which are like rays of the soul, and the first designations of forms. The determinations of the lower universal essence are those fibres which are derived from the most

simple; but those of the lowest are the arterial and venous vessels. As the essences, so also the determinations are in turn derived from one another, the higher imparting being to the lower. From these determinations, or from these determining essences, all the organic viscera, and consequently the whole bodily system, is woven and formed. It appears hence what the body is; namely, that it is so composite that it falls under the notice of sense, under physical laws, under geometrical ratios and figures, and also under the terms of speech. Again, it appears that the lower essences have derived from the inert and heavier elements of the world this feature, that they are able to coalesce into a lower essence, and to be of use to functions in the ultimate parts of the world. If, therefore, you abstract from the blood these elementary and terrestrial parts, and if you abstract from the animal spirit its purer parts of the same kind, what then remains is nothing but a form derived from the determinations of the soul, or the veriest being of the body, presented under a similar form to that which is seized by the senses when it is found combined with terrestrial elements; but which form is purified of its really corporeal parts. In respect to the cerebrum, however: this acts the part of a middle cause, both in respect to the essences and to the determinations. In respect to essences: from the cortical substance where the soul resides in its most eminent and as it were its first organic clothing, the cerebrum receives the animal spirit, and prepares it so that it may be of use to the blood, or that it may attend it; or again, that the blood may be produced thence by the addition of terrestrial elements. In respect to determinations: the cerebrum receives the fibres generated from the cortex itself; these it rolls together and determines into fascicles and nerves in such a manner that they are able to perform in the body all things in agreement with the intention of the soul. Concerning the three universal essences and their determinations, see "The Peritonæum."

[1] See "Regnum Animale," part i. Latin edition, Nos. 252-258, pp. 405-411; English edition, Nos. 312-318, pp. 486-493.

F. *The Chain and Bond of Uses.*[1]

84. *It is the cerebrum through which the intercourse between the soul and the body is established; for it is as it were the link and the uniting medium.* From what follows it will appear that the soul is in the cerebrum as it were in its heaven and Olympus, although it is essentially everywhere, and present in every individual part; in the cerebrum, however, is formed as it were its court and palace chamber, from which it looks around on all things belonging to it, and determines them into act in agreement with its intuition. That such is the quality of the soul in the cerebrum, results from its form, which is such that it imparts to it the power of being such, as it is intrinsically. That there may be a perpetual communication between the soul which resides there and the body, the cerebrum was formed.

85. *The quality of the cerebrum, therefore, will appear most manifestly from the chain of the determinations, the fluxion of the operations, and the circle of ends and of uses, by which the soul is united to the body, and* vice versâ. For all fibres derive their origin from, and are under the auspices of, the cortical substance, or what amounts to the same thing, all fibres terminate in that substance. In order that fibres may be, it is necessary that all operations should be determined according to the influx of the fibres; for the fibres are determinations of causes and of effects, and they are as it were highways and rays, according to which the soul by operating puts itself forth. The subjects and substances of the operations are the fibres; accidents and modes without substances and subjects are nothing. That the operations follow this pathway [*i.e.* of the fibres], and their nexus, appears from the particulars. Now, as it is the cerebrum which receives the fibres where they are called medullary, and as it despatches them into the body where they are styled nervous, it follows that the quality of the cerebrum may be known from this circumstance.

86. *It is the cerebrum in which the soul disposes and unfolds*

[1] From Codex 58, Photolithographed MSS., vol. vi. pp. 83-92.

its purest and most simple organic forms, or the cortical and grey substances, in such order, that from them, as from beginnings, it is able to behold, and to enter upon, the campus and playground of all its operations, and as from centres to look around upon all things as upon circumferences, so that it is able to embrace and to keep everything under its auspices and intuition. It must be well kept in view what the cerebrum is, and what the cortical substance: the former is the sphere of causes, but the latter of ends; the cortical substance, consequently, constitutes the higher, and the cerebrum the lower sphere; for the cortical substance, when regarded in its individual parts, is in a higher sphere; since each individual or singular substance is most purely organic, and is a cerebrum in a least effigy, and thence all things flow out as from their beginnings. Suppose now that there are myriads of this kind of eminent cerebra; arrange them in the most suitable order, and at the same time form them into congeries, then divide them over and over again, and there results thence a composite and concrete mass.

This cannot be called the higher sphere, but in respect to its composition and arrangement it is called the cerebrum. From the composition of unities in which the higher sphere reigns, results the lower sphere, which is that of causes, *i.e.* the cerebrum; for it is not the action and modification between these substances, nor the changes of state between them, but the action and modification, and hence the changes, in them, which impart the capacity of perceiving sensation and of acting. Wherefore the cerebrum is as it were the preserver and regulator, so that the soul in these its principles may act upon the animal mind (*animus*), and upon the rational or intellectual mind; for when the connection between these is disturbed, the power also perishes for these sensories and organs to act in consort; since all conspire together in the production of the effect. The more there are of the above substances, the more perfectly do they perform what they have to do, and they also mutually bring one another into a state of unanimity; even as is the case with the eyes, several of which see more than one eye. This arrangement, which agrees completely with the modes of acting in general, causes all things to be done in an orderly way; wherefore this general form corresponds to the form of the forces of each. It may be said, therefore, that the cerebrum is as it were the bond, the preserver and regulator of all substances which hold the place of ends or of beginnings; although there is also an action between the substances, and a change of state of the cerebrum itself, which likewise under a certain general sense comes to our knowledge; for without a general modification, as in sound, individual modifications are not perceived. What the cerebrum is, appears from a change of the faculties in some diseases, as in apoplexy, epilepsy, paralysis, etc., likewise in many morbid states of the animal mind (*animus*), in a cerebrum wounded by various accidents; not that on this account the interior sensations are wounded, but that they are not able to act conveniently in general consort, or the connection being injured, that they are unable to behold things in general; wherefore also they return into their former state, when the connection is restored. Otherwise these organic forms are also connected in an irregular manner with their blood-vessels, so that there is no longer a general sight and intuition; nevertheless, if they were left in freedom, under an effort of the soul, they would at once reduce themselves into order; but as they are situated in a certain general campus, to which they are attached, they have no power of coming into a state of order, except by external means.

87. *Again, it is in the cerebrum that the soul from its organic forms or its cortical substances produces the fibres, expands them in the first place, then entwines them into knots and plexuses, and finally connects and concentrates them with fibres of another origin, surrounds them with coatings, and sends them out in fascicles, as nerves, into the regions of its body.* Hence the medulla of the cerebrum, which is a continuous fibre, is gathered up and clothed with vascular capillaries. Thence arises that globe which is called the centrum ovale (corona radiata). How great is the abundance of the cortical sub-

stances or of the principles from which the fibres arise, can easily be comprehended from this consideration, that its whole circumference consists of them. The cerebrum is thus a complex of fibres, which it receives from the whole of its surface or circumference, and which it compounds in various manners namely, into series, fascicles, plexuses within plexuses; for its medullary congeries is everywhere pervious to fluids. It may be seen that the cerebrum first unfolds these fibres, so that they are as it were left to their own freedom, as ought to be the case in every origin and in every conception of things. Soon, however, it urges them together, limits them, invests them with coverings, and connects them so that they cannot stray away, but are kept under the auspices of the soul. Those fibres which the cerebrum transmits into the body, namely, into its sensory and motory organs, that is, into the muscles subject to the will,—these it leads through its appendage the corpora striata: these fibres are such as originate from the cortex of the anterior cerebrum, where the soul holds as it were its court; that is, its highest court in the midst of those protuberances (*umbones*), where the highest lobes are; its middle court around the former, where the second lobes are; and the lower court, where the third lobes are. That it carries the remaining fibres towards the corpus callosum, and thence into the body of the fornix, and towards its chemical organs, will be demonstrated in its series in what follows. That the fibres of the cerebrum itself pass also into the nerves, appears from the olfactory, and likewise from the optic nerves. It will be shown in what follows that these fibres also pass towards the ear, the tongue, and the cuticles; but that they are nevertheless invested by fibres of another region, namely, of the corpora striata, the medulla oblongata, and the spinal marrow, and especially also of the cerebellum. Besides, on the way, and indeed by application, the cerebrum disposes the remaining fibres to act in agreement with the will. These emissary fibres also the cerebrum not only entwines with vascular capillaries, as with most rarefied sheaths, but it also encircles them with pia mater, and finally with dura mater. It is thus the office of the cerebrum to arrange and roll together into becoming order these infant fibres, and besides to encompass them with coverings and fasciæ, and in this manner to prepare them, so that they may distinctly enter into the regions of the body. The cerebrum is therefore the mediating cause of all the determinations of the soul, and especially of those which are subject to the arbitrament of the understanding and of the will; wherefore, the proper fibres of the cerebrum do not tend in any other direction than into the organs of the senses, and into those muscles which are to be ruled by the will. The fibres of the cerebellum, however, tend into the organs or viscera of the abdomen and the chest. On the other hand, again, the fibres from both these sources summon to themselves the fibres of the medulla oblongata and of the spinal marrow as auxiliary forces. For each cortical gland is the producer of a fibre; wherefore as far as the pons Varolii the fibre of the cerebrum is associated with the fibres of the corpora striata; but below or from the beginning of the pons Varolii the fibre of the cerebellum is added; from the medulla oblongata, however, downwards, fibres of a threefold origin are associated together.

88. *Thus the soul by means of the cerebrum, and the cerebrum by means of the upper corpora striata, and finally by the medulla oblongata and the spinal marrow, constructs and weaves together the muscular and organic circumference of the body, and likewise its trunks or stems;* that is, the whole of that part of the body which is to be subjected to the auspices of the rational mind; for the muscles subject to the will press upon the circumference of the body, and constitute the trunks or stems, such as the arms, hands, loins, feet, soles, and toes. This same circumference is likewise furnished with the sense of touch: the organs of sense, such as the eye and the rest, are also placed in the circumference of the body; for they are likewise exposed to an appulse of the things with which they come into contact. From the formation of the chick in the egg it appears that the

above-mentioned organs are designed first of all, see Malpighi; for there is nothing except the fibre which constructs all things, so that the body is a texture of the fibres of both brains, and also of the medulla oblongata and the spinal marrow. That all this, however, takes place by the mediation of the upper corpora striata, which are an appendage of the cerebrum, is proved by many things; namely, by the fact that the fibres of the cerebrum descend chiefly by that channel; further, that its fibres have to be strengthened by more robust ones, in order that they may be able to produce actions; also that by means of these corpora striata the cerebrum may take a rest, and have a respite from its work of reasoning, and as it were may withdraw itself from the body; so that the soul of the cerebrum simply issues these commands, but the corpora striata execute them. On this subject, however, see the chapter on the Corpora Striata.

The remaining parts of the body, however, such as the viscera of the abdomen and thorax, are constructed and formed also by the cerebellum by means of the fibres of the medulla oblongata and the spinal marrow; for to these viscera are sent simply the fibres of the eighth pair and of the great sympathetic nerve, which belong to the cerebellum. Nature namely governs their function, but the cerebrum the motion of the muscles and the sensations of the organs; wherefore, in order that nature and the will may reign equably together, and lest the will by the extension of its limits should break up the community so constituted, and likewise the whole kingdom, the fibre of the cerebellum is mixed with that of the cerebrum wherever the will rules. On this subject, however, see the chapter on the Cerebellum.

These fibres of the cerebrum proceed from its anterior province, which is divided into lobes, where the soul has instituted as it were three courts—a highest, a middle, and a lowest. From the anterior province proceed all the fibres of the cerebrum, which after passing through the corpora striata enter into the kingdom of the body. This will have to be demonstrated below. This province from the top of the crown to the lowest part is divided into three pairs of lobes. These lobes are marked out and encompassed by the carotid artery. By dint of divisions the cerebrum enjoys here the greatest capacity of expanding itself to receive all sensations, and again of being on the stretch to produce actions. The supreme or highest court enjoys this capacity more than the second, which is larger, and is called the middle; and this enjoys it more than the lowest. That all sensations chiefly affect the anterior province of the cerebrum, and that the voluntary conatus or efforts proceed thence, will also be demonstrated below. If this portion of the cerebrum therefore is wounded, then the internal senses—imagination, memory, thought—suffer; the very will is weakened, and the power of its determination blunted; this is influenced also by the state of the corpora striata and their connection with the fibres of the cerebrum. This is not the case if the injury is in the back-part of the cerebrum, which is not subject in a like manner to the general state of change. The above divisions are called courts, because there the soul acts upon the rational mind, thinks, judges, draws conclusions, wills, and determines the things concluded into actions.

89. *When the soul enters upon the work of weaving together its organic body, its first care is to prepare the blood by the two brains, and at the same time to excite its vessels; for by them the organs of the body, the motory as well as the sensory, and likewise the viscera, are to be determined and formed.* For there are three universal essences; namely, the highest or the soul, the lower or the animal spirit, and the lowest or the blood. Each of the lower essences in its sphere acts the part which the soul exercises in the highest region. As there are three essences, so also there are three determining forces, that is, the most simple fibres, the composite fibres, and the blood-vessels. See the chapter on the Peritonæum [in the "Regnum Animale"]. Without the blood, the body, such as it acts in the ultimate parts of the world, cannot exist. The very motory organs without the blood are useless; the organs of sense also are in like manner

deprived thereby of their point and sense. The whole blood, therefore, is on account of the actions of the muscles, as well as for the sake of the organs of sense; consequently, it is also for the sake of the faculty of the body of communicating with the soul.

90. *For the purpose of preparing the blood the soul has established in the cerebrum an illustrious chemical laboratory, which it has arranged into members and organs, and by the ministry of which it distils and elaborates a lymph animated by the animal spirit, whereby it imbues the blood with its own inmost essence, nature, and life.* This is the object of the organs of the cerebrum, namely, the corpus callosum, the fornix, the three ventricles, the choroid plexus, the glands of the isthmus, the infundibulum, the pituitary gland, the cavernous sinuses, and several more; for the very animal spirit must be in the blood, in order that it may act the part of a corporeal soul, or the part of the soul in the body. That there are two natures in the blood, see Part I. [the "Regnum Animale"]. The animal spirit cannot be poured into the blood-vessels, because it is most volatile, unless it is conveyed thither coupled with lymph. Therefore this lymph is the very purer blood; see also Part I. [of the "Regnum Animale"]. On this account the cerebrum is a large conglomerate gland, to which corresponds the pituitary gland, as a conglobate gland; see chapter xxiii. of the present work concerning the Glands. On this account the cerebrum must be called an illustrious laboratory. That this is the object for which the organs of the cerebrum, the uses of which are shrouded in so much obscurity, have been called into existence, will be demonstrated in detail below; likewise what particular share each of them has in this work.

91. *This work is in charge of the fibres of the convex or upper portion of the cerebrum;* just as the task of building up the motory and sensory organs of the body is in charge of the fibres of the anterior part, as has been stated above; for where the great fissure of the cerebrum [Sylvian fissure] with the lobes ceases, this portion begins. The whole of the fibre of this region namely is conveyed towards the corpus callosum, a part also

towards the fornix; and that part which [runs] into the corpus callosum is concentrated in the body of the fornix, and is thus employed in the structure of these organs. All this, however, will be demonstrated in what follows.

92. *The cerebellum in like manner establishes several laboratories or viscera in the body, which prepare the chyle by which the same blood is to be corporified;* as has been shown in Parts I. and II. [of the "Regnum Animale"], where the viscera of those regions have been demonstrated. See there the Epilogue of Part I. For as the blood consists of two natures, one of which is spiritual, and the other corporeal, so also there must be two laboratories, of which one is in the superior sphere or in the cerebrum, and the other in the lower sphere or in the body; but of the latter there are several. There are also several laboratories of the purer lymph, but the cerebrum is as it were the general fountain of all; the rest are like brooklets; for each fibre carries its own spirit down into the body.

93. *The lymph of the cerebrum is carried down by the jugular vein, and the chyle of the body is conveyed by the thoracic duct in such a manner that they meet one another, and produce that noble offspring, the blood.* For the jugular vein brings down the lymph of the cerebrum, and at its foot is the subclavian vein in which the thoracic duct is inserted. That this is so, see in Part I. ["Regnum Animale"] the chapter on the Glands and the Thoracic Duct; see also our present part concerning the cerebrum towards the end.

94. *In order that the soul may at the same time excite the blood-vessels, the soul despatches fibres of both brains to the extreme ends of the body; it works them up into forms similar to glands, and develops thence new filaments which serve the blood in the place of vessels.* Concerning this, see chapter vi. in Part II. of the present work on the Corporeal Fibre and the Cuticles, and also chapter v. in Part I. on the Arteries of the Cerebrum. These fibres, which are called corporeal, serve a twofold use; first, they convey to the cortex of the cerebrum the purest elements for the elaboration of the animal spirit; secondly, on

being rolled up into vascular forms they serve to the blood as means of conveyance. But unless these things are well explained anatomically with all their particulars, and unless they are demonstrated by the general rules of physics, geometry, and philosophy, they are only with great difficulty believed by the understanding.

95. *These filaments which form the inmost membrane of the arteries, return by the carotid and vertebral arteries into the cerebrum, and are inserted and continued into its principles, or into the cortical substances, and also into the fibres.* On this subject see chapter vi. in Part II. on the Corporeal Fibre and the Cuticles; and chapter v. in Part I. on the Arteries of the Cerebrum.

96. *It is made plain thence what is the nature of the cerebrum, or what connection is established by the cerebrum between the fibres of the principles from the soul and between the vessels of the body; and in what manner, according to its connection, flows that circle which must be called the circle of life, or that of the animal spirits from the fibres into the vessels, and that of the blood from the vessels into the fibres; consequently, what is the nature of the intercourse between the soul where are the principles, and between the body which rules the effects of the principles.* But concerning these things see my psychology, where the intercourse between the soul and body will be treated; for we must know first what and of what nature is the soul; then of what nature is the cortical substance from which the soul, as from its principles, governs the individual things which are of the body.

97. *By the expansion and constriction of its cortical substances, consequently by the cerebrum, the soul excites this, its organic machine or body, alternately into motion, or it actuates and animates it; it thus perpetuates the nexus and circle instituted by itself, and preserves its conjunction and integrity.* It has been shown in respect to the cerebrum that it is excited into an animatory motion; and indeed by the cortical substances; and further, that by this motion, which is universal, belonging to all, it institutes the remaining motions of the body; and again, that by this motion it extracts the spirit of the blood, and transmits it into

the fibres: and, consequently, that thereby it vivifies the whole bodily system with spirit, or consequently, that by the fibres it transmits it into the whole body; for each cortical gland, like a little heart, is prefixed to its fibre. In this manner the cerebrum animates all things by connection [with itself]; everything which is woven of fibres it furnishes with spirit, and into everything it pours soul. On this account the cerebrum must be called the animatory organ of the whole body. All this animatory motion in the daytime arises from the cerebrum; but in the night-time from the cerebellum, upon which then devolves the sceptre of rule. On this subject I shall treat elsewhere.

98. *From all this it follows that the modes of the sensations of the body according to the fibres, like rays, flash into the cerebrum, and by the cerebrum into the cortical substances, which are the last and the first termini of the fibres; and from these they flash into the soul, which resides in these substances, as in its principles, endowed with the faculty of perceiving, thinking, and judging.* Of this nature is the influx of the sensations towards the soul by means of the cerebrum (this has been confirmed by the [untranslated] treatise on the Senses); namely, by the royal road through the corpora striata, chiefly towards the anterior part of the cerebrum; where the soul has constituted as it were three courts. By this arrangement the cerebrum is the *common or general sensorium.* The remaining modes, or those which happen in the viscera, in accordance with their fibres press towards the cerebellum; where those substances, that is, the cortical, are not so free and expanded, but are in a more compressed form, so that these modes are not able to reach the consciousness of our mind or to become evident to it. The very fibres also [which lead into the cerebellum] are not sensitive; for they are not soft like those proceeding from the external organs of sense, that is, from those of smell, sight, and hearing, and as are most of those which belong to the fifth pair; for such as is the quality of the fibre, such is the sense which is transmitted. The faculty of receiving, perceiving, and thinking

consists in this, that the fibres are able to undergo infinite states of mutation, and that each mutation corresponds to an idea. On this subject I have treated above [in the Part on the Senses], and it will also be demonstrated in what follows. Without such a faculty in the principles there is no power given of internal, and hence of intellectual sensation. Those modes which from the senses press into the superior sphere, put on there as it were a new habit; they lay aside more and more the finite limits, and become rational modes; and they contemplate only truth and falsity, and are affected by moral, and finally by spiritual good and evil. This at first blush appears indeed paradoxical; but this is due to an obscure notion, or to an entire absence of the notion, of the doctrine of order and degrees; or because we have not imagined to ourselves any other order, or any other degree, than such as exists between what is greatest and what is least. The relation between what is greatest and least, however, exists in every sphere. The higher sphere, on the other hand, puts on an altogether different essence and nature, which is unable to penetrate to the sensation of a lower sphere; but the higher it is, the nearer it approaches to the spiritual nature and essence of the soul.

99. *From this also it follows that by these same substances or principles, those things which have been judged, concluded, and elected, hence the matters of the will, by their fibres, united to those of the corpora striata, of the medulla oblongata, and of the spinal marrow, are transferred to the muscles of the body and determined into act.* There are two operations in the human understanding, without taking into consideration the perception which first receives objects; namely, the intuition of truth by which it is discovered what good is, what its nature is, why it is, and how it is to be obtained; the second, however, is the affection of good, whence arises love, that is, when we embrace good with love, or when we desire good. Wherefore between the intuition of truth and the affection of good there is a certain intermediate or election; namely, that we should elect the better and the best. Whatever, therefore, is elected by these same beginnings

or principles, that, under the auspices of the animal mind, is determined into act; this also is said to emanate from the will, because from the faculty of electing good and evil. The intuitions of truth, however, arise solely by mutations of state, because by simple ideas, and by such as are collected into analyses; but the determinations of the will originate from the living expansion and constriction of the individual cortical substances, or the particular animation of those fibres which correspond to the motory fibres of the muscles. For as there is an animation of the cerebrum, so also there is a constriction and expansion of each of its glands or corcula; in a like manner there is a determination of the individual substances, and hence also a similar action. Thence, indeed, as from its corcula or little hearts, the spirit of the fibres is delegated into the muscles; and the muscles by the aid of the blood which reacts, perform their constriction and expansion. On this subject, however, I shall treat in my psychology; here I am allowed to state only generals, but not particulars.

100. *The phenomena of the surrounding visible world penetrate in this manner from the external organs of sense to the inmost sensorium, or to the soul itself, and from this by voluntary determinations they flow out into actions; by a perpetual circle, according to the flux of the fibres, and by means of the cerebrum, they thus flow from the surrounding physical world back again into the soul, or rather into the moral world, which is made up of human society.* As all things go in a circle through the cerebrum, or as the cerebrum is the uniting medium of all things, such also is the case with the individual cortical substances where the soul resides in the beginnings of the sensations and actions. Thither also are conveyed the sensations in accordance with the fibres, and thence the determinations proceed into act; so that in the cortical substance, or in a higher sphere, just as in the cerebrum, a similar circle is performed. Where the inmost sensation, perception, and thought is, there also is the will and the first determination. During the accomplishment of this circle, whatever enters from the natural, surrounding world,

if it enters only into the imagination, returns again into the same world; if, however, it enters the intellectual sphere, it returns into the moral world. If it flows in from the moral world, it returns into the spiritual. This perpetual circle, therefore, on this account resembles a spiral line, which perpetually bends upwards, and thus moves in a transcending line. This, however, is as yet of too sublime a nature to be explained to the common understanding.

101. *But because the will, which is born from a certain rational mind, a faculty subordinate to the soul, acting from free choice,* i.e. *from the intuition of truth and the affection of good—induces perpetual changes on the natural state of the body, and very often perverts its limits and order, therefore to the cerebrum, which acts from will based on previous knowledge, there was adjoined the cerebellum, which acts from the necessity of order, of love, and of equity or justice flowing thence, and thus from nature.* It is a thing known also at large that the things flowing from the cerebrum are voluntary, but those flowing from the cerebellum are natural. The very form even can be shown to be such as it must be, in order that the soul may act thus or in some other manner. Compare Part II. chapter i. on the Cortical Substance. Upon the form also it depends that a thing is such, as it is seized by the senses. The cerebellum is adjoined to the cerebrum not only in the head, but also in the fibres. This is the reason why both the medulla oblongata and the spinal marrow receive fibres from both, and by the nerves transmit them into the body. That the necessity of order and of love rules a soul left to itself, cannot be called into question; but whatever is alien to or is separated from the organic connection formed by itself, this it castigates, which is an effect of love, or it totally puts it away, which is an effect of hatred; either, however, is an attribute of justice.

102. *In order, therefore, that nature may restore what the will destroys, power was given to the cerebrum of inducing on its body alternately rest or sleep, or else a state of wakefulness.* That this is peculiar to the cerebrum appears from the slumber of the

senses, and also of the actions; for then everything that belongs to the cerebrum is in a state of rest. In order that it may be known what sleep is, the fabric of the cerebrum must be well examined; for it is divided, and as it were ramified into larger and smaller, and even into least folds. The cortical substance by virtue of these folds or commissures can be expanded in various ways. The more it is expanded, the more it is on the stretch for the reception of sensation, and also for the power of thought. It is only a degree of expansion which renders the mind capable of perceiving objects, of revolving these perceptions in itself, and finally of determining them into act; wherefore those lobes which are in the anterior part of the cerebrum are endowed with that faculty, especially the highest; but as soon as ever these least folds collapse in themselves, that power is removed, and the cerebrum then falls back into its primitive state or into sleep. Out of this it is awakened, as soon as the cerebrum by means of its folds is erected. There result hence various degrees of sleep, and also of wakefulness. The corpora striata also contribute their share to this; for they then relax the fibres which pass between theirs. When these fibres are flaccid as it were, the very intercourse ceases; for all sensation and action proceed by this way, as has been shown above. This, however, will be explained better in what follows.

103. *In order that all these things may take place in due order, the cerebrum was constructed so that it is able by the force of its animation, or of expansion and constriction, to expel through determined exits the humours which perpetually percolate from the arteries between the dura and pia maters, the convolutions of the cortical substance, and between the medullary fibres; lest anything in this middle camp or in the cerebrum should interfere with or stop the voluntary and natural sports.* That humours penetrate everywhere will be confirmed in the chapters treating of the separate parts. Between the meninges are wide interstices; between the cortical substances are anfractuosities, sulci, folds, commissures. Between the medullary fibres collected into fascicles are perpetual little spaces; for there are plexuses

between plexuses. From the arteries which are thus led about there are produced perpetual humours or percolations. Wherefore, unless asylums were provided into which these humours are sent out, the cerebrum in these interstices would be obstructed, and the intercourse established would be rendered impotent. This also appears from several diseases of the head. On this account there are perpetual passages towards the olfactory bulbs between the larger plexuses or interstices; and thence through the foramina of the lamina cribrosa into the nostrils. Between the lesser plexuses and their fascicles and tunics there are passages into the nerves; and again between the least plexuses into the fascicles of the fibres. On this subject see Part II. chapter iii. on the Arachnoid Membrane.

G. *A Summary.*

104. Through the cerebrum the intercourse is established between the soul and the body; for it arranges and unfolds the cortical substances; it likewise receives, folds together, and transmits the fibres, of which it constructs the muscular envelope and the sensorial organs of the body. These fibres it sends out from its anterior province. For this purpose it undertakes first to prepare the blood, and to excite the vessels of the body. For the preparation of the blood it rears an illustrious chemical laboratory, divided into members and organs; into this it sends out fibres from its posterior region. The cerebellum, however, constructs the viscera of the body through which the chyle is prepared, which when mingled with the lymph of the cerebrum produces the blood. For the purpose of exciting the vessels, in the extremities of the body the brain rolls up its fibres into little glands, and thence it produces new fibres, which are the beginnings of the blood-vessels. These fibres and these vessels it again leads back to its cortical substances, and finally inserts them into its fibres; whence it may be seen of what nature is the nexus and the circle, and likewise the intercourse established by the cerebrum. The cerebrum, therefore, is the general

animatory organ of its body; and likewise its *general organ of voluntary motion,* consequently also its *general sensorium.* But as the will frequently perverts the natural states of the body, the fibres of the cerebrum, which are subject to volition, are associated with fibres of the cerebellum, which are subject to nature; nature, therefore, restores what the will destroys. The cerebrum also induces on the body alternately a state of sleep and a state of wakefulness. Moreover, the cerebrum determines abroad and expels by paved ways its humours, lest they might obstruct the above-mentioned functions.

Wherefore: (1) The intercourse between the soul and the body is effected by the cerebrum.

(2) It is established as an orb, around which the internal sensories are arranged.

(3) Through this orb every sensory fibre, and also every motory fibre, subject to volition, is led.

(4) The cerebrum by its fibres constructs the muscular envelope and the organs of sense of the body.

(5) Together with the cerebellum it prepares the blood, wherefore it is a gland and an illustrious chemical laboratory.

(6) It excites the blood-vessels of the body.

(7) These it leads back to itself and to their beginnings, entwining them therein.

(8) The cerebrum is the general animatory organ of its body.

(9) Consequently, it is its general sensorium.

(10) Sleep and a state of wakefulness are alternately induced by the cerebrum.

(11) It is likewise an organ for the discharge of the humour which would otherwise clog up the roadways, and would interfere with, or altogether stop, the above-mentioned functions.

APPENDICES TO CHAPTER I.

I.

THE CEREBRUM, ITS SUBSTANCES AND MEMBERS IN GENERAL.[1]

104*a*. THE cerebrum gives to the body life, motion, and being; but the soul gives these to the cerebrum, and God to the soul: wherefore we live and move and have our being in God. The cerebrum imparts *life*, that is, sensation, perception, understanding, and will; and it imparts *motion*, that is, the power of acting in agreement with will and with nature; and it imparts *being*, which consists in living by moving, and in being moved by living. In order that the being of the body should be of the brain, throughout its universal kingdom it sends out fibres as rays, and as highways of determinations; so that in the body there is nothing except the fibre of the brain, and in the fibre nothing but the [animal] spirit, which reigns also in the blood. It is also generally acknowledged that the cerebrum is the common sensory, as well as the general motory organ; but it is not so well known that it is also the laboratory of the [animal] spirits and of the blood, and therefore most abundantly furnished with organs and a chemical apparatus. The sensory and motory faculty of the cerebrum will be discussed in our psychology; here we shall simply speak of its function of preparing the inmost and spirituous essences of the blood, by which it imparts being to the body; for the body lives by the blood.

[1] The substance of this appendix figures in Codex 55 (Photolithographed MSS., vol. v.) as chapter vii. In Codex 58 it was superseded by section B of the present chapter, entitled "The Fabric of the Cerebrum." As it contains, nevertheless, an important summary of the Brain, we subjoin it here under its original title.—EDITOR.

104*b*. This must be premised as a general principle, that the cortical substance taken collectively is what is properly called the cerebrum; for in it begins the fibre, and in it terminates the least blood-vessel; it is therefore in the first and last terminus, or in the centre of the forces of the body. It has been shown above that each least cortical substance, or each spherule or particle of the cortex, is a least cerebrum, a least sensory or least organ, or a least eye of interior sight; in like manner a least motory organ, a least heart, or glandule; and finally, a least laboratory for the elaboration of the spirits. Here and nowhere else the beginnings of the animal body must be sought for; wherefore we must beware lest we begin its structure anywhere else outside of the cortical sphere. The abundant supply of these spherules is so great that they cannot be counted by units, but by myriads; especially in the human brain, which exceeds all others in size. The greater their number, the greater the skill by which they are distributed and connected; and the more perfect they are by nature, the more do they excel in power and strength, even as a number of eyes see more than one eye. But unless they are developed both in respect to quantity and quality, they soon grow torpid and dull; for one easily draws the other away into a similar condition, and covers it up with extraneous things; wherefore care and intention must be co-equal with original size and dimension.

104*c*. In order that the cerebrum or the cortical substance may derive distinctly every sensation from the organs of its body; in order that it may issue its commands to each muscle, and may distinctly determine actions; again, that it may be animated by an alternate motion, and therefore may expand and contract as to each of its parts and as to its whole mass; further, in order that it may distinctly prepare the animal spirit, and pour it into the fibre and red blood—in short, in order that the cerebrum may perform at the same time, and yet distinctly, so many different offices, it is necessary that on its surface it should present convolutions of such a nature, and that there should be so many distinctions in its structure. This form flows from the necessity of the case, as being most suitable to the nature of its soul; for nothing is unseen by nature, or rather by the spiritual essence, which is on the look-out in the principles; that which follows, or is posterior, like that which is merely instrumental, at the least sign or beckoning it receives, at once falls into a state of obedience; in this manner the machine of the world has been formed. In order that these essential parts of the cerebrum or of the cortical substance may be properly co-ordinated, and at the same time subordinated, there are in the cerebrum hemispheres, and thus the whole of it is bipartite; again, there are lobes in it; further, convolutions and gyres; there are also particular clusters and individual substances. In order that the particular and individual parts may act freely in their sphere according to their own nature, they are divided from one another by intervals, fissures, sulci, and again by membranes; they are thus interrupted and conjoined by so many hinges and articulations. Each part has thus its own sensation and motion; it conceives its essence, generates its spirit, and from its little laboratory cares for the blood and the life of the body; besides, thus and in no other manner they adjoin to themselves, and hence admit, the least arteries, and they also put forth fibres or fascicles of fibres. This is the cause of the wonderful fabric of the cerebrum, cerebellum, medulla oblongata, and spinal marrow; but it is due to the connection of the parts, to their agreement and form, that these large bodies, consisting of such an infinite number of principles, nevertheless as a whole conspire together unanimously in the production of general and specific effects.

104*d*. If any one examines the form of the cerebrum more thoroughly, and if he contemplates its members, anfractuosities, protuberances, cavities, and parts under one gaze, he easily recognises that all things in it, in general and in particular, are formed in agreement with the inmost laws of nature, so as to be in a perennial state of motion. For there are in it axes, centres, poles, and again, larger and smaller circles, which furnish it with power, and which have this effect, that the cerebrum undergoes its alternate motion as it were spontaneously and naturally, without any effort at expansion and constriction.

104*e*. There are two *axes*—the longitudinal and the transverse. The *longitudinal axis* runs through the middle of the cerebrum and the medulla oblongata; from the septum lucidum, under the body of the fornix, through the third ventricle and the aqueduct to the fourth ventricle and the calamus scriptorius, and sometimes further into certain cavities of the spinal marrow on the back; there, besides, it is inflected and continued through the anterior fissure of the same spinal cord down to the cauda equina. This axis is hollow, and is interrupted by certain obstructions or septa; as, for instance, at either end of the third ventricle, then again by the valve of Vieussens, and afterwards in several other places. It may also be traced on the external face of the cerebrum; for instance, through the deep fissure between the *umbones* or the protuberances in front of the brain, and also by the interstice between the hemispheres under the longitudinal sinus. The *transverse axis*, however, runs from the middle of the occipital bone through the straight sinus into the third ventricle; and afterwards through the infundibulum into the pituitary gland, near the sella turcica of the sphenoid bone. This axis also is hollow and interpolated in a like manner. Both axes are for the purpose of conveying the fluids of the cerebrum; the transverse axis, however, for conveying the spirituous essences, as well as the blood.

104*f*. There are also two *centres;* one which is peculiar to the cerebrum, and the other which is common to the cerebrum, as well as to the cerebellum and the medulla oblongata. The centre *peculiar* to the cerebrum is the body of the fornix; for the greater part of the medullary substance of the cerebrum in both hemispheres is determined towards the corpus callosum, and thence into the body of the fornix, where it is collected. The *common* centre, however, of the encephalon is the pineal gland; for between the three large bodies [constituting the encephalon] there is a certain isthmus, on which are the corpora quadrigemina and the pineal gland, which occupies the central place. The body of the fornix and the above-mentioned pineal gland are like two navels (*umbilici*) placed in the longitudinal axis; the former from its state of equilibrium has respect to both hemispheres of the cerebrum, but the latter from its state of equilibrium has respect to the cerebrum as well as to the cerebellum and the medulla oblongata. Both also are in a state of quiescence in their places, while everything in the circumference is in a state of motion. The pineal gland is also touched lightly by the transverse axis; for the straight sinus tends in that direction; yet immediately afterwards the axis diverges from it, and while it is turned towards the infundibulum, it is carried along and proceeds between the two centres.

104*g*. The medullary part of the cerebrum which is not carried from the corpus callosum towards the body of the fornix, is likewise determined, both from the front as well as from the back, into the stem of the medulla oblongata; and thence, together with the fibres of the cerebellum and those which are proper to the medulla oblongata, it is determined into the vertebral column, and here and there into the nerves, which burst out through the apertures of the cranium. There are thus as many special determinations as there are roots of nerves, and in general as many as there are fascicles or entire nerves.

104*h*. The *pole* is marked in the circumference, but not in the structure of the cerebrum. It is in the forepart of the head, and occupies the loftiest place, namely, where the crista frontalis joins the crista galli (or ethmoidalis); for thence start the falx cerebri and the superior longitudinal sinus; the gyres and anfractuosities of the cerebrum also proceed thence in a continuous series, likewise the sulci themselves. There also begin the fissures and passages between the medullary fibres of the cerebrum, which converge towards the olfactory bulbs, and thence towards the lamina cribrosa. The aforesaid olfactory bulbs extend their roots throughout the entire cerebrum; for when they are inflated the whole mass of the cerebrum is expanded: it is thus that the tranquil station of all parts is there at the pole. If the longitudinal axis of the cerebrum is continued further, it also strikes this pole. The poles common to the cerebrum, the cerebellum, and the medulla oblongata are, however, at either end of the transverse axis, namely, in the middle of the occipital bone, and in the middle of the sphenoid bone or in the sella turcica. All the poles have mutual respect to one another, as the termini of motion. The cerebellum also is furnished with its own poles or cynosures.

104*i*. The circles are as numerous as the gyres and anfractuosities which mark and distinguish the surface of the cerebrum; they are more inflected, and hence smaller near the pole; but they are more open, and hence greater at a distance from the pole; they are all like spiral lines following a different direction, but which sooner or later return into a circular form. There are several which on the surface are partly contiguous, but which after a moderate deflection become partly continuous; below also they run in an oblique direction, and open into the curvature or bosom of another circle, and thus become continuous; so that there is a constant chain, or a perpetual circuit. In their fluxion these circles apply themselves to the borders of the hemispheres beside the superior longitudinal sinus; and they concentrate their forces near the meeting-place of the sinuses, or near the torcular Herophili. The spiral form is not simple, but composite, on account of the manifold uses and determinations for which the cortical substance which forms these circuits and gyres is destined: for it is necessary that the cortical particles on the surface should be consociated and have mutual respect to one another; just as is the case with the fibres in the texture of the cerebrum, and in the body; for in this and in no other manner can the convolutions be unfolded both in general and in particular.

104*j*. There are, however, as many *diameters* as there are fibres generated from the individual substances of the cortex or grey mass, which particles or glandules are like so many centres. As soon as these fibres are born, sometimes after circuitous windings they enter into fascicles; these when covered by a soft membrane seek their axes and their general centres; and not indeed in straight lines, but for the most part in cross lines, and in such as are wound almost like spirals. Thence arises the medulla or white mass, which is an inextricable texture, similar to a Gordian knot; and yet the determination of the fibres having been given, they are borne onward in order to perform every use of the kingdom. The centres are thus situated and congregated near the surface; in an inverse order to that observed in simple forms, where the centres are in the middle.

104*k*. Such is the general form, or that of the whole cerebrum. Yet each cluster or glome also, of which the convolutions and anfractuosities consist, has its own form; for as many glomes or tori as there are, just so many cerebra or cerebella are there in a smaller effigy; since upon being dissected in the middle they present ramifications similar to those of the cerebellum. Each corticle spherule also has its own form; for they are encompassed by a most attenuated meninx; they have also a surface which appears striated or streaked; and, besides, a refined medulla, or a congeries of least fibrillæ: consequently they have also their centres, poles, axes, diameters, and circles or spirals. For it is they which animate and raise the cerebrum, or whence the cerebrum derives its animations; their form, consequently, must be more perfect than that of the cerebrum itself; because they are bodies of a more simple, prior, superior, and interior nature. It appears hence how inextricable the cerebrum is; and that if we sweat a thousand years in its examination, it will nevertheless appear to us as if we had succeeded in observing simply its outermost surfaces and coarser crusts, and indeed with but an imperfect and fallacious sense; and yet on the basis of such knowledge, which is almost none in comparison with those things which still remain hidden from us, we vainly attempt to deserve the epithet learned.

II.

THE FUNCTIONS OF THE BRAIN IN GENERAL.[1]

104*l*. The cerebrum receives the fibres which are sent out from the cortical glandules or from the principles; it converts them into fascicles, perpetual knots, and into a kind of ganglioform plexuses; through the corpora striata it determines them into the medulla oblongata, and afterwards into the spinal cord; it consociates them with fibres which are peculiar to these medullæ, and with those of the cerebellum, and it leads them forth in the form of nerve-roots, gathers them up into nerves, and thus extends them in a determinate form even to the muscles which are subject to the will. The cerebrum is thus *the general organ of voluntary motion;* for it acts as an intermediate cause, that the principles or ends may flow into effects, or that the will may be determined into acts, and that in each single determination the fibre of the cerebrum may reign together with that of the cerebellum, that is, the fibre of the will as well as that of nature. Again, that in the brain the fibres may be disposed for all series of natural actions in the body; because action results solely from the expansion and contraction of the cortical glands, and hence from the expression of the spirit into suitable fibres.

104*m*. The cerebrum also conveys modes or sensations along the fibres from the sensory organs to the very principles and to the soul, and consequently to the very cortical glands, where the soul resides clothed with an organical garment; and where it perceives the modes of the sensations, thinks and reflects on the things perceived, forms judgments from thoughts, and elects, wills, and desires in accordance with its judgments; and con-

[1] This article seems to have been superseded by sub-section D, p. 56, bearing the same title, which the author prefaced by the following remark: "The order in pointing out the functions of the cerebrum is to be as follows; for I have become better informed in respect to them." The superseded article, however, has not been crossed out by the author, wherefore we add it here in the form of an appendix. The original is contained in Codex 58, and is reproduced in vol. vi. of the Photolithographed MSS. of Swedenborg, on pages 69 to 75.—EDITOR.

sequently whence it determines acts. The cerebrum acts the part of an intermediate cause by paving ways, by weaving fibres into plexuses within plexuses, by instituting perpetual anastomoses, so that there may be no sensory modification which does not flash into every fibre, and at the same time into the whole cortex of the cerebrum. On this account the cerebrum is called *the general sensory* or organ of sense; since the organs, whether eye, ear, or tongue, do not sensate, nor even the cerebrum regarded in itself, but that substance of the cerebrum which occupies the place of a principle, and the soul which resides there in its inmost parts and its centres. The royal road of the sensory modes is through the corpora striata into the whole medulla of the cerebrum, and thus into the cortex, which is there in its state of expansion, in order that it may perceive each single moment of varieties. In order, therefore, that nothing may escape the soul in that sphere and region, the sensory fibres are more elastic and softer; but the motory fibres harder. These fibres seem to derive their origins from the highest and anterior region of the cerebrum, or from the forepart of the head, and from the portion nearest to the face, where there is the greatest faculty of expansion.

104*n*. The cerebrum also mixes the spirit which has been conceived and distilled in the cortical substance with a certain purer lymph, and weds it to the same, and thereby prepares it, so that it may serve as an interior essence to the blood of the body. For the blood consists of two natures—a spiritual and a natural; the former of which is supplied by the brain, and the latter by the viscera which prepare the chyle. Wherefore the cerebrum is a gland by eminence—*par excellence*—or is the model of conglomerate glands, and consequently an *illustrious chymical laboratory.* It receives, indeed, a spirituous essence chiefly from the glandules of the posterior region of the surface of the cerebrum, and through fibres it carries the same into the corpus callosum, and from that body through the fornix into the lateral ventricles, where through the offices of the choroid plexus it is mixed with a purer lymph. From the lateral ventricles this lymph is received by the third ventricle, and thence through the infundibulum it is conveyed into the pituitary gland, which is the conglobate gland of the cerebrum; whence by three different ways it is carried into the jugular veins; and after it has undergone there a second mixture, at the end of that vein or of the subclavian vein it meets with the chyle of the body, which is conveyed thither by the thoracic duct. This is the origin of the twofold nature of which the blood consists. On account of this function of the cerebrum it is cut up into so many organs, glands, cavities, and ventricles, the use of which can never be explored, unless we know what is contained in the red blood: wherefore in these things also the cerebrum acts the part of an intermediate cause, and establishes an intercourse; for the blood constitutes chiefly the essence of the body, and in order that the soul may be united to that essence, so that it may act as the vicegerent of the soul in the lowest sphere, the cerebrum has been formed as an intermediate organ.

104*o*. The cerebrum besides by its alternate movements of expansion and constriction, and by the assistance of the lungs, excites the body and all its viscera into a similar perennial motion; and by this means it transmits, in each alternate time, the soul and its animal spirit through all the fibres into every province of the body; thus animating and vivifying each part in the universal body, and the universal body with all its parts, so that they live by acting, and act by living. On this account the cerebrum must be styled *the general organ of animation.* For the first origin of all motions is in the principles, that is, where the principles of the causes, and hence of the effects, have sway; consequently in the cortical substance. Thence it descends through the medullary and nervous fibres; and because there is nothing in the body which lives, except the soul, and nothing which acts, except the simple fibre, therefore the cerebrum is the very intermediate organ of the end, or of the first efficient cause. For every cortical glandule is like a little heart or corculum; the fibre which is produced thence is like its arterial vessel; and by each systaltic and diastaltic motion of the little hearts the spirit is driven out from the little hearts through the fibres, as the blood is driven out from its heart through the vessels. Wherefore the cerebrum is called the general organ of animation for two reasons; *first*, because it pours out the animal spirit, and *secondly*, because it excites a universal motion, and through that a number of singular or individual motions. It is the animation of the individual cortical glandules which excites the individual motory fibres into corresponding acts; hence arise the determinations of the will. The cerebrum, at the beckoning of the rational mind and of its will, excites this universal action in the daytime, or while the senses are in a state of wakefulness; consequently it also stimulates the cerebellum, the medulla oblongata, the spinal cord, and likewise the whole cortex and the fibres, into a similar action. But at night, while the will lies asleep, the cerebellum takes up the sceptre, and chiefly institutes the movements of animation; and as these flow from the source of nature, they are more constant and deeper; and since the cerebrum is then forced by the cerebellum into similar movements, the cerebellum sometimes labours with difficulty, and with a struggle, as may be seen from the state of the respiration.

104*p*. The body is woven of mere fibres, as of so many determinations of its form; for nothing is formed in the body but what is formed by fibres; the very sanguineous vessels which are ultimate determinations are woven of fibres. As these fibres proceed from substances which are situated in the cerebrum and in other parts besides, and as they pass through the ground prepared for them, that is, through the cerebrum and the medullæ—therefore the cerebrum may also be denominated *the general weaving or textorial organ*. For the cerebrum with its substances, which hold the place of a beginning, exists first, and the rest take their existence by-and-by, or in due order successively. Wherefore the cerebrum first receives these universal determinations or fibres, and connects them into larger fibres, and at last into fascicles and diminutive laminæ; and it determines them in such an order, that the fabrics which in course of time result, correspond altogether to the intuition of ends in the soul. For this purpose the cerebrum first spreads them out, but presently connects and reduces them into a certain nervous process or peduncle; and from this afterwards, as from a centre, it despatches and sends out each of the fibres to its particular function and work. Thus all things exist in a determinate form. In this matter also the cerebrum acts the part of an intermediate cause, so that the soul according to its idea and intuition, and according to its eminent form, and its end, may conceive and produce an organism, in which, as in a type or image, its idea or ideal is represented.

104*q*. It appears hence very clearly and distinctly that every bodily organism, or the body, is altogether formed in accordance with the idea or ideal of its soul, or in conformity with the intuitions of its ends; for nothing is ever represented in the body by uses which in the soul does not correspond to some one of its ends. The ends which are in the soul simultaneously are successively unfolded in the body; where they again exist simultaneously, but have to be evolved thence successively. The uses themselves, by acts and effects in the body, represent the ends and the principles which are in the soul; but the effects in which the uses are, or by means of which they are set forth, are in the very being of the soul; for the ends and the intuitions of ends must be contained in a certain substance, as their subject. Hence also it must be concluded that according to the quality of the soul such will be the representative formation of its organism, or such will be the body, by means of which its ends may be actually produced. Further, that the organs are not the causes of our faculties, but the media whereby effects are produced organically, in harmony with the principles and nature of the soul. And lastly, that the nature of the world, or of the lower physical sphere, is so subject to the beckonings of the higher nature, that the latter simply regards ends, and becomes actuated in accordance with its nature, and that the lower nature flows altogether in agreement with its beckonings, and in obedience to it, so that there is nothing so intricate in the lower nature, but is brought into act at the command of the higher: so much so, indeed, that the physical world is altogether subject to the spiritual world and nature. There is nothing so diminutive or imperceptible which does not proceed into an effect at the will of the spiritual form and essence; and how much more at the Divine will. This spiritual form must be assumed as of an infinitely perfect form, which is capable of undergoing in an instant an infinite number of states and changes, and thus of putting on whatever agrees with the succession of the ends. This is seen clearly in the organism of our body, where there is no organ, or any part of an organ, which does not perform a peculiar use which by intermediate uses is referred to a universal and general use. The brain, taken at large, acts the part of an intermediate cause to all these uses, wherefore it deserves to be called *the general formative organ of the body and its organs;* as well as the organ *which arranges and governs them* in such a manner, that each of the things belonging to the soul is represented in each and all of the things belonging to the body. For the soul can flow into the body only by means of the cerebrum, even as the end can flow into the effect only by means of the cause, which in respect to the effect is called the efficient cause, but in respect to the end the intermediate or mediatory cause.

104*r*. The cerebrum not only conveys the modes of the external sensations to the inmost or highest sphere, where the soul resides, but it also keeps the interior sensories or the cortical substances in becoming order in their connection, general form, situation, and state, so that they can perform their offices according to the order of nature which has been instituted; so, indeed, that the inmost sense or that of our rational mind may receive distinctly the ideas excited from the memory, that it may weigh and discuss them, that is, think and judge; and finally, that it may elect and will; or what amounts to the same thing, that our understanding may behold ends, and in the intuition of ends may distinguish what is true from what is false; and again, that it may elect love and desire good, and reject and shun evil. This we must take as granted in respect to our inmost sensory. But in order that the sensories may do this, there is need of the cerebrum by which they may be kept in due order and in their proper arrangement: wherefore the cerebrum is *the general regulating organ, both in respect to the situation and the state of the inmost sensory.* This also is especially seen from experience; for if the cerebrum is either inflamed, or obstructed, or flaccid, or injured otherwise, the intellectual faculty is unsettled; as in paralysis, melancholy, in cases of delirium, in atrophy, apoplexy, in fevers, and other diseases; nay, the determination of the will also is similarly affected. For each single cortical substance contributes its share to this intellectory (that is, to this organ of the understanding); wherefore they all must be kept in a due faculty of expansion and constriction, that is, in their state, and in their proper connection and general form or situation, so that there may result hence a harmonious variety of all these substances, and an organical form; for which purpose the cerebrum is required. The same also applies to the fibres which flow from their principles, and pass through the centrum ovale or the corona radiata of the cerebrum.

104*s*. The cerebrum acts the part of a *regulating organ* not only of the inmost sensories, where the intellect resides, but also *of the internal sight and its memory and recollection;* of that faculty, namely, which presents to the intellect material ideas for discussion, in order that hence they may exist abstractedly from material terms. It thus acts as the regulating organ of all those affections which result from the internal sight or imagination; consequently, of all its delights, which through the external organs of sense flow in from the circumfluous and visible world; and likewise of the appetites which are excited by the blood and its organs, that is, by the body. Nay, it acts also as the regulating organ of those lusts which are ascribed to the animal mind (*animus*), and which result partly from the world and the body, partly from a man's own ideas, and partly from the intellectual mind which gives its assent.

For this internal sight depends upon the general state of the cortical substances, and their faculty of undergoing changes, inasmuch as it is the general state of the understanding; wherefore, when the one is injured, the other also is injured. The regulating organ of all these operations is the cerebrum.

104*t*. The cerebrum also conjoins the determinations proper to the body, that is, the sanguineous vessels, with the fibres from the cortical substance of the cerebrum; consequently, in the capacity of a uniting medium it conjoins the body with the soul. For those sanguineous vessels which arise from the carotid arteries it leads distinctly to the last goals, and at the same time to the first goals; and therefore it consociates the blood-vessels with the fibres through the medium of the cortex. Every least offshoot, namely, of the smallest artery is determined towards its cortical glandule, and there it deposits the spirit of its blood as if it had simply borrowed it; and besides, it imports there the purest elements, by means of which the animal spirit is to be embodied, or furnished with a body. On this account the cerebrum is *the uniting medium of the determinations of the body and the soul.* Hence in the cerebrum is a perpetual nexus of the lowest with the highest things, and a perennial stream of operations flowing in and out. For the blood describes not only a perennial circle through its vessels, but also a transcendent circle from its vessels into the fibres, and from the fibres into the blood-vessels. Through the medium of the cerebrum, therefore, there is a perpetual passage from the first to the last, and from the last to the first boundaries. This circuit in what follows is called the circle of life.

104*u*. In order that these operations may be properly carried on, the cerebrum claims to itself its full right over its own arteries and veins; nor does it suffer these vessels to continue under the government of the heart. As soon, therefore, as these vessels touch the threshold of the cranium, they submit themselves to the animation of the cerebrum, and to its systole and diastole. This, indeed, is the reason why the cortical surface of the cerebrum is divided into two hemispheres; these into lobes;

these again into convolutions similar to those of the intestines; these further by furrows into gyres or glomes, and finally into clusters, grapes, and simple spherules. For this reason the hemispheres act from both sides upon the longitudinal sinuses, and the cerebrum together with the cerebellum upon the lateral sinuses and the straight sinus; on this account, again, the large fissures of the lobes act upon the trunks and the first branches of the carotid artery, and the individual anfractuous clusters upon the least branches, and so forth: namely, for this purpose, that the vessels should at last be determined most distinctly to each of the cortical glandules; wherefore the cerebrum *is the directing organ of its own blood and of its vessels* on their way to the highest sphere. And as it is the directing organ of the sanguineous vessels, so also it is of the fibres, into which the vessels are continued through the medium of the cortex; for whatever is passive in the fibres and in the fascicles of fibres, is derived from the arterial ramifications.

104*v*. In order that the external sensations or those of the body may communicate with the inmost sensation, and the inmost sensation through the determinations of the will with the motory tracts of the body; and in order that the inmost faculties may be preserved in their state of integrity: it is necessary that the liquids which are expressed from the little arteries, and which fill up the anfractuosities, sulci, rifts, and interstices between the fibres, should be properly discharged. In order, therefore, that all parts may be kept in due order and fit to perform their uses, it is necessary that these and similar liquids should be cast abroad; namely, the grosser humours through the olfactory bulbs and the lamina cribrosa; the lymph of a better description between the roots or fascicles of nerves, and thus finally between the fibres of nerves. This is the office of the cerebrum, wherefore in a certain sense it also acts the part of *an organ for the discharge of phlegma and for purgation.* For there are perpetual passages, both larger and smaller, each filled with its lymph; which lymph by the animatory force of the cerebrum is urged towards its outlets. Without this beneficial arrangement, the brain would within an hour be choked up with phlegma, and all its natural functions, both those which are internal or belong to the soul, and those which are external or belong to the body, would be blunted, exposed to danger, and even suspended altogether.

104*w*. Besides, among the offices of the cerebrum the following does not occupy the lowest place, namely, that by which it is able to rouse up and make intent the sharpness of the external as well as of the internal senses, and on the other hand to blunt it and put it to sleep; and by which in addition to sensation, it is able to do so also with the faculty of determining the resolutions of the will into acts. Wherefore it is the cerebrum which in alternate periods *induces a state of wakefulness, or puts the body and its sensory and motory organs to sleep*, and then gets the body into a state of rest, and also into a state where it is left to nature, as during its uterine existence. For the substances of the cerebrum are intersected and interpolated by perpetual folds and commissures; little rifts and clefts, namely, ramify through the same, just like blood-vessels. As long as these clefts and rifts are stretched apart, all the little cortical spherules or the little sensories are likewise kept in their diurnal expansion, or in their state of wakefulness, and on the alert; but as soon as these particles collapse in themselves and subside, a certain lethargy, somnolence, and dulness seizes them. For the little sensories are awake, and communicate with the body, even to their becoming conscious of everything that happens, as long as the sensories themselves are erect, raised up, and expanded, and as long as the blood which presses towards them through the least vessels rubs against their neighbouring parts. But it is different when they collapse into a more compact mass, and when they put on a state similar to that of the cerebellum.

104*x*. From all this it appears that the cerebrum is in the place of an intermediate cause in respect to all the operations and affections which from the sphere of principles flow down into the sphere of effects, and which from the sphere of effects flow back into that of the principles. Wherefore *all intercourse between the soul and the body is instituted by the cerebrum;* namely, between the soul, where it is engaged in inmost sensation, and where in the will it determines resolutions; but where the soul attends to natural necessities, it is in the cerebellum, and also in the cerebrum, when the will lies in a state of sleep.

104*y*. I deemed it useful to premise these remarks on the functions of the cerebrum, that is, to set forth at the very outset the uses which are to be confirmed and demonstrated specifically and particularly by a thorough examination of the fabric of the cerebrum. Without a statement of Uses at the outset, the particular confirmations and demonstrations appear more obscurely, as is the case with particular ideas without a general and universal theory, and also with the images of ocular vision without a universal and general light. For particulars must by all means be referred to their general, and singulars to their universal, in order that they may be submitted to the understanding. We are, therefore, now in a position to approach particulars.

III.

SUPPLEMENT TO SUB-SECTION ON THE SOUL.[1]

104*z*. *The soul is thus like a certain Deity of its microcosm or universe,* which, in proportion to its growth, it constructs, and as it were builds into its own image; that is, its organical fabric it constructs in accordance with its own essential form; its operations and functions it forms in agreement with its own nature, and thus its uses in harmony with the ends which it beholds in itself. And this is so much the case that the soul in its microcosm is the only thing which is, acts, and lives; for it imparts to the

[1] In the margin of this paragraph of the sub-section on the soul the author has written: "*It is to be observed* that this paragraph must not be inserted in the chapter or thesis, for it is premature; it is to be reserved. It seems to me that I have been ordered thus." The Latin original of this paragraph will be found in vol. vi. of the Photolithographed MSS. of Swedenborg, p. 83.

latter from itself essence, power, force, and life. On this account it knits together, weaves, and forms its body in such a manner that it is everywhere present in it, and that by virtue of its presence in it, it becomes cognizant of all things that happen, and has also the ability of doing those things which it knows; nay, it also provides that it should subsist perennially, even as it has existed. On this account the soul is endowed with, and enjoys, a certain kind of omnipresence, omniscience, omnipotence, and providence in its own little world; although each of these qualities is circumscribed and limited. The soul governs this its universe like some kingdom, and indeed according to the order of its nature, from love as well as from justice; and in order that these qualities may flourish by the nexus of all things in the body, and by the mutual respect of the parts flowing thence, the soul perpetually moves and animates its kingdom. But there is adjoined to the soul another, either a goddess as it were, or a queen, which administers a part of the empire not so much from nature and the necessity of love and of justice flowing thence, but from the understanding of truth and the affection of good, nay, even from a certain voluntary choice; this is called the rational mind, which is properly that which belongs to us, and is human. *All these* [superior substances] *by means of the cerebrum reach the effect, wherefore this contains the reason of all the things which follow, and it also refers itself to those things by which it is preceded, upon which singulars and the universal, the parts as well as the generals, depend; and on account of which they exist so, and not otherwise.* Yet as the body is related to its soul, so the soul is related to the God of the universe, to whom alone belongs without limit Omnipresence, Omniscience, Providence, Esse, Doing, Living; for from Him the soul has acquired its essence, power, force, and life.

CHAPTER II.

THE MOTION OF THE BRAIN: SHOWING THAT ITS ANIMATION IS COINCIDENT WITH THE RESPIRATION OF THE LUNGS.[1]

105. BEFORE approaching the subject of the moments or intervals of motion observed by the two brains and medullæ, which motion we call animation, it will be requisite as a foundation to prove the motion of this viscus by experience. We must not treat of these moments before we have ascertained their existence, nor inquire into quality before we are certain of actuality. For the ancients utterly denied the existence of this motion, as also do certain of the moderns, though it has at last been clearly detected by several great anatomists, such as Ridley, Vieussens, Baglivi, Fantoni, Bellini, Pacchioni, and others; and so clear is the evidence of its existence that whoever doubts it at the present day must doubt the senses of sight and touch. In asserting the existence of this motion, it will be requisite merely to cite the experimental facts recorded by the above illustrious authors; these facts being worth innumerable arguments. Thus Ridley says, that having opened the head of a living dog, "he observed a systaltic motion of the dura mater and longitudinal sinus, . . . analogous to the pulsation of the heart, which was quicker than usual, and exactly corresponding with it in point of time. . . . When one blade of a blunt pair of scissors was cautiously introduced into an aperture made in the membrane, and the latter was slit open, the cerebrum covered with the pia mater protruded through the aperture, its motion still continuing strong to the touch. . . . On afterwards

[1] For the sake of convenient reference this chapter is inserted from part ii. of the "Œconomia Regni Animalis" in the translation of the Rev. Augustus Clissold, M.A., as edited by Dr. J. J. Garth Wilkinson. Part ii. of the "Œconomia," etc., was published in Amsterdam in 1741.—EDITOR.

gently smearing over the dura mater with a few drops of oil of vitriol, no vibration of the membrane, or at least only an insignificant and obscure vibration, was perceived, . . . though on applying the finger, the pulse of the brain itself was very distinct. . . . When a knife was driven deeply into the brain, the animal manifested signs of great pain; and when the blade of a knife was passed right through to the opposite side of the skull, horrible spasms were the result. . . . Lastly, not only the author himself, but others who witnessed the experiment, on thrusting their fingers into the brain, observed that its systole and diastole were carried on in spite of the great resistance thus opposed" (Philosophical Transactions, an. 1703, pp. 1481-1483). And Vieussens says: "We assert that the whole mass of the brain, especially where it is at some distance from the bones of the skull, has a natural motion of intumescence and detumescence, and we prove it by the single fact, that on opening the head of a dog, or of any other animal, traces of the several external convolutions of the brain are found accurately and deeply engraved upon the bones of the skull. Such traces of the exterior figure of the convolutions of the brain could never be imprinted upon the inner surface of the skull, if the brain were entirely destitute of motion; for no one, we presume, will affirm that the dura mater, as it lies between the skull and the brain, is capable of producing depressions in the skull" (*Neurographia Universalis*, cap. vi. p. 41; fol., Lyons, 1685). Baglivi says: "Whoever wishes to be assured upon this matter, has only to inspect and consider the anterior part of the cranium in a new-born child; for the bones being exceedingly soft, by placing the palm of the hand upon them we shall feel a strong and regular motion of systole and diastole. . . . But if we wish to perceive still more clearly the systole and diastole of the dura mater in its whole extent, we may do so in wounds of the head which are accompanied by fracture of the skull, and penetrate to the brain (such as we ourselves have seen in several of the Italian hospitals), and we shall then find that the entire portion of the dura mater laid bare by the wound pulsates equably and forcibly, and not only in those channels and furrows that are hollowed out by the little arteries distributed through it: as would be the case if the motion of the dura mater depended upon these little arteries; supposing which, should convulsive motions supervene from the wound, we should be quite at a loss to account for the strong and evident pulsation discernible throughout the dura mater, and distinguished by its own proper intervals and spaces, so that one would really think it was the heart that was pulsating. [This phenomenon the author has witnessed often and in the presence of others]" (*De Fibrâ Motrice Specimen*, lib. i. cap. iv.). And Fantoni says: "Nothing in the brain is more conspicuous than its alternate swelling and subsiding, or dilatation and contraction: these motions are visible in cases of wounds of the head and in the vivisection of brutes. . . . We find it recorded of Zoroaster, the celebrated King of the Bactrians, . . . that on the very day that he was born his brain palpitated to such a degree as to repel a hand when placed upon it. . . . It is well known by experiments that in living animals, when the brain is wounded, and the finger thrust well into it, a very strong diastole and systole of its substance are perceptible. To state a general opinion, not a particle of the brain is destitute of this motion: all the glands and all the little tubes enjoy an alternate and regular compression" (*Epist. ad Pacchionum*, in Pacch. Operibus, pp. 171, 172; 4to, Rome, 1741). I say nothing of other observations to the same effect, drawn directly from living subjects, and recorded by a great number of celebrated authors, as Pacchioni, Mayow, and particularly Bellini in his *Opuscula*, where he speaks of the systaltic motion of the brain and the natural contractility of the spinal marrow. For from the citations already given it is sufficiently evident that the brain has an alternate motion of an internal kind; in other words, a motion arising out of its own bosom; also that its entire surface, namely, the surrounding membranes, the blood-vessels, and also the septa and sinuses, depend upon the animatory vibration of the subjacent or interjacent brain, and in part also the dura mater, which is the uniting medium between the motions of the brain and heart, as will be seen in the sequel.

106. We must, in the first place, bear in mind that it is a very difficult task to explore accurately in living subjects the distinct intervals of the elevation of the brain; for in order to perceive them, a considerable portion of the skull must first be raised; the dura mater which adheres to the skull beside the sutures must then be separated from it, and this mater must be divided, in order to open a passage for the finger to the substance of the brain. The following obstacles to a just observation of effects arise from these proceedings:—

Either in consequence of the dura mater being detached from the bones, and divided, the force and ability of the brain to reciprocate its motions proportionably fail; for its faculty of restitution depends upon this outermost membrane, as its lever, or rather as its spring.

Or else the animal, in consequence of pain, fright, or stupor, is unable to draw its breath; for when life is in danger, all freedom of (animatory) breathing is gone, and consequently all regular and distinct respiration of the brain.

Or else the sinuses of the dura mater, especially the superior longitudinal sinus, and perhaps also the two lateral sinuses, fill with blood. For as the arterial blood then rushes immediately into the sinuses, and a full egress through the jugular veins is denied it, in consequence of the contraction of the brain, and its cessation from motion, the brain becomes quiescent, or else with great effort labours to make an inward motion, and as it were to overcome its own substances. This likewise takes place whenever the neck or chest is tightly bound with a ligature in the manner sometimes adopted for destroying dogs.

Or else there is some hindrance arising from extravasated blood and serum. It generally happens in vivisections, in consequence of the contractions and efforts they produce, that the channels are clogged and the interstices filled that exist both without and within the substance of the brains and marrow, as a provision for the free exercise of expansion and constriction.

Or else if we do not reach the brain itself, we perceive either by sight or touch the motion of the dura mater alone, and conclude from it to that of the brain. But here we are deceived by first appearances; for there is a mixed or compound motion in the dura mater,—one motion owing to its arteries, which communicate immediately with the arteries on the outside of the head, and another motion received from the brain through the medium of the three great sinuses. This is the reason, as I think, why Baglivi, Pacchioni, and all other anatomists, so far as I know, founding their assertions upon what appears to them to be experimental fact and evidence, assert that the moments or pulses of the brain and heart are synchronous. But that this is not the case with the brain itself will appear from a closer investigation of the phenomena.

107. Let us next proceed to arguments; first, to such as are probable, next to such as are more demonstrative. The subject is so wide, that if what we have stated be true, we shall find clear and ample confirmation not only from the whole of anatomy, but from the whole circle of medical experience and animal physiology. Indeed it is a subject which, as we proceed, cannot remain long in obscurity; for the brain considered in its widest acceptation, that is, as comprising the cerebrum, cerebellum, medulla oblongata, and spinal cord, reigns universally and particularly in the fibres of the body; and the heart in its arteries and vessels. Hence wherever there is a fibre associated with an artery, or an artery with a fibre, that is to say, throughout the whole body, manifest signs must exist to decide the question whether or not the action of one flows concordantly into the action of the other. But let us come to the arguments.

I.

108. There does not seem to be much probability in the opinion that every time the heart beats the blood rushes into the brain, and rouses the entire mass thereof to perform reciprocal motions with it; for the brain is elevated not only surfacewise,

but also through the whole of its substance, as ascertained by experiments. And the heart beats, nay, experiences subsultus and palpitation, sometimes from a slight, sometimes from a graver cause, and this either rapidly, slowly, feebly, strongly, or irregularly. Now that the brain itself experiences a similar fluctuation and inconstancy of motion, is, I say, a circumstance destitute of probability, for in this case, whatever morbid cause prevailed in the body, whether it were some malignant nature or undue quantity of the blood or serum, some aneurism, polypous accretion, or other incidental malady, the brain would assume and imitate the inconstant motion of the heart; which could not but be attended with imminent danger to this most noble organ, and particularly to its cortical substance, which requires the most refined blood, because it requires its purest essence.

109. Were the motions of the two organs synchronous, in this case either the motion of the brain would flow into the motion of the heart, or the motion of the heart into that of the brain; if the former were the case, then the brain could not be moved by causes originating in the body, as already indicated; if the latter, then the brain would be moved by all the causes that affect the pulse. This likewise appears to be repugnant to the constant and certain laws of nature and of the animal economy, nay, even to the laws of subordination; for the brain is prior to the heart, hence its motion is prior to the motion of the heart; as is evident from the observations of Malpighi and others on the chick in the incubated egg. What is prior does not in the order of nature suffer itself to be commanded by what is posterior; nor what is superior by what is inferior; nor what is interior by what is exterior; just as in civil order, the master must not be under the control of the servant; that is to say, the brain must not be under the control of the heart, unless the brain purposes to live under the jurisdiction of the crasser blood, or to lead a kind of mere corporeal life governed by instinct.

110. Neither does it appear probable that the small blood-

vessels that pervade the surface of the brain, or its proximate membrane, have such a degree of strength, and swell to so great an extent as to elevate the entire subjacent mass of the brain; for according to the experience of Ridley, Fantoni, and others (no. 105), the pulse of the brain is perceptible internally, and swells up from beneath the dura mater, so that the traces of its arteries and of the furrows of the brain appear accurately imprinted upon the inner tables of the sinciput. Wepfer also doubted whether the arteries possessed this power, and candidly expresses himself on the motion of the brain. "That the brain is moved by the arteries," says he, "although it be furnished with very many, and although considerable ones lie under its base, is more than I can venture to assert; considering the inadequacy of the arterial pulse to elevate so large a mass as that of the brain in the human subject" (*Exerc. de loc. aff. in Apoplexiâ*, p. 44). And Fantoni says, "The mass of the brain is large: the force of compression operates upon its whole surface; and not only this, but also upon its inmost substance and very core" (*Epist. cit.* p. 172). Hence we may infer that in all probability the arteries themselves are not the cause of the motion of the brain; but that its origin must be sought elsewhere, that is to say, in the brain itself; and consequently inasmuch as the origin of its motion is different from that of the heart, it follows that the two may either coincide or not coincide. For in order that the two origins of the motion of two bodies may constantly unite with each other in their progress, it is requisite that there be a third uniting and intermediate body, which shall be dependent equally upon both, and which shall continue under the same necessity of reciprocating its motions, as the impulsive causes of both the bodies.

111. That the origin of the motion of the brain is voluntary, or in the will, we may plainly infer from this, that the brain knows what it wills, and wills what it knows, and hence is capable of being the cause of its own motion or animation. That it is the cause and author of its motion in particular, is sufficiently evident from its active power over the muscles of the body. If

it has the power of unfolding itself and its substances in every particular (see Part II. nos. 62-106), it follows that it has the power of doing the same thing in general. This follows as a matter of course, because every particular taken collectively is identical with the general. Similar is the origin of respiration or pulmonary motion, for every one knows that it is voluntary during the day. If, therefore, the origin of the motion of the brain be voluntary, and if that of the lungs be also voluntary, it would appear that the animation or respiration of the brain is coincident with the motion of the lungs rather than with that of the heart, whose systole and diastole are entirely spontaneous or natural. There is indeed an animation of the lungs which is partly spontaneous, as during sleep, but such also appears to be that of the cerebellum, which assumes the government at night, when the cerebrum sleeps in respect to any exercise of will upon its parts, and the cerebellum draws a deeper and more regular inspiration uninterrupted by any voluntary animations of the cerebrum. Thus this voluntary motion, mixed with the natural motion, appears to be referable to both brains, for the motion of the cerebellum and the two medullæ is coincident with the motion of the cerebrum, as shown above.

112. As we may argue from the origin of the motion of the brain, so may we argue likewise from the final cause, and from the effect of this motion. The effect is, by the animation of the brain, to propel the purest fluid or animal spirit from the cortical substances through the medullary fibres into the nervous fibres of the body, and thus to animate its whole kingdom, and make it live, at every successive moment, by means of the transmission of this fluid. In order for this effect to extend to the uttermost hamlets and corners of the kingdom, it was necessary for it to summon to co-operation some other motory agent in the body having a motion concurrent with its own; and this agent is no other than the lungs, which appear to act the same part in general as the brain does universally in particular. For the pulmonary action plainly extends to every single

point of the body; and even if it does not act upon all, still it is in the effort so to do, as observation and experiment might sufficiently attest, were this the time to adduce them. Now if these two motions are concordant in their intervals, then by means of this general auxiliary, the spirit, which is the life of the body, will be diffused rapidly and in its natural vehicle round the whole inferior region. (See Part II. nos. 98-106.)

113. The case would be otherwise were the motion of the brain not consociated with the motion of the lungs, but with that of the heart, in those creatures which respire; for the heart acts solely upon the red blood, the brain acts more universally, and with each lung, upon the purer or white blood, and at the same time also upon the spirit of the blood, or the exquisitely subtile essence of the nerves. If the circle of the red blood were performed in the arteries at the same intervals as the circle of the nervous fluid in the nerves, I scarcely know whether any muscle in the body, with the exception of that of the heart and arteries (which are stimulated to action solely by the influent blood), would suffer itself to be incited to act; for in proportion as the nerve acted, the blood would react, when nevertheless in order to produce any alternate motion, action and reaction must be so ordered that one may alternately overcome the other. Hence it is most wisely provided that the motion of the brain shall be coincident with the motion of the heart only when a universal concord prevails throughout the several parts of the body, as in embryos and creatures that have never breathed; in which cases the lungs and all the muscles remain inactive. But as soon as the motive forces are to be excited into acts,—as, for instance, from the first moment of birth, and especially of respiration,—the brain seems to leave the company of the heart, and to associate itself with the lungs; producing, instead of an inactivity of the muscles, a voluntary activity; and instead of an insensibility of the organs, a voluntary sensibility. Hence by these two extreme motions,—for the motion of the brain is the first in order and that of the lungs is the last,—the intermediate motion, namely, that of the heart, is wonderfully kept in a

state of perpetual connection with each, or in such a state as to allow of an influx of the one into the other.

114. And the general state of animation cannot be seen better reflected than in the general state of the pulmonic respiration. For as often as the brain is intent, and thinking deeply, or is occupied with anxious cares, the lungs draw their breath tacitly and slowly, and the breast either rises to a fixed level, and fears by any deep breath to disturb the quiet of the brain, or else compresses itself, and admits only a small amount of air. When the brain is exhilarated and joyous, the lungs expand and unfold. When the brain collapses with fear, the lungs do the same. When the brain is disturbed by anger, the lungs are the same. And so it is in the case of all other affections in which similar states are observed to be superinduced upon both, and this sometimes without any sensible change in the vibration of the heart and arteries of the body.

115. But we abstain from adducing further arguments of this kind, because, as we have said, they are only probable, albeit they favour not a little our view of the subject, when we have once conceived it. We shall now proceed to anatomical, and afterwards to medical experience, from which we shall find that we obtain a clearer light. For, as already observed, if our proposition be true, everything will pronounce in its favour; for the brain, heart, and lungs move every point in the living animal.

II.

116. From the arteries peculiar to the cerebrum and cerebellum, namely, the internal carotid and the vertebral arteries, it is very evident that the sphere of the heart's activity does not extend into the sphere of the brain's activity; for on the confines of the two, where the arteries pass out of the body and enter the sphere of the brain, by an ingenious provision a boundary line is established to prevent the two currents from becoming confounded with each other, that is to say, to prevent the blood arising from the body from rushing without restraint

into the hollow of the cranium, and much more into the brain.

117. For where the internal carotid separates from the trunk, or from the external carotid (which it does near the larynx, in the petrous process of the temporal bones, between the great process of the occiput and the styliform process, a little below the Eustachian tube), it suddenly enters an osseous canal, in which it twists itself about at various angles, backward and forward in such a wonderful manner, that to trace its tortuosities by a drawing and verbal description would require a true artist, so various are its angularities. On this subject Morgagni says: "I do not see how a figure that exhibits the curvatures of the carotid artery, only in reference to those which follow a perpendicular line, can be the best method of expressing them, because when this artery crosses the substance of the cranium it is curved transversely; which Lower represents by another figure that presents the artery to view not laterally, like Willis's figure, but from behind; although even this is not the best mode of representation" (*Advers. Anat.* vi., Anim. 5). A clear proof this, that as soon as the blood of the body arrives at this first point of ingress, or last boundary of the body and first boundary of the brain, it feels that it has passed into another sphere of activity, and aims at disengaging itself from the force and empire of the heart, and at breaking the continuity of its fluxion. For it is evident that if the heart attempts to propel the blood beyond this limit, the attempt at further progress is effectually checked "by the constant curvature or barrier of the shores," as Willis expresses it (*Cerebri Anatome,* cap. viii.). And in every part of the body where an artery goes out in a perpendicular line from the trunk, as the intercostal arteries do from the aorta, and also several others, it is a sign of the continuous fluxion of the blood being in some measure retarded, and the more so in proportion as the artery is more frequently reflected at such a perpendicular, as the internal carotid is in the cuneiform bone, as well as afterwards. I shall say nothing here of the import of the fact that this takes place near the

larynx, in the petrous process, a little below the Eustachian tube, where a little sesamoid bone is sometimes found, etc.

118. Not only the internal carotid, but also the other common artery of the interior of the head, namely, the vertebral, is compelled to undergo similar modes of reflection and infraction in its passage to the large foramen of the occiput. For "as this artery ascends and passes through the transverse foramen of the second vertebra, it is generally incurvated to accommodate itself to the particular obliquity of this foramen; . . . and between this foramen and that in the first vertebra it takes another larger turn, in a direction contrary to the former. Having passed the transverse foramen of the first vertebra, it is considerably incurvated a third time, from before backwards, as it goes through the superior and posterior notch in this vertebra." Such is Winslow's accurate description of these curvatures (*Exp. Anat.*, *Tr. des Artères*, no. 96). Ridley gives a figure of the uppermost curve, and describes it as follows: "The vertebral artery . . . entering the brain at the last and largest foramen of the skull, . . . coming thither on each side out of the hole in the transverse process of the first vertebra of the neck [or between the first vertebra and the bone of the occiput, as Ridley points out in describing fig. 1, E, to which he refers the reader],[1] after a very remarkable curved manner, . . . and by no means like to the delineation and description given by Lower and Dr. Willis, etc. etc." (Anatomy of the Brain, chap. iv. p. 35.) This artery, therefore, disengages itself from the power and pressure of the heart, lest the brain, or rather the spinal cord, medulla oblongata, and cerebellum should be compelled to rise at every beat of the heart, or every momentum of the blood. But to return to the internal carotid artery.

119. This artery, on passing through its foramen, and entering the hollow of the cranium, does not immediately climb to the brain, but rises and curves over a certain osseous mound at the posterior clinoid processes; it next passes downward into the cavernous sinuses, and even in these it has a sinuous course.

[1] An interpolation by Swedenborg.—Tr.

Such a number of inflexions in every direction made by a single artery in its progress as one and the same trunk, sufficiently indicate that its blood, as propelled by the heart, cannot invade the province of the brain, unless the brain allow it to do so; that it consequently rids itself of the stroke of the heart, if not in the osseous foramen, at least afterwards in the cavity of the skull.

120. Nor is this the only precaution taken with a view of separating the sanguineous current of the inferior region from that of the superior; for the very coat of the artery is itself adapted to co-operate in producing this result, since the artery is said to divest itself of its muscular coat as soon as it enters the foramen, and to procure another more suitable, and which shall comply with the motion of the brain. For it is the muscular coat continued from the large muscle of the heart that alone propagates the pulse through the arteries; so that wherever this coat is, the heart is virtually present. Hence without this auxiliary fibre disposed into annular forms, or continued by the same method, the pulse ceases to act, for it cannot extend beyond the termination of this tunic.

121. The carotid artery subjects itself to the dura mater upon its first arrival at the entrance of the cranium, and again in the cavernous sinuses, to the duplicatures of the dura mater, to the upper of which on the side of the sella turcica it sometimes seems to wish to unite by means of vessels and intercommunicating septa; finally, before reaching the brain it perforates this membrane. There is also a kind of foramen cœcum, covered solely with this membrane, upon which the artery lies, and of which Heister makes mention (*Comp. Anat.* no. 100). Thus in place of the muscular coat this artery borrows as it were an outer coat or tunic from the mater of the brain, in the place where this mater, proceeding from the circumference and processes of the maters of both brains, is concentrated about the middle of the sphenoidal bone or sella turcica with the whole of its general vibration. The pia mater also receives the advancing artery after it has crossed another foramen, according to Ridley, who

says: "After this crooked passage into the brain, they [the carotids] are propagated quite through its substance, having first divested themselves of that thick coat borrowed of the dura mater; . . . but not without the mediation or intervention of the pia mater, which membrane all the branches of the aforesaid . . . more or less prop themselves upon before they enter on and disperse themselves through the substance of the brain itself" (Anatomy of the Brain, chap. iv. p. 33). And again, between the above-mentioned adscititious tunic of the artery and its own proper tunic it admits frequent offsets from the great sympathetic nerve, which enfold this virtually new artery, and do not quit it, thus enveloped, until it is under the foot of the brain. It may be shown by a variety of proofs that the said great sympathetic nerve conveys the animus and motion of the brain and spinal marrow from its primary origins—a subject which I shall briefly touch upon in the sequel (no. 132). The carotid artery, therefore, thus stripped of its muscular motive tunic, is invested with other tunics more suitable, and which, as we have said, comply with the pulse of the brain (no. 120), hence at once, in its new cradle and swaddling-clothes, it is inaugurated into a motion different from that which it brought with it from the heart and aorta.

122. And it is worthy of remark, that as soon as this, the proper artery of the brain, subsides into the valley of the cavernous sinuses, it swells out into somewhat of a belly, that is to say, from a smaller diameter it widens into one considerably larger, and forms indeed a kind of sinus. Besides, what has been observed by Vieussens, Willis, and others, Wepfer alludes to this particular as follows: "While the parts of the carotid artery are still near to each other, and as it were conglomerated or doubled up together,[1] they present the appearance of a kind of bladder placed at the sides of the sella

[1] Wepfer had previously given a plate of the sigmoid curvature of the internal carotid artery (*Op. cit.* p. 38), in which plate the sides of the artery are somewhat separated from each other, in order the better to display its sinuous and tortuous course; hence in the passage cited by Swedenborg he speaks of the parts while they are still in their natural situation.—Tr.

turcica, and are larger in size than a nutmeg, and fill the whole space under the dura mater in this situation" (*Observationes Anatomicæ ex Cadaveribus eorum quos sustulit Apoplexia*, p. 39; 12mo, Schaffhus. 1675). That the same is the case in the vertebral artery, see Ridley, "Anatomy of the Brain," fig. 1, E. Now this is contrary to the usage and nature of all the other arteries in the body, which as they recede from the heart do not increase in width, but always slowly decrease in the form of a cone, tapering to the finest and most delicate point. Wherever they begin again to enlarge, as in the veins, they immediately lose their pulsific force; a clear indication that in this place principally the heart ceases to pulsate, or a new origin of motion takes up the former, and that here also the artery forms a channel, cistern, or receptacle from which the brain can take out its blood according as it wants it.

I know that similar swellings and nodes have been observed in the arteries of the silkworm and other multicord insects by Malpighi and Swammerdam; but wherever these exist, there are always new fountain-heads or origins of pulsatory motion, as we are abundantly instructed by the admirable observations of Malpighi, which I will in part cite in illustration of this phenomenon. "The diastole of the upper hearts," says he, "occurred but seldom, that of the lower hearts was quick and frequent, and that of the middle hearts again occurred only at long intervals: in this instance the pulse at last continued about the head alone, the other hearts being at rest, and the motion was wavy, directed from below upwards. In the butterfly likewise the heart began to pulsate at the lower part, and the pulsation extended upwards toward the head; and if while this was the case the cardiac pipe was cut across, then the lower section exhibited a motion from below to above, which motion was exceedingly rapid at the bottom of the pipe, and comparatively slow and infrequent higher up; but on the other hand, the upper section pulsated the contrary way. . . . In the silkworm again, just before it passed into the chrysalis state, the motion of the heart, previous to the opening of the belly, was directed from below upwards, but after the opening the point of departure was changed, and seventy pulsations ensued, freely traversing the entire line of the hearts; yet gradually the motion regained its first direction from the tail to the head, and at last on slightly drawing apart [the parietes of] the lower heart with the nails, the movement from above downwards was revived. Very often after death a variety of motions are displayed by these numerous intercommunicating hearts" ("Economy," etc., part i. no. 244). It is to be noted that these little hearts are mere vesicles or swellings of the artery, not unlike those of the carotids in the cavernous sinuses.

123. It is therefore the right of the brain, fortified with these safeguards and munitions, to admit from the heart, as the common reservoir, no other and no more blood than it wants, and only at the stated moments in which it makes its demand, as indeed experience testifies. Thus Wepfer says: "More than once I have injected water coloured with saffron into the carotid before its division into its external and internal branches, and I have remarked that the arteries of the dura mater were rapidly coloured and filled with the injection, while almost none of it appeared in the internal carotid, on account of the curve which that artery makes near the styloid process as it is about to enter the osseous canal" (*Op. cit.* pp. 102, 103). I am not ignorant that Vieussens, Willis, and Pacchioni arrived at a somewhat different result; but none of these writers mentions whether the tincture was injected on the outside of the foramen of the cranium, or on the inside, or in what subject the experiment was made.

124. But in most brutes that hang the head and feed on herbage, animal nature, in prohibiting the incursion of the blood into the head, has recourse to a method different from that which is adopted in man, and yet even in these the contrivance is wonderful to prevent the blood from flowing into the brain according to the pulsatory movements of the heart. For in such animals, as soon as the internal carotid passes into the cranium, it splits into twigs, on which it is almost spent, with

the exception of a small residual canal; being accompanied with little bands which are produced principally from the dura mater, which either constitutes or invests the parietes of the cavernous sinuses, according to Morgagni (*Advers. Anat.* vi., Anim. 18). But the greater part of these ramifications unite again into one artery before they climb the brain. We find, therefore, that in this manner likewise the pulse of the heart is compelled to stop at the point where the pulse of the brain begins. This is the origin of the *rete mirabile,* which exhibits three generic varieties in three classes of subjects. The *first* is that network called rete mirabile by way of eminence, as also rete Galenum, although Galen appears to use the term in a wider sense. This kind of network is very conspicuous in the cavernous sinuses, interwoven with little membranous bands and cords, and with vessels wonderfully twisted like ropes. The *second* kind is formed when the carotid artery does not carry round the offsets, however numerous, that proceed from it, in these sinuses, but hides them in the duplicatures of the dura mater, especially at the posterior side of the sella turcica, near the circular sinus, at the beginnings of the basilar sinuses, and likewise at the sides, where the carotid runs close to the pituitary gland, and perhaps also above, as Vieussens seems to intimate (*Neurographia Universalis,* lib. i. cap. vii.?). The *third* kind of rete exists when there are either no traces, or no visible ones, of its appearance, but only some twigs taken from the carotid are insinuated into the gland, the rete thus existing in the gland alone; according to the statement of Ridley. But these observations are only by the way.

125. But let us pursue this artery further, for the sake of ascertaining whether the heart can claim any power over it when it becomes an internal or cerebral artery. For as soon as it reaches the brain, it disposes its larger branches between the lobes thereof, or in the fissures of the lobes; its smaller branches and offsets between the convolutions, sulci, and ridges; it then carries them on more deeply into the substance of the brain, and indeed to every individual cortical and grey spherule in whatever corner and intimate recess it lies concealed. For

this reason Ruysch maintains that the whole of the cortical substance is vascular (*Thes. Anat.* i. ass. iii. no. 19, *et in oper. passim*), and thus it is everywhere most obvious that while the brain is animating the system from this its substance, and twisting in and out its winding gyres and labyrinthine mazes, every artery is at the same time undergoing its alternation of expansion and constriction, is deriving its blood by alternations from the carotid, and propelling it into the great and small sinuses of the mater. The anatomy of the brain abounds in proofs that there is not the smallest twig but indicates (and I should not be far from the truth if I said demonstrates) that this artery is situated in the stream of the general and particular motion of the viscus, and indeed so situated, that when the two brains perform their systole, the blood-vessels of both perform their diastole, and *vice versâ*. Hence that the brain is the mover of its own arteries, veins, and sinuses, and the dispenser of its own blood. Wherefore Ridley justly contends from experiments made upon a living dog "that the sinuses themselves have no pulsation other than what is communicated to them from the subjacent brain" (Anatomy of the Brain, chap. vi. p. 50).

126. We must not omit to mention that as the carotid and vertebral arteries in ascending to the brain twist into tortuous forms (nos. 117-119), so also does the lower part of the sinuses into which the venous blood of both brains ultimately passes. For the lateral sinuses, before they precipitate themselves into the round osseous cells in the petrous bones, or into the jugular veins, turn to the right and left along the sides of the occiput, as Vieussens observes (*Neurographia Universalis*, lib. i. cap. ii.); nor do they merely descend to the base of the cranium, but proceed still further towards the middle of the base, as Morgagni observes (*Advers. Anat.* vi., Anim. 1). Moreover, as the carotid and vertebral arteries in their way to the brain first dilate into a ventricose channel (no. 112), so also does the lower part of the sinuses, for it enlarges to form an ampullated cavity or retort. At length as the internal carotid again contracts from a large belly into a narrow trunk, from which it ramifies (no. 112),

so also does the lower part of the sinuses on entering into the osseous caverns and jugular vein. Thus as the former is contrary to the usage and nature of arteries, so the latter is contrary to the usage and nature of veins. Finally, as the carotid admits a fibrillary plexus from the great sympathetic nerve into its own proper tunic (no. 111), so also does the jugular vein admit a similar plexus from the par vagum, with which it passes out through the same foramen, and at the same time also from the great sympathetic nerve; for both these nerves run between the above artery and vein, and send filaments from a ganglion to each, as Lancisi shows (*De Motu Cordis*, etc., tab. vi. fig. 1). From this parallel we learn that the arterial blood does not enter the brain, and that the venous blood does not leave it, without the consent of the brain, and that it is in the power of the brain, and flows from its mode of acting, either to admit or to emit the blood; for everywhere in the extremes we find receptacles from which and to which the brain, which acts as an intermediate, extends the boundaries of its activity.

127. As it is now quite evident that the arterial blood can by no means be poured into the hemispheres of the brain by the mere power and force of the heart, so in like manner the venous blood of the brain can by no means rush into the chambers of the heart at the moments in which the heart performs its diastole, or the auricle its systole. For a bolt or muscular sphincter is interposed behind the superior vena cava (the conflux of all the blood of the brains and of nearly all the blood of the spinal marrow) and before the right auricle of the heart, but no such barrier exists between the right auricle and inferior cava, which collects the blood from nearly the whole body. Thus abundant precaution is taken to prevent the blood of one organ from disturbing the vibrations of another and converting them into its own.

128. But all the arguments adduced in this section are not sufficient to prove that the motion of the brain, if it does not coincide with that of the heart, coincides nevertheless with that of the lungs. Let us therefore come nearer to the point.

III.

129. We may learn from the blood of the spinal marrow more clearly than from the blood of the brains what are the intervals of its influx and efflux, and more particularly we may learn this from the blood of the dorsal and thoracic portion of the spine, which lies close along the pulmonary region; wherefore if the cerebral and pulmonary motions coincide with each other, we ought to find more evident proofs of it here than above and below. It is well known that the spinal cord transmits its blood from its cervical portion to the vertebral vein, from its thoracic portion to the vena azygos, and from its lower portion or cauda equina to the lumbar vein. Now let us examine the vena azygos which receives the blood of the dorsal region.

130. The azygos or vena sine pari in man is situated along the vertebræ, between the membranes of the pleura, and derives its blood from the sinuses and veins of the spinal marrow. But outside the vertebral sheath it receives the blood from the whole spiratory fields of the lungs, as from the right and left intercostal muscles, from the vertebral muscles, from the dentati and pectorales, from the diaphragm, through which it ascends at one side, from the mammary veins, from the pleura itself, from the sternum, from the spinal nerves, and from the abdominal muscles; in a word, from all the musculo-motive fibres that grow pale when the lungs breathe; for that the carneo-motive or muscular fibre expels its blood at the time and in the degree in which it is constricted is a well-known fact, although some persons, to favour a hypothesis, love to leave experience in this matter. The vessels which redden are the large vessels that receive the blood from the smallest vessels constructing the carneo-motive fibre. If, then, there be a common vein that receives the blood equally from these muscles and from the sinuses of the spine, it seems to follow, as a matter of course, that the times of influx for the two coincide; consequently, that the spine, which equally with the brain is the mover and dis-

penser of its own proper blood, moves systaltically with the lungs.

That the spinal cord takes in and sends out its blood at the same intervals in which it expands and contracts, is in some measure evident from those numerous arterial and venous offsets that come through the anterior fissures from its grey axis, or which insinuate themselves into it: and from the distribution of the same blood over the proximate membrane, and over the roots of the nerves which go out through the very notches by which the arterial blood enters and the venous departs; from the passage of its blood-vessels in a kind of gentle spire, conformably to the reciprocal contortion of the spine; so that of necessity the vein must be wrung out at the moments of the expansion of the axis or grey substance of the spinal marrow, in which moments every branch without the vertebræ that receives the blood (in short, the intercostal vein with the recipient vena azygos) disposes and opens itself to receive this new supply. And because these two motions are coincident when the muscle ministering to the inspiration of the lungs expels the blood, it follows that they cannot differ in their moments or intervals. And this seems to be the reason why the intercostal arteries come off from the aorta at right angles, and why the intercostal veins run into the cava at right angles, as we have above observed elsewhere.

131. That the trunk of this vein sends out its blood into the superior cava with which it inosculates, exactly at the same intervals in which the bronchia and trachea, or together with these, the lungs, constrict themselves, is indicated clearly by the curvature of the azygos around the bronchia, and by its intimate union with the same parts, or with the trachea, by the fibres and vessels that penetrate it: as also by the semi-sphincter with which it is furnished at the place of inosculation, and which is supplied by a particular nerve derived from the family of spinal nerves; respecting which subject see Morgagni and Lancisi.

132. And that every branch of the azygos admits its own

proper blood at the same alternate intervals in which the trunk admits its own blood; that is to say, at the times when the lungs perform their inspiration, or the grey axis of the spinal cord unfolds itself, is evident from the nerve that enters and occupies them all. For the great sympathetic nerve, which, as above observed, envelops the carotid and partly the jugular vein, here also goes to perform the same office. Thus the said nerve puts forth a trunk in the neck from both its inferior ganglionic plexuses, which trunk divides on each side into branches, about the fourth or fifth dorsal vertebra; and these branches afterwards again unite into one. They send out cords or fibres on each side, which in divers ways go to, cross over, and embrace all the branches of the vena azygos, as well as in various places the trunk of that vein; and higher up, the vena cava; and creep over the branches with erratic windings and ivy-like tendrils, as Lancisi describes it[1] (*Dissert. de Venâ sine Pari*). Thus this nerve plays the same part here as we have observed that it performs in the carotid and jugular veins; that is to say, it disposes these veins to a movement through spaces at a similar rate.

That this nerve itself is moved, and can move the branches that it embraces, only at the intervals in which the spinal marrow moves, we may infer from the mere description of it. For the spinal nerves, excepting the first and the three last, immediately at their exit from the spinal marrow produce small ganglioform bodies, from which twigs and short cords are sent transversely to the great sympathetic nerve; from each, for instance, in the neck there is sent one simple cord ; in the thorax two, one from the superior, the other from the inferior part of the little ganglion; and again in the lumbar region only one. Of all these cords one large and general nerve is composed, which everywhere thus acquires new origins and new forces, just as a river enlarges by tributary streams. The medullary stem passes into these ganglions, which are set close

[1] See the description of the vena azygos, "Economy," etc., part i. no. 567; and in the "Animal Kingdom," part ii. no. 425, note (*b*).—Tr.

to the vertebræ, near the points of exit, like barleycorns, together with the fibres and roots of the nerves, and together also with the two meninges, and with certain twigs containing the blood proper to them, so that they are necessarily in the same motion of vibration with the inmost medulla; as consequently also is the great sympathetic nerve which is born of all these, and in the dorsal region with a double origin. Thus whatever state of modification affects the spine, the same also will affect the nerve that occupies these little venous branches, and consequently the same will affect the vein that conducts the blood to the azygos; and the azygos will be kept in the same by the same nerve being attached underneath to the pulmonary pipes. The interval of its dilatation will thus coincide with the constriction of the veins and sinuses of the spinal marrow within the sheath, and with that of the intercostal muscles out of it, and at the same time with those of the little ganglions that send branches out from the side into this common or great sympathetic nerve.

133. As the vena azygos derives to it the blood of the whole spiratory field, so the internal jugular vein, which is the common vein of the brains, derives to it nearly all the blood from the muscles of the scutiform cartilage, and from the upper part of the trachea, and from the muscles that assist it. For this vein descends near the side of the cervical vertebræ, and near the windpipe, as may be seen in Eustachius, *Tabul. Anat.* tab. x. fig. 1. It receives a large branch from the above-mentioned cartilage of the larynx and its muscles, and a fresh one again from the lowest root; it receives also a large branch from the right jugular vein, into which several run, as shown by the same plate, and from the trachea and the muscles that assist respiration and speech. These facts abundantly indicate, in my opinion, that the familiar and natural mode of fluxion of these veins is the pulmonic, or, what is the same thing, that it is that of the bronchia, windpipe, and larynx, which concur every time with the respiration of the lungs.

134. And it cannot, I think, be doubted that the animatory

motion of the cerebrum and cerebellum is continued also to the spinal marrow, from which in this and the following section we deduce the principal force of our argument; for all these viscera are conjoined as mutual appendages by continuous medullary processes, by the grey substance, which is concentrated into an axis in the spinal cord; they are conjoined also by the blood-vessels and the two membranes, namely, the dura and pia mater, and by the arachnoid membrane; so that it follows as a necessary consequence that all have one and the same common moving effort, as confirmed by experience in living subjects.

Thus from the carotid, as it enters the hollow of the cranium, until it passes through the brain, and thence through the dorsal spine into the azygos toward the superior cava at the muscular mouth of the right auricle of the heart, there is one continuous connection and circle of causes. But we have now sufficiently argued the point from the fluxion of the arteries and veins.

IV.

135. The nerves which run out from this dorsal region of the spinal marrow, no less than the arteries and veins of which we have hitherto spoken, confirm the concordance of motions between the brains and the lungs; for, with the exception of the twigs sent into the trunk of the great sympathetic nerve, all the nerves that come from this region are spent upon the muscles that open the cavity of the thorax for the respiration of the lungs, and that fitly inflect the vertebral column. For there are twelve pairs of nerves corresponding with the twelve ribs, along which latter the nerves travel in appropriate furrows. The seven upper pairs accompany the ribs to the sternum, and supply all the intercostal muscles, perforating and intimately entering them. The five lower pairs send down cords from the cartilages of the false ribs to the muscles of the abdomen, and to several other muscles that concur to respiration. These nerves may be seen delineated upon a large

scale by Vieussens, and the muscles described to which they are sent (*Neurographia Universalis*, cap. vii. and tab. xxvii.).

136. That these nerves, which are sent out from the middle and lower part of the spinal marrow for the single purpose of opening the chest, are excited to effect this purpose at the moments when the spinal marrow moves systaltically, has already been shown. For all those muscles called intercostal, and supplied with these nerves, are destitute of antagonists, which is not the case with any other muscles in the body. Consequently when the brains and medullæ, by their common animation, act and flow into the nerves of the body, and from these into the muscles, the intercostal muscles alone exhibit any conspicuous effect of motion, all the others being quiescent, since in proportion to their action there is also a reaction; neither are they stimulated to action unless this equilibrium be taken away by some particular force of motion or inspiration—an office belonging solely to the brain. Hence it follows, in my opinion, that every time the brains animate, and with them the spinal cord, they flow into their nerves, and these into their muscles, consequently into the intercostal muscles, by the contraction of which the ribs are raised and the chest opened, which movement takes place at the very times when the lungs inspire.

137. From whatever source we derive the cause of muscular motion, whether from the immediate influx of the brains into their nerves, or from any kind of touch or friction of a nerve in the body itself, it is evident that the pulmonary cavity is not opened naturally, or of itself and its own accord (I do not here speak of the voluntary act of opening, which is performed in as many ways as the brain commands, or as the bodily state requires), except at the times when the brains animate and the lungs respire. For whether we deduce muscular motion from the immediate influx of the brains into their nerves, as when the brains exert their active or living force, that is, animate; or whether we deduce it from any friction or touch of a nerve in the body; it is here provided that neither one nor the other, as a cause, or as a minister to the principal cause, shall be wanting

to preserve the continuation of the motion, since in the vertebral foramina through which the above-mentioned nerves pass out, there is a peculiar mechanism of such wonderful construction, that as often as the ribs are raised a certain species of friction strikes the issuing nerve; the foramina being composed by the meeting of the notches cut out in the inferior part of the superior vertebra, and in the superior part of the inferior vertebra. Thus whatever the time or manner in which the vertebral column bends, or the ribs conjointly rise, the notch of the superior vertebra, by reaction and friction, acts upon one part of the nerve sent out, while the notch of the inferior vertebra is acting in a contrary manner upon the other part. This takes place more especially in the dorsal region, but not to such an extent in the lumbar, the vertebral notches in the dorsal region being carved out more boldly than those of the lumbar. The manner in which this is effected may be even mechanically exhibited to the eye. Moreover, the ganglionic bodies exterior to the notches are constricted at the same moment, and by a certain mode of contraction operate conjointly upon the nerves above mentioned. Consequently, whether the intercostal muscles are stimulated to action by the former cause or by the latter, or by both together, there can be no want of an active force and efficient cause in the nerves, and derivatively in their muscles, so that the whole of this region, both without and within the vertebral case, may unanimously conspire to produce the motion of respiration.

We may confirm these views by a remarkable experiment recorded by Swammerdam. "We observe," says he, "in many animals, that as soon as the beginning of the spinal marrow in the cranium is disturbed, all the subjacent muscles suddenly contract. And this also happens in the same manner with respect to all the twigs of the nerves proceeding from the spinal marrow; at least when they are handled; although in this case only some particular muscles are set in motion, or perhaps only the single muscle through which the irritated twig is distributed" (*Biblia Naturæ*, p. 843). Swammerdam also states that he showed an experiment confirming the latter remark, as applied to the femoral nerves and muscles of the frog, to the Grand Duke of Tuscany, in the year 1658 (*Ibid.* p. 839).[1]

V.

138. But all these things are more clearly and distinctly seen in multicord insects, as nymphs, caterpillars, and butterflies, which have indeed several tracheæ and pulmonary pipes, and several little spinal cords or outgrowths of the brain. The above universal and predominant motions cannot but be more distinctly imprinted and represented by the fluxion and mutual communication of the nerves and vessels in these creatures; for they live principally under the auspices of the above motions, because under natural instinct.

139. From Malpighi's golden treatise on the silkworm (*Dissert. Epistolic. de Bombyce*), and Swammerdam's work on the anatomy of insects (*Biblia Naturæ*), we actually see by the microscope that the several dilatations of the spinal marrow in insects, which dilatations appear to be so many succenturiate cerebra or cerebella, exert the powers of their activity principally upon the little trachea: for every such molecule or ganglioform body of the spinal marrow produces two large pairs of nerves, of which the upper immediately flows into and operates upon the nearest tracheæ and pulmonary pipes; whereas in the larger animals we find them acting first upon the ribs, the osseous and cartilaginous grate of the chest, and so upon the lungs mediately. On the other hand, from the said tracheæ the blood immediately enters the brain and this medulla, divided as it is into several, and pervades and irrigates the whole from the top to the bottom, so that it follows of necessity that such as is the motion in the medulla, similar is that in the lungs, and *vice versâ.* But we had better give Malpighi's own words. "The lungs," says he, "so abound in the silkworm, that nearly every ring has two of them, and all parts of even the viscera

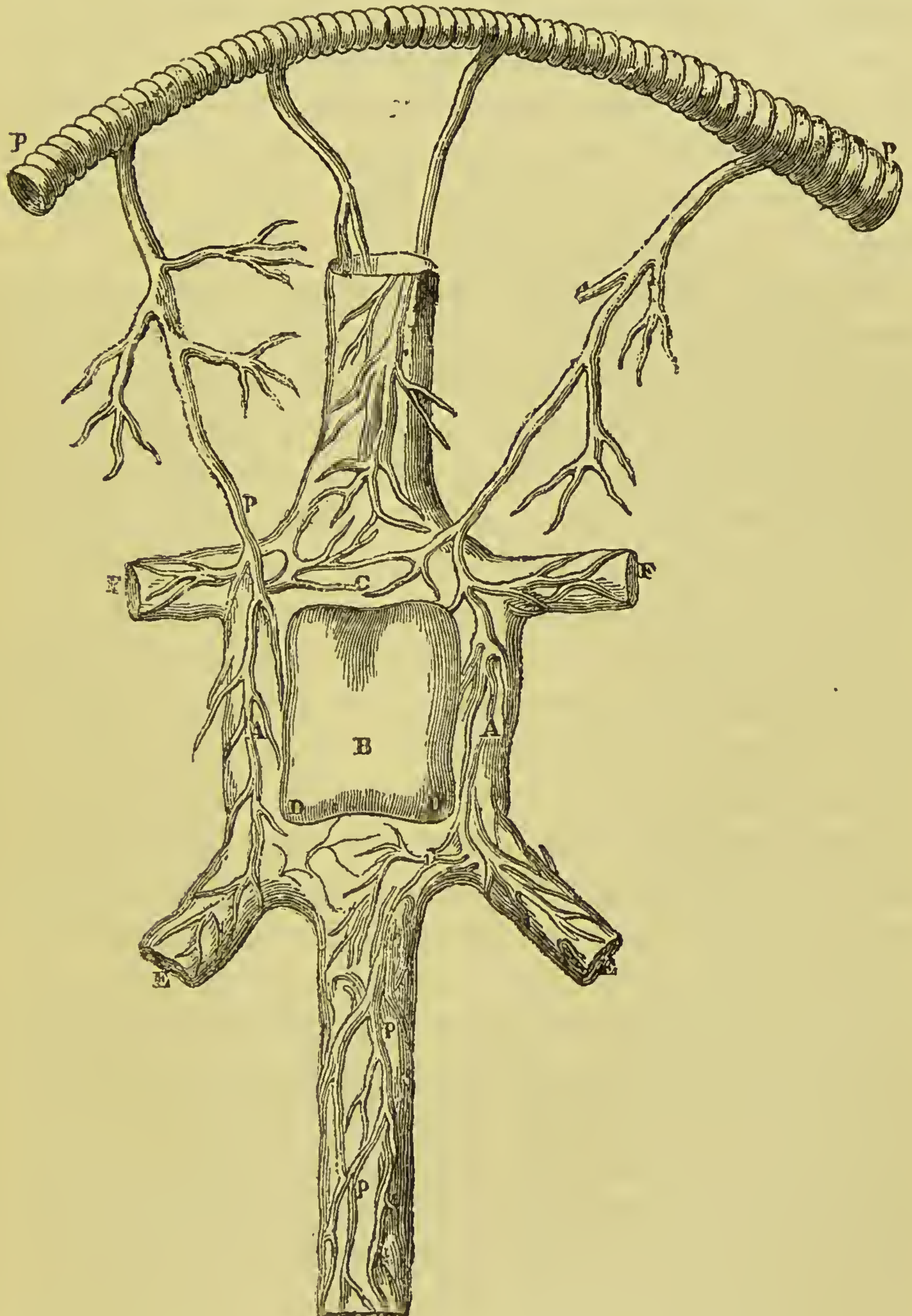
[1] See the "Animal Kingdom," no. 449, note (z).—Tr.

have pulmonary derivations" (*Dissert. Epistolic. de Bombyce*, p. 13; fol., Londin., 1686). And again he says: "The spinal marrow is not of a uniform thickness, gradually decreasing from the top to the bottom, . . . but consists of a cord with oval nodules placed upon it at intervals. . . . The cortical substance, which forms the nodules, stands out on the side next the rings: on the other or inner side it is covered by the medullary substance. . . . On each side two large pairs of nerves are given off, . . . of which the upper pair is sent to the neighbouring trunks of the trachea. There are . . . thirteen globules or nodules; for over the first orifice of the trachea, two, but little distant from each other, . . . ascend toward the head. . . . The lower globules beyond the first ring . . . are situated in a line from the orifices of the trachea. . . . The nodules above mentioned are supplied by minute branches of the trachea; for from each of its orifices two branches run toward the intermediate spine, and meeting each other in the middle, generate a mutual anastomosis, which gives out minute twigs, that closely embrace the globules and the prolongation of the spine" (*Ibid.* pp. 20, 21). "The cavity of the cranium is filled with many parts, namely, with a portion of the spinal marrow, with the extreme branches of the trachea, etc." (*Ibid.* p. 22.) But the author's figure more clearly shows the close relationship and consanguinity between the brain or spinal marrow and the tracheæ or lungs; and the reader will do well to consult it, for he will then see with his own eyes that there can be no motion in the one without the same motion existing at the same time in the other.[1]

140. In other insects most acutely examined by Swammerdam, a similar concordance of motions is seen as in a picture.

[1] This figure so well illustrates the author's present doctrine that we have thought it advisable to insert it here. It represents a portion of the spinal marrow with a tracheal pipe and its ramifications. AA is the white exterior part of an oval globule or nodule on the spinal marrow. B, the inner cineritious part, curved above at C, and sometimes forming below two appendages at DD, but which are short, and in the line of the nerves EE, which run obliquely down to the muscles and joints; while the nerves FF are sent to the neighbouring trunks of the trachea. PPPPPP are branches of the trachea.—Tr.

"The ramifications of the trachea," says Swammerdam, "constitute the principal part of the louse; they exist in immense numbers in the head, breast, belly, and legs, and even in the



antennæ or horns. . . . The pulmonary pipes may not only be discovered in the head, breast, and abdomen, but they extend also into the intestines, the ovary, the spinal marrow, the brain, and, in fine, into all the internal parts of the body. All these things I have distinctly seen" (*Biblia Naturæ*, pp. 71-73; and tab. i. figs. 4, 7, 8). "The spinal marrow of the louse consists of three large ganglia or dilatations. . . . The membrane investing it is interwoven with a vast number of pulmonary pipes. . . . Vast numbers also are suspended at the sides of the nerves. . . . The dura mater of the brain . . . is also furnished with pulmonary pipes" (*Ibid.* pp. 81, 82). Speaking of the hemerobios or ephemerus, he says that its spinal marrow "consists of eleven nodular tubercles, . . . and has a large number of air-pipes; *so that even the brain and the nerves are ventilated as it were with a continual supply of fresh air*"[1] (*Ibid.* pp. 253, 254). See also what he says in this respect of the water-scorpion (*Ibid.* p. 231); of the cossis (pp. 312-314, 316); of the scarabæus (pp. 335, 337-339); of the flea (pp. 359, 360); of the bee (pp. 405, 406, 431, 432, 452-454, 497, 498); of the worm of the gadfly (pp. 662, 663); and of the acarus (pp. 704, 706).[2]

141. As the structure in all these cases is more simple, and nearer to the nature of the thing than in larger animals (whose viscera must be more elaborately and artificially woven, and their connections more complex, to suit the concourse of vital motions), so here we may see as in a picture that the most universal motions of the whole animal or animating system are those of the brains and the lungs. For in these most simple living creatures the brain acts upon the motive fibrils of the whole body by means of the nerves in consort with the numberless air-pipes; but not by means of the hearts, which, disposed under the lobules of the lungs, flow mediately and involuntarily with their blood into the motive fibres. The same is the case in animals that have only one heart, and two lungs, and a continued spinal marrow. For in these cases every time the brain acts by the nerves upon the muscles, it summons the lungs to assist it, which superadd general force to the most particular forces of the brain; as we may clearly see in all attempts at action, whether in lifting weights, making beds, extruding the fæces,

[1] The italics are Swedenborg's.—Tr.

[2] See also the "Animal Kingdom," no. 391.—Tr.

fighting, wrestling, sneezing, yawning, speaking or singing, expelling the child from the womb, or any other effort, when straightway the most general force of the lungs is immediately so exactly applied to every special force of the brain, that the action of all parts necessarily combines into one, which without a perpetual conspiring of the said viscera would never be the case.

VI.

142. Now since in creatures of this very simple character we observe so close a conjunction between the pulmonary pipes and the brains, that there is reason for believing that the one is necessarily agitated and as it were ventilated by and with the other; we may hence fairly suspect that there is also a similar commerce between the air that we draw into the cavities of the nares and convey to the pulmonary vesicles, and the brain. For nature is the same in the least sphere as in the greater and the greatest, although with a difference of connection and degrees. Now then let us see what influx there is of the air drawn through the nostrils into the brain when it animates. But before we can touch this subject closely, we must well examine the bulbs of the olfactory nerves, and the olfactory nerves themselves proceeding from them, as also the cavities of the ethmoid bone, and compare these parts with the phenomena presented by the insect tribe, as discovered by the microscope, and mentioned in the preceding sub-section (V. nos. 138-140).

143. In man the olfactory bulbs are very thin and small; but in other animals, and more especially in those which have an acute sense of smell, they are like two bottles, very large and round, broad at their commencement, and decreasing by degrees, and they occupy a very considerable part of the base of the brain. In some animals, as calves, these bulbs contain a cavity full of limpid fluid, the inflation of which cavity by means of the blowpipe will cause the whole mass of the brain to rise and swell up; according to the experience of Willis (*Cerebri Anatome*, cap. i.). They lie upon the dura mater, all the way

from the clinoid processes to the ethmoid bone; they are pretty soft; and when they reach the lamina cribrosa of the crista galli, they transmit a vast number of filaments through its foramina. As these descend, they are invested with and accompanied by an equal number of little prolongations of the meninges of the brain, and proceed until they reach the pulpy flesh and follicles and granulated substance of the mucous membrane, in which they terminate. Some authors derive the origin of the fibres extensively from the posterior and anterior lobes, and from the middle portion of the centrum ovale (corona radiata); some, more limitedly, only from the anterior part of the medulla oblongata, and from the corpora striata, from which, running obliquely in concealment, they at last come out between the anterior and posterior lobes. Meanwhile the mucous membrane in which they are inserted expands far and wide, making a variety of circumflexions, for it insinuates itself into the cavities of the six sinuses, and into the four cells of the spongy and turbinated bones.

144. From this slight description of the olfactory bulbs, olfactory nerves, and cavities of the ethmoid bone, we may see how it happens that no air can be drawn through the nostrils into the larynx and trachea, or into the lungs, without in its passage first coming in contact with the papillæ, glands, sensitive membranes and fibrils which are derived from the brain into the expanded mucous membrane that invests the above cavities. Thus whether the air be cold or warm, or filled with fragrant or fetid effluvia, this outspreading sensorial organ will necessarily be irritated by the contact; and if the organ, then also its meningeal fibre and prolongation; and if these, then the medullary substance of the brain is excited, with which the above processes from the corpora striata communicate on all sides; for in the calf, when they are inflated with air, the entire mass of the brain is raised thereby (no. 143). And if the medullary and interior substance of the brain, and at the same time both its membranes, or the exterior, be excited, it is impossible but that the cortical substance, mediate between both, and con-

tinuous with both, must be rendered conscious and participant of the contact and irritation; in other words, it is impossible but that the sense shall instantaneously diffuse itself throughout the whole brain, and, as we may fairly conjecture, excite it to act. We in some measure experience this in our own persons, if we notice how deeply we fetch our breath and how we fill the brain with pleasure in a fragrant garden, and how straitly and with what constricted lungs we breathe in an atmosphere of fetid smells.

145. But whether the air itself, or rather its warm or cold temperature, and whether the effluvia that it contains in large quantities in the lowest atmospheric strata, as often as they are inspired, excite the brain to act, is a question which cannot be illustrated more clearly than by contemplating the greatest degree of excitation perceptible to our senses. Having done this, we may proceed to draw inferences with respect to the lesser degrees, which scarcely come within the sensible sphere at all. Sneezing is the highest degree of animation or respiration, and as it were a species of convulsion. It is excited, as is well known, by the impact of subtile and spicular bodies upon the membrane of the nostrils, also by urinous spirits, fine titillating powder, the solar rays, and other external causes. It is excited also by internal causes, as when anything stops up the little foramina of the lamina cribrosa, or the little interstices of the medullary substance, or the winding channels of the cortical or grey substance, as may be known from the effect produced; for when the pituitary substances which clogged the parts are expelled by the act of sneezing, the brain is immediately quiet, and composes its cortical tori into their due order; and the lungs with their vesicles do the same; which yet neither of them can do without a great expansion and sudden contraction of the viscera. How this is done may be shown if we take for granted the animatory motion of the brain. That the dura mater is evidently contracted at the moments of sneezing, is a fact considered unquestionable by all the authors I have ever read; for it is perceptible to the senses of touch and sight in the case of

persons struck on the head, and where the brain has been laid open by wounds and removal of the cranial bones. Besides, every one knows that when the brain is somnolent, or when, as in a great variety of maladies, it, together with the lungs, begins to be inert, it is resuscitated to the performance of its proper motion by the application of urinous salts titillating the nostrils. This then, as I have said, is the highest degree of excitation, and consequently of constriction and expansion, belonging to the brain and lungs. All other excitations are lesser degrees of the same genus, arising from similar causes, that is, from the contact of air and effluvia. These lesser degrees we may infer from the superior or highest; so that whenever the air is drawn in, there is some inciting substance that moves the brain to perform its reciprocations. The reason is, that in compounds the same effect cannot be obtained except mediately, which in the more simple substances is obtained immediately. I do not say that the air is the cause of the animation of the brain, because it is at the option of the brain to draw in the air, or to animate. But when it is the will of the brain that the air should be inspired through the nostrils, this air becomes a kind of conjoint motory and impulsive cause of the continuation of its motion, as we had occasion to say of the friction of the nerves issuing from the spinal sheath, which friction is a subservient cause. This excellently meets the questions put by Boerhaave, where he says: "Why is there so extensive a communication between the interior of the nose and the muscles of respiration? . . . Does not sneezing excite and increase the motion of the brain, of the spirits, and of all the humours? Why does it so frequently occur in the morning after sleep?" (*Inst. Med.* no. 507.)

Now then we see clearly why, as I stated at the beginning of this section, in the most simple animalcula there is so close a conjunction between the pulmonary pipes and the brains; and why in larger animals a similar conjunction prevails, with a difference only as to connection and degrees.

146. The olfactory bulbs are so thin and small in the human

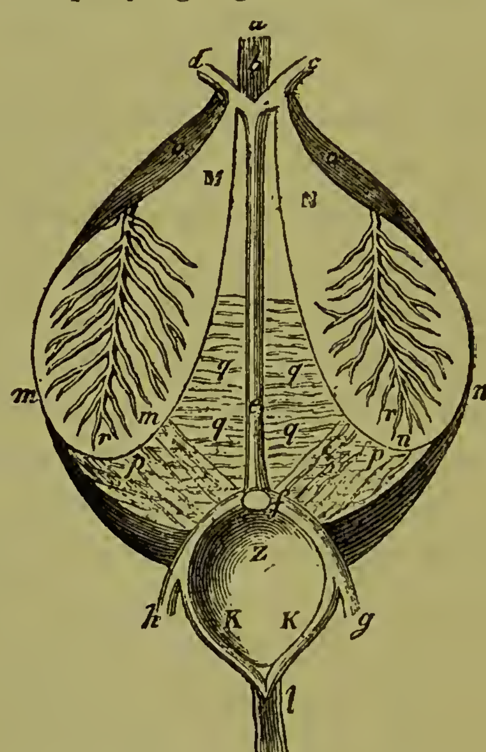
subject, and their roots are not extended so widely into the medullary substance of the brain as in brute animals, because the human brain is not intended to be so excited by external causes as the brains of irrational animals which live under the guidance of their instincts, and are stimulated to act by all causes; by the internal, or those proper to the body; and by the external, or those proper to the senses. For whenever the human brain is pondering reasons, and directing the rational mind to them, it desires to be at rest, and to draw breath quietly, as is usual with intense thinkers: it also, in order that it may be left to itself, deprives all the organs of their acumen, and consequently also the olfactory organ; lest anything should disturb its own process of analysis, and provoke a greater influx of blood than such a state of the brain then requires. Power therefore is given it to draw in the air through a shorter passage, without its coming in contact with the sensory fibrils, namely, through the mouth, differently from what we find to be the case with other animals. But brutes, as they have no reasoning power, in order to avail themselves of all the cause of their instincts, and to apply it to themselves and their own nature, are under the necessity of continually expanding the acuteness of their sensations to the ultimate degree, so as to provide for themselves out of present objects. Hence it is that they are endowed with such exquisite organs of smell, and with such very ample olfactory bulbs, occupying the greater part of the base of the brain, and entering into the medullary substance.

VII.

147. But as the animation of the brain flows by a natural necessity into the respiration of the lungs; and as there are amphibious animals that live alternately in the water and the air, or that alternately draw and retain the pulmonary breath, hence I felt anxious to examine the brains of such animals, and although I have dissected several, I shall here describe only that of the *drake*. This bird, as we all know, sometimes dives into

the water with its whole body, sometimes with its neck and head (just as is the case with swans, geese, and other birds of the kind), and so retains for some time the breath of the lungs, if not of the brain. If by removing the cranium we lay bare the brain of any of these birds, either while it is alive or after its neck is twisted, we witness a very remarkable spectacle, and one well worthy of observation. For in either case the arteries of the brain come in view, shining conspicuously through the dura mater.

148. The accompanying figure represents the upper surface



of the cerebrum and cerebellum. This surface is covered with a membrane or dura mater, which is in close contact with the pia mater, and surrounds it, but does not anywhere adhere to the cranium except beside the orbits, and where the nerves and blood-vessels make their exits and entrances. The orbits are placed about *oo*. Under the dura mater, in which no arteries are visible, blood-vessels run in most beautiful order, and are better seen when this transparent covering is removed. The longitudinal sinus (*c*) runs between the hemispheres in a slight fissure; and divides above and below into two arms, the upper (*d*, *c*) at the sides of the olfactory nerves; the lower (*f*, *h*, *g*) between the cerebrum and cerebellum. From (*f*) the point of union the straight sinus dips down deeply. The inferior arms or lateral sinuses (*fh*, *fg*) pass out of the cranium by their own foramina, first however giving off two remarkable sinuses (*kk*), which uniting, descend to the spinal marrow. When the dura mater is removed, the sinuses are taken away, for the latter are comprised within a duplicature of the dura mater. There is also an extremely fine membrane, which besides the above, invests the sinus within, and is seen when the dura mater is pulled away from the brain. The arteries have two origins, one at the base of the skull, under a kind of osseous barrier, which is identical with the posterior clinoid process, over which they curve, and this, at the sides of the pituitary gland, before they climb the cerebrum; the other, in the orbits, below (*oo*), where the dura mater, as we have said, adheres to the bone. The first-named arteries, which come from the base of the skull or from the internal carotid, ascending at the sides of the brain, which are not represented here, reunite principally into a large branch, which bends circularly from (*m*) to (M), or from (*n*) to (N), and runs into the two superior arms of the longitudinal sinus. From this semicircle innumerable twigs diverge right into the trunk of the sinus (*qq*), and some into its posterior arms (*pp*). But the arteries from the other or superior origin, which come up from the orbits to the surface, go forth and ramify in the form of a tree (*or*, *or*); but whether or not they run to the semicircular subtense (*mm*, *nn*), I did not happen to see, although they certainly approach very near it. The substance of the brain is so rich in blood-vessels as to be intensely red; and indeed one might imagine that nearly the whole was one mass of blood dotted with cortical substances, for but little medullary substance is to be seen.

149. From the fluxion of the sinuses and arteries through the posterior or superior surface of the brain of the drake, and of which I have here given only a very rough sketch and general description, it is clear at first sight that the arteries

have two sources, and discharge their sinuses by two different ways, and that the semicircular subtense passes as an intermediate between the blood-vessels derived from these two sources, alternately receiving the blood which also alternately flows in; so that when this bird respires the air, there is a large influx of blood through the carotids, and a large efflux through the lateral sinuses (*fgh*), but when its respiration is intercepted by the neck being held under water, there is a large influx through the orbital arteries and a large efflux through the divaricated rostral sinuses (*dc*), underneath which the olfactory nerves proceed, in the middle of the semicircle (*mm*, *nn*), which lends to each its own little channel, whether the little branches flow in or out.

Thus it is provided by a wonderful expedient that the brain itself shall be the uniting medium between the motions of the heart and brain, which medium is supplied in land animals by the dura mater attached to the cranium, and a little distant from the surface of the brain.

VIII.

150. But hitherto we have derived the series of confirmatory arguments from anatomical investigations alone. But the real truth is, that anatomy dictates nothing more than the probability of our position, and is dumb except in cases of vivisection. For although the connections of the vessels, nerves, and air-tubes coincide with the influx of motions, still they do so only in reference to the judgment of the mind, which should it cherish any other preconceived idea, it is with difficulty persuaded, unless the contrary be demonstrated to sight and touch. It is necessary then that the fact should be exhibited to the senses by opening the skull. But perhaps you will say, why all this circuitous and operose deduction when a single living example would settle the matter? Be it so; yet the subject upon which we enlarge is well worthy of our pains; for it is only by the course we adopt that we can scrutinize and evolve

the causes of the wonderful influx of motions established by the mutual connections of the nerves and vessels. This is the reason why I carry the thread of this Part round the vast field of the animal system. For to speak from a cause is to speak to innumerable effects; but to speak from an effect is to speak to only a few causes.

151. The history of diseases is full of phenomena and symptoms that by the light of anatomical experience will explain the present subject almost to the life. Hence it will not be unadvisable to cite some morbid instances by way of authority; but they must be few, for were we to quote all, we should enter upon far too large a field. And in fact one and the same disease originates more seldom from the brain than from the body; for example, difficult respiration, or painful, stertorous, panting, asthmatic, deep and high respiration, or quick, slow, suffocative, cold respiration, etc.; these are no signs that there is necessarily any affection of the cerebrum, cerebellum, medullæ, cranium, meninges, vessels, or cortex; but generally that there is an affection of the organs immediately subservient to respiration, as the larynx, trachea, bronchia, lungs, pleura, diaphragm, nerves, muscles, thorax, ribs, sternum, abdomen, or some other part that is between the brains and the viscus affected. Any muscle, for instance, which we know to be put in motion at the will of the brain, becomes unable to act in case either itself or its antagonist be cut, flaccid, inflamed, or tendinous, or in case its tendon, fulcrum, surface, or nerve be injured in any part of its progress from the medulla, or its artery be injured in its progress from the heart: when nevertheless the supreme fountain of causes is in the brains. Thus I do not see the use of medical knowledge if anatomy does not teach the seat [of the disease].

152. In those who have received wounds of the head, or either by accident or the trepan have lost a part of the skull covering the brain, when the acuteness of the pain ceases, the contraction and elevation of the brain and dura mater are clearly seen to be synchronous with the same motions of the lungs. Baglivi, who so strenuously vindicates the position, that the pulsations

of the dura mater are analogous to those of the heart, and *vice versâ,* still does not hesitate to adduce a memorable example of a woman seventy years of age, which makes against himself. "When the head," says he, "is suffering from a wound, or from pain, or torpor, attend to the changes that take place in the inferior parts. Near the temple of Tellus, now the church of St. Pantalleone, built on the site of the house of Cassius, in the Street Suburra within the Carinæ, I knew a woman seventy years old, who suffered under severe asthma with continual cough, but whenever she strongly compressed the top of her head with both her hands, the asthma and catarrhal cough immediately ceased; and this, so long as the pressure was continued; but when she withdrew her hands, both symptoms immediately returned: which might be the case many times in the course of the day. In this instance, was the pericranium affected and supported by the strong compression of the hands, and was the effect propagated to its origin, the dura mater; so that the latter acquiring additional power and tone, the motions of the liquids in the inferior parts were better directed, and thus the asthma and cough immediately ceased? Assuredly a more probable way of accounting for the facts cannot well be conceived" (*Specimen Quatuor Librorum de Fibrâ Motrice,* lib. i. cap. v. *ad fin.*). Unless perhaps the joinings and sutures of the cranium were so loose (as was found to be the case in the head of Pascal after his death), that by the assistance of the hands, the patient forced the dura mater attached to the sutures to perform its natural office in assisting in the elevation of the brain, the dilatation of the sinuses, and the due influx of blood thereinto.

153. Similar cases occur in those who after the application of the trepan are desired by all skilful surgeons to hold the breath strongly, by which means the collected sanies is extruded, or is prevented from passing inwards. Thus Nuck says: "If the blood or sanies does not come out spontaneously, the dura mater must be depressed by the decussorium;[1] and in order that

[1] "An instrument which by gently pressing on the dura mater causes an evacuation of the pus collected between the cranium and the before-mentioned

the matter collected in the cavity of the cranium may the better find an exit, let the patient close his mouth and nostrils, and hold his breath, and then when the brain is compressed the more deeply-seated matter will rush out" (*Operationes et Experimenta Chirurgica,* exp. v. p. 21; 12mo, Lugd. Bat. 1692). And Boerhaave says in his aphorisms on wounds of the head and on the trepan, "Sneezing and holding the breath will help the patient during the operation of elevating depressed portions of the skull" (*Aphorismi de cogn. et cur. Morbis,* no. 271). And again he says, "Deep and slow respiration indicates an obstructed brain, and the diseases attending or following it, as coma, lethargy, delirium," etc. (*Inst. Med.* no. 986.) I forbear to make further citations, for all the authors that I have consulted are of one and the same opinion upon this point; a proof that the brains are elevated at the moments when the lungs respire; thus producing effects upon the membranous and osseous coverings and the fluids between them.

154. In all brains obstructed by any sanies, viscid phlegm, or other malignant impurity, the faculty of reciprocation is similarly impeded, either in whole or in part; as in apoplexy, epilepsy, and the like; of which an excellent account has been given by Wepfer, illustrated by many cases, of which I will select but one, all the rest being of the same nature. One Reiter, he relates, who had been troubled for a long time with a violent cough, which was attributed to suppressed gout, was found lying upon the ground, deaf to the loudest exclamations, and deprived of all his senses as well as of animal motion. His pulse was at first strong, full, and quick, but soon became comparatively weak and small, and increased in quickness. *His respiration also was laborious, and soon became irregular, often seeming as if it was on the point of ceasing altogether.*[1] He died the same day. When the cranium was opened and the dura mater divided, a large quantity of dark blood [cruor]

membrane, through the perforation made by the trepan" (James' "Medical Dictionary").—Tr.

[1] The italics are Swedenborg's.—Tr.

flowed out from the considerable space that lies between the dura and pia mater. And the blood stagnated not only round the base of the brain, but it also reached as far as the vertex, and to the anterior and posterior parts, and in fact it insinuated itself between almost all the convolutions of the brain. On opening the ventricles they also were found filled with blood, not excepting even the fourth ventricle. The lateral ventricles near the base were in a manner torn, as if they had been fissured by over-distension (*Op. cit.* pp. 1-5). Let us now keep to cases of apoplexy, because it is well known by *post-mortem* examination that in such cases the brain is obstructed, compressed, or injured. Boerhaave has classified the causes of this disease; stating that it arises from every cause that alters the blood, lymph, and matter of the spirits, so that they cannot pass freely through the arteries of the brain, but stick and fasten there. Such causes are often polypous concretions in the carotid and vertebral arteries; inflammatory thickness of the blood; a gross, glutinous, pituitary, sluggish quality in the whole mass of the blood: also whatever so compresses the arteries and nervous vessels of the brain, that the blood and spirits can no longer flow through them; all tumours growing within the cranium, whether inflammatory, purulent, serous, pituitary, steatomatous, schirrous, or osseous, etc. The effect, according to the same author, is difficult, deep, stertorous respiration; and the disease is heralded by the respiration becoming hurried on the slightest motion, attended with compression of the alæ nasi; and by nightmare, stupor, sleepiness, vacillating memory, and many other concomitants; respecting all which, see Boerhaave, *Aphorismi*, etc., no. 1007-1035.[1]

It is needless here to introduce a whole crowd of authorities all tending to evidence the same positions, such as we find in the various Transactions of the learned, and in the works of the most experienced physicians, treating of patients labouring under catalepsy, hydrocephalus, dropsy, paralysis, phrenitis leucophlegmasia, scorbutic affections, gout, delirium, mania

[1] See also his "Institutiones Medicæ," no. 860.—Tr.

melancholia, pneumonia, angina, convulsions, hydrophobia, etc.; in all which cases the lungs either cease to respire, as in apnœa; or respire with pain, as in dyspnœa; or respire frequently with trouble and wheezing, as in asthma, when this malady reaches its common fountain, the brain, or when it immediately descends from it. According to the observations made in neurology, and particularly by Vieussens (see "Economy," etc., part i. no. 559), we find that as soon as the brain is cut it loses the power of raising itself; or even if it be strongly compressed with the hand, so as to be forced to stop its animations, the respiration of the lungs ceases, though not the pulsation of the heart, unless similar violence has been done to the cerebellum. Exactly the same effects will be produced in a greater or less degree, if instead of the compression produced by the hand, either blood, lymph, hydatids, scirrhus, or anything else, intrude upon the spaces between the meninges, upon the winding channels between the cortical substances, upon the interstices between the medullary fibres, or into any of the other cavities that are to be dilated and constricted in general or particular with the brain; or if any rigidity or incapability of moving affect the substances themselves.

Now from these considerations it appears that the diagnostic signs of compression, obstruction, or lesion of the cerebrum, cerebellum, or spinal marrow will be more evident if derived from the respiration of the lungs than if derived from the pulsation of the heart; although it is better still to derive them from both at once; for the respiration of the lungs indicates the peculiarities in the transflux of the spirits through the nerves; and the pulse of the heart, the peculiarities in the transflux of the blood through the arteries; consequently the two together indicate the effect with its own real cause.

IX.

155. That there is such a close relationship between the animations of the brain and body, that their moments are

contemporaneous, is a fact which has not escaped the observation either of modern or of ancient anatomists. But although they have tacitly admitted it, yet none of them have chosen to avow it openly, and, as I apprehend, for this reason, that in each extremity of the animal body the heart manifests its presence by its pulsation; whence they have been led to think that no artery had anywhere any other motion than that of the heart itself, which consequently they did not venture to deprive of universal rule, even over the brain, so far as regards the blood; and still less when they observed the dura mater pulsating with similar alternations. But I cannot help thinking, that had the learned once fallen into the opinion that the brain took the control over its own proper vessels as soon as it received them within its cranium or osseous fortress, they would likewise have been led into the opinion that the brains animate when the lungs respire. Indeed, upon this opinion they had already begun to touch, but could scarcely reconcile it with the preconceived opinion respecting the pulsation of the heart extending to the brains; and hence every one had recourse to his own particular method of reconciling the two motions.

156. That they tacitly admitted the fact is evident from their writings. "Beyond all doubt," says Willis, "the dura mater is contracted . . . in the act of sneezing" (*Cerebri Anatome*, cap. vi.).[1] And Valsalva says: "As the external air with which we are surrounded, and of which the mouth and nostrils are constantly full, is immediately continuous with the air that fills the tubes and the tympanum, so it comes also into immediate contact with the dura mater; and therefore according as the same external air is various, it is enabled also to exercise various forces upon the dura mater and upon the brain" (*Tractatus de Aure Humanâ*, cap. v. no. 8). And Pacchioni, inquiring into the cause of the phenomenon, seems inclined to ascribe the expansion of the brain to the fermentation of the blood. "Wherefore," says he, "when the arterial blood, the air of the blood, and the pure air, reach the brain and its

[1] See "Economy," etc., part i. no. 283, vol. i. p. 262.—Tr.

cavities, the air . . . will not only actuate the fluid blood and lymph within the ventricles of the brain and spinal marrow, by [further] dissolving and fermenting them, but will also distend and inflate the parietes of the ventricles and other cavities to an immense extent; so as necessarily to cause the body of the cerebrum and cerebellum to fill a greater space, and in a manner to be thrust outwards" (*Opera*, p. 91; 4to, Rome, 1741). And Fantoni says: "This we clearly see, and detect by actual touch, in those who have lost any considerable portion of the skull by wounds; and these degrees of motion are various according as the arteries beat gently or strongly, and as their diameter is greater or less; and also according as the respiration is vehement or the reverse" (*Epist. ad Pacchionum*, in Pacch. *Oper.* pp. 171, 172).

157. The reader will be surprised to find that even Baglivi at last candidly moots the same question among his Postulates, in apparent contrariety to what he had said of the motive fibre in the dura mater; as though he were doubtful which side to take. "Since the dura mater," says he, "is almost the sole mistress of the motion of the liquids and solids in the living body, and in a manner has the government of the heart itself, as we manifestly perceive from the passions of the mind, *the question arises, whether the said motion of the dura mater be not partly natural and partly voluntary, that is to say, mixed, like the motion of the respiratory organs*[1] [see Part II. no. 111]: so that we can, at the command of the will, or as our temporary affections require, render the motion more or less intense or gentle, fitted to express and propel a greater or less quantity of the nervous liquid. [See *Ibid.* no. 112] . . . And thus according to the various degrees of contraction and relaxation in the membranes, various motions and various appearances may arise in the liquids and solids of the living body" (*De Fibrâ Motrice*, lib. i. cap. v. coroll. et post. xiii.). From this and other arguments which he adduces, he grants that the motion of the dura mater is partly voluntary; and hence is not like that of

[1] The italics are Swedenborg's.—Tr.

the heart, which is purely natural, but like that of the lungs, which is mixed. He goes on to say: "The great degree of power and force exercised by the air in quickening the motion of liquids during respiration . . . may be very clearly inferred from the following experiment. . . . Take a mastiff, and fasten it to a table in the usual way: then carefully make an opening in the throat, and in this opening place a canula so constructed that by the motion of the lips air may be freely blown into the lungs. . . . Blow from time to time through the canula, and you will then find that as long as you continue to blow, the dog will be easy, and will make no complaint, and manifest no violent motions; but the moment it is deprived of this artificial air, its whole body will be seized with convulsive motions, and with most difficult and almost suffocating respiration, together with a thousand other serious symptoms, all of which again disappear the moment air is again blown through the canula into the lungs. Now if the force of the air is of such great efficacy in quickening the motion of liquids through the lungs, why may we not suspect that the same force contributes in some way to the motion of the dura mater, either by elasticity or some other occult mechanical means?" etc. (*Op. cit. Epist.* in cap. v.)

158. "That the air inspired in respiration contributes to the motion of the dura mater, was long ago obscurely indicated by Galen, Lib. *de Respirationis Utilitate*, cap. v. ad fin.; and Lib. *de Dogmatibus Hippocratis et Platonis*."[1] It appears then that our view was not without its weight among the ancients, only that a leader was wanting, at whose declaration a conclusion might be formed from the preceding facts and concessions.

X.

159. But perhaps you will oppose to me the experience of the greatest anatomists, who by touch and sight have observed the motion of the dura mater to be synchronous with that of the heart or arteries of the body; for there is not one of them, so

[1] Baglivi, *De Fibrâ Motrice*, lib. i. cap. v. in *Epist.*—Tr.

far as I know, but has fallen in with this general opinion. For if you apply the finger to the fontanelle in the infant, you will notice a plain agreement between its pulses and those of the heart; and what amounts to the same in adults also. Thus Baglivi says: "In cases of wounds of the head, where the dura mater has been laid bare, I have observed, on placing my right hand over the patient's heart, that the dura mater pulsated at the very same time as the heart, nor could I detect any interval between the pulsation of the two" (*Op. cit.* lib. i. cap. v.). But although this excellent author calls the dura mater "the heart of the brain" (*Ibid.*), and maintains that "its motion is impressed upon it in the primordial stages of generation, by reason of the peculiar structure of its fibres, which is not very unlike that of the fibres of the heart" (*Ibid.* cap. v. in *Epist.*); and although he is supported by all this experience, nevertheless he seems to be divided between two opinions, and to fluctuate toward the other side of the question, as appears from the passages above cited, and as will appear further in the sequel. Ridley tells us that "he observed a systaltic motion of the dura mater and longitudinal sinus . . . analogous to the pulsation of the heart, which was quicker than usual, and exactly corresponding with it in point of time." (See above, no. 105.) But it is well to be noted that the vibration of the heart was found by this author to be more rapid than the vibration of the dura mater [?] or longitudinal sinus; consequently a discrepancy in time was observed, such as there is between the motions of the heart and of the lungs when compressed. Realdo Colombo says: "When the head of a living dog is stripped of its skin, you may very readily fracture its skull; and by dividing the membranes, see the motion of the brain. For the brain moves in the same manner as all confess that the heart itself moves, namely, with a motion of dilatation and constriction" (*De Re Anatomicâ*, lib. xv.; lib. xiv., *de vivâ Sectione*). But this writer passes over the main point to be noticed, namely, whether or no the brain dilates and constricts synchronously with the heart. We need make no further citations. Those already given are quite sufficient to perplex the mind, and render it unable easily to take either one side of the question or the other; but the thing will become clear if we duly examine the mixed or compound motion of the dura mater.

160. Here we may repeat a former observation (in no. 106), that it is extremely difficult accurately to detect in living subjects the distinct intervals of the elevation of the brain; for unless the brain itself be presented to view, we only perceive the motion of the dura mater; and this motion is mixed, consisting of one motion from the arteries, and of another from the brain received through the medium of the three sinuses; and hence we are deceived by first appearances. This is the reason why Baglivi, Pacchioni, Vieussens, and all the other authors that I have hitherto consulted, deriving their information apparently from experience and autopsy, assert that the rhythms or pulses of the brain and heart are concordant.

161. *In the first place*, there is no question that under the finger the dura mater receives a motion from its arteries; for it has innumerable arteries, and only a few veins, and these are rejected towards the sides of the sinuses, or their processes. These arteries of the dura mater immediately communicate with the arteries on the outside of the head, and are sent into the anterior and posterior part of the membrane, through their own proper foramina, as also through the foramen spinosum of the sphenoid bone, through the foramen by which the eighth pair of nerves and the jugular vein escape, according to the observations of Ridley (Anatomy of the Brain, chap. iii. p. 22, and fig. 2, *kk*), and through the carotic foramen, whether the meningeal artery comes off from the carotid as a twig, or enters as an accompanying branch from the external carotid, as the same author seems to intimate: still no artery of this membrane ever arises from the internal carotid after it once ascends the brain, lest the motions of the two should be confounded. Thus even after birth this internal periosteum maintains the same compact that it formerly entered into with the external periosteum or pericranium, and corresponds with it in a marked manner in the brains of infants, and during inflammation, particularly near the fontanelle, where, joined to the pericranium in the

remarkable space between the coronal and sagittal sutures, and anteriorly by the frontal suture, and constructed of an immense number of arteries confluent from both hemispheres of the dura mater, and communicating with the arteries on the outside of the head, but not with those of the brain (as we may see in one of Ruysch's plates, *Thes. Anat.* v. tab. ii. fig. 4), it remains open for a considerable time.

162. *In the second place,* that the dura mater is expanded and contracted by the subjacent brain, appears from its connection with the longitudinal and lateral sinuses, and with the straight sinus, and from the connection of these with the brain by vessels and membranous prolongations and cords; and from the position of the sinuses themselves in the duplicature of the dura mater, and between the hemispheres and brains: also from the oblique course and inflexion of the fibres of the dura mater in exact agreement with the direction of the motion from the circumference towards its centres; and from the similar progression of the cords; and from the insertion of the little veins running into it from the brain into the sinuses in a manner corresponding with the peculiar expansion and contraction of the brain: also from the common course of its arteries from their origins over the cerebrum and cerebellum toward the straight sinus, to which the motions of the cerebrum and cerebellum themselves tend; and from innumerable other indications in the fabric of the dura mater and sinuses. But it is even yet more evident from autopsy; for Ridley, having made an experiment upon a living dog, shows that "the sinuses themselves have no pulsation other than what is communicated to them from the subjacent brain" (Anatomy of the Brain, chap. vi. p. 50). And again he says: "We saw a systaltic motion of the brain propelling outwards the small quantity of blood which was left in the orifice" (Philosophical Transactions, no. 287, an. 1703, p. 1482). Thus if the sinus itself be dependent on the motion of the brain, so of course must be the inner lamina of the dura mater, which invests and surrounds the sinus, and is continued

[1] Concerning the respiratory motion of the longitudinal sinus, see the experiment of Messrs. Key and Retzius in no. 328*p*.—EDITOR.

into the processes. And Pacchioni says: "The dura mater appears to me to have a mixed motion, namely, one motion of constriction and restitution; and another, of elevation and depression. . . . So that the natural motion of its circumference consists in a gentle and bland alternation of contraction and relaxation" (*Opera*, pp. 153, 154; 4to, Rome, 1741). Baglivi says: "The true systaltic and compressive motion of the dura mater is not found on its external surface, but in its centre and middle, about the falx and all its septa, where the membrane is furnished with strong lacertous cords" (*Dissertatio varii Argumenti*, cap. ii.). And Fantoni says: "Although the contractile motion is with more difficulty seen in the head, yet it may be observed in the upper part of the dura mater, as indeed it has been seen by various anatomists, who have clearly witnessed the motions of this membrane, and have observed that they are dependent upon the motions of the arteries and brain" (*Epist. cit.* in Pacch. *Oper.* p. 169).

163. Thus I think it is evident that the dura mater has a mixed or compound motion; that is to say, two motions; one pulsatile and sensible to the touch, corresponding to the vibration of its arteries; and another expansive, coming from the whole of the circumference where the sinuses are situated, and which latter motion is not so perceptible to the sense of touch. Nevertheless that it does exist is evident not only from the proofs above adduced, but also from the extreme elasticity of the fibres of the dura mater, and their capacity of expansion and contraction; from the duplication or triplication of its strata or laminæ, between which the arteries run; and from the twofold discharge of its venous blood, namely, either into the sinuses through particular small orifices, according to the observation of Winslow (*Exp. Anat. Tr. de la Teste*, no. 36), or through the sutures into the substance of the cranium, or all the way to the pericranium, and sometimes through a particular foramen near the junction of the sagittal suture with the lambdoidal. And a similar discharge of venous blood obtains in the body, where

[1] Concerning the elastic quality of the dura mater, see note ii. on "The Structure and Use of the Dura Mater," nos. 4-10.—EDITOR.

two motions, as of the heart and lungs, alternate their play; for example, in all the intercostal veins, whose blood is derived into the vena azygos at the times of the respirations, as above observed (Part II. nos. 129-134); but at the other times, when the respiration is not determined thither, the blood is derived into the inferior cava, for the intercostals tend directly thither also, etc. Thus Pacchioni says: "The motion of the dura mater is not simply pulsatile, as Mayow and others have thought: . . . for it is quite evident that this pulsatile motion is not the genuine motion of the dura mater, but is rather owing to the brain and to the arteries of the pia and dura mater," etc. (*Opera*, pp. 152, 153; 4to, Rome, 1741.)[1] And in another place he says: "The motion of the dura mater . . . is composed, first, of the constrictive motion of the whole membrane and its segments over the cortex of the cerebrum and cerebellum; and secondly, of the resilient motion of the membrane to the internal parietes of the cranium," etc. etc. (*Ibid.* p. 92.) And Baglivi says: "The motion of restitution consists in the relaxation of the fibres previously on the stretch" (*Dissert. varii Argumenti*, cap. ii.). And again: "Two motions may be granted in parts of this kind; one, proceeding from the membranes to the parts; the other, proceeding from the parts to the membranes" (*De Fibrâ Motrice*, cap. v.). So that all our authors wonderfully agree in the fact that there are two motions in the dura mater, although each of them has his own problem to defend; Baglivi maintaining that the systole and diastole of the heart depend upon the systole and diastole of the dura mater (*Ibid.* cap. v.); and Pacchioni that the dura mater is a membranous muscle of a peculiar kind (*Opera*, p. 136; ed. cit.). Still, as I have said, they all agree to the above opinion; for as the dura mater vibrates at once with the heart and with the brain, it is in a manner the uniting medium of both their motions. And for this reason, before the brain sends off its veins into the sinuses, it transmits them into the borders of the dura mater (as also does the spinal marrow), which borders depend immediately upon the motion of the brain.

[1] See "Economy," etc., part i. no. 281, vol. i. p. 256.—Tr.

Now from these considerations we may conclude that the internal lamina of the dura mater belongs to the brain, the external to the heart, and the middle, where the arteries run, to both;[1] but with this qualification, that in infancy the latter belongs rather to the heart; in old age rather to the brain; and in middle age to both equally. For in infancy the numerous arteries of the dura mater climb over the sinuses beside the external or cardiac lamina and the fontanelle; in old age they turn aside to the processes that are composed of the internal or cerebral lamina; and this to such an extent at last, when the effete or senile brain gasps for breath and begins to die, that the motion of the dura mater ceases to be mixed and compound; all which positions will be proved in chapter iv. on the Dura Mater.

164. Nothing is more common or better known in nature or art, nothing is more in agreement with the laws of both, than that two or more motions may subsist simultaneously in one body or extense; and this is particularly the case in the animal body, where nature reigns in all her science and art.[2] As in the lungs, for instance, the arteries and veins of which then especially concur with the systole and diastole of the heart, when the lungs themselves alternate their own motions in a different manner. Likewise in the diaphragm, which co-operates with both; also in every part of the thorax and abdomen, where the motions of both the heart and lungs are constant and persistent. Still more evidently in the pericardium, which may aptly be compared with the dura mater; for it surrounds the heart much in the same manner as the dura mater surrounds the brain. That the pericardium is acted on in a general manner corresponding to the traction of the lungs, is evident from its connection with the diaphragm, the mediastinum, the sternum, and the bronchial vesicles; from its insinuation between the lobes of the lungs; and from its continuation from the pleura; and still its arteries keep time with the vibrations of the heart. Thus the motions of the lungs and heart in one and the same space are

[1] Concerning the various layers of the dura mater, see note ii. nos. 1-3.—Edito

[2] See the "Animal Kingdom," no. 165 (p); no. 425 (x). —Tr.

perfectly harmonious, so that the members freely live by their concurrence, because the fibres of the nerves are filled by the motion of the one, and the arteries of the body by the motion of the other. And indeed for this reason the cardiac nerves are always transmitted through the pericardium before they go to the parenchyma of the heart.

165. Before we close this section on the dura mater, I will propose to the most experienced anatomists of our age a matter possibly worthy of their further observation: namely, that the dura mater, which in itself is passive, and belongs equally to the inferior and superior regions of the body, seems to undergo pretty nearly the same changes in regard to the direction of the blood-vessels as we observe throughout the body, and particularly in the heart. For it is well known that after birth the blood changes its course considerably, and no longer runs through the canalis venosus, ductus arteriosus, and foramen ovale, etc., but closes the old ways and opens new ones. So also in the dura mater. The distribution of the arteries through this membrane during infancy is well shown in a beautiful figure by Ruysch (*Thes. Anat.* v. tab. ii. fig. 4). The distribution long after birth is represented in the figures of Ridley, Vieussens, Willis, and others; in which the fluxion of the vessels is seen to be of a widely different character. Thus in the infantile membrane the vessels are applied more closely to their sinuses, and run in abundance over the longitudinal sinus; but in the dura mater of adults a large portion of the vessels is obliterated, and changed into quasi-tendinous fibres, like the ductus arteriosus and umbilical vessels; that portion only remaining which agrees exactly with the direction of both the motion of expansion and contraction. And this, to the end that in the embryo the motion of the brain may coincide with the motion of the heart, but in the child and the adult with the motion of the lungs, and the motion of the dura mater with that of both. And it would be worthy of observation, whether the cœcal diverticula or foramina of the longitudinal sinus, which are closed in adults, were open and more numerous in the fœtal state.

XI.

166. In the present and last section we propose to make a few observations on the point of use, for of right we measure everything by its utility. The knowledge of what motions in the animal system are concordant, and of what are not concordant, is immensely conducive to the entire interests of anatomy, medicine, and physiology: as we may infer more particularly from the fact that the motions of the brain and lungs are the most universal and the predominant motions, by the co-operation of which we enjoy the privilege of living distinctly. Whatever therefore constitutes life in the animal, in the same degree constitutes life in the sciences relating to the animal. But this subject will be better seen if we say a few words respecting it.

167. When we obtain a knowledge and distinct perception of the universal and natural motions in the animal body, we are necessarily led to infer that it is only by such a knowledge that we can comprehend the stupendous connections of the blood-vessels in the body itself, in the brain, and in the confines between the two, of which we have hitherto been treating. That we can comprehend, for instance, why the carotid artery in the human subject arises as a branch and not as a trunk from the arch of the aorta; why the internal carotid twists through the cranium in angular flexures and repeated diametral gyres: why again, after entering the cranium, it winds about into similar gyres; why it expands into a ventricose bed (see above, no. 112), as do also the lateral sinuses; why it puts off the motive coat of the arteries of the body, and puts on a plexiform coat instead; why it subjects itself to the dura mater, and afterwards entirely to the pia mater: with many other peculiarities, of which in our preceding remarks we have, I think, spoken as fully as the occasion would admit.

168. By the same knowledge we may also comprehend why the most general nerves of the body, as the great sympathetic and par vagum, sent into the provinces of the body to govern the natural motions, take possession of and envelop the vessels,

as the carotid arteries, and the jugular, vertebral, and azygos veins, and their branches. For these nerves so order it, that when they come into the kingdom of the heart, they still pass under the control of the brain; and cause all the special and particular motions of the body to terminate in the universal motion of the brain, and the common motion of the lungs, just as they begin from them. For it is indeed highly interesting to observe that the motions of the living body constitute an entire series, there being primary, intermediate, and ultimate motions; and that the intermediate motions, which are also kept in a certain series by their proper motions, which are more universal than themselves, subsist and flourish under the auspices of the most universal motions. These, and several other things, will never be traced to their causes; I mean, they will never be laid open to the rational sight, or to the mind, unless we first know the times, modes, and nature of the motions.

169. From a distinct perception of the above motions we may also perceive why the blood-vessels of the brain and dura mater, and the blood-vessels of the body, undergo such remarkable changes as soon as the infant or chick is excluded into the atmosphere, and begins to draw the new breath; why it salutes the new air with deep sighs, yawns, and sneezes; these being natural helps for turning the hinge of the motions. The causes of all these effects would never come to light as the infant does, unless we explored the nature of the motions which are the efficients here.

170. Much less without a previous knowledge and distinct perception of these motions can we understand how the brain, and the human brain particularly, is enabled to be the mover and dispenser of its blood; how it has the power of not admitting more than its state requires; and this, with so notable a difference in man and in brutes. For by these means alone can the brain be left to itself, and to the analysis of its reasons: by these alone can it so govern all things that unanimity may still reign over the discords of the body, as it does when the brain

fears no invasion from the blood of the body, which cannot burst in without invitation, because the animations of the brains and lungs are coincident. And as the brain has the power of acting upon its fibres and vessels, it also has the power of acting upon the muscles, which depend upon the fibres: wherefore without a concord existed between the motions of the brain and lungs, the brain could exercise no jurisdiction, because it could possess none, over any motive fibre of the body.

171. Finally, from the same knowledge we may understand how the affections of the brain flow into the body, and how the diseases of the body flow into the brain. It follows as a consequence from this doctrine that in proportion as disorders spring from a deeper and higher source, they fall with greater certainty upon the lower spheres, and spread more widely. Thus if they proceed from the brain itself, which holds the highest place; or from the spinal marrow, which holds the place next under the brain; or from the nerves, by which the brain is continued, according as they are more or less distant from their origins or ends; instantly the subjacent region (which is wider in proportion to its distance from the supreme fountain) is affected with the disorder which influences its superior; although it is to be observed that the region of the superior is not affected by the disorder of the inferior until after a certain interval of time has elapsed. This would not be so did the motion of the heart and arteries of the body coincide with the motion of the brain and nervous fibres; for then the contagion would diffuse itself upwards and downwards equally.

172. These utilities then we promise to anatomical, physiological, and pathological science, from a knowledge and distinct perception of the coincidence of the motions of the brain and lungs; from which, after we have expounded them in their universal relations, it is easy to descend to particulars. [In Note I., published as an appendix to the present volume, the Motion of the Brain will be found discussed in full in the light of modern science.—EDITOR.]

CHAPTER III.

THE CRANIUM AND ITS BONES.[1]

173. As I am about to treat of the cerebrum, it does not seem out of place that the skull and its bones should likewise be treated upon at the outset. As the skull, however, is that bony fortification and bulwark which encloses the brain and limits its motion; and as it attaches to itself the very dura mater, receives the longitudinal sinus, collects and smooths the processes of the dura mater; and as besides, in most tender subjects, or while the embryo is being formed, it adheres as a kindred substance to the brain itself, and makes common cause with it, I deem it right to premise also a short chapter, like an introductory preface, on these bones. It would be unscientific to enter any kingdom without first exploring its boundaries, or to step into a town without first inspecting its walls; for quite a number of things are represented in them, which will be of use in illustrating the subject-matter of the following chapters. In order, then, to exhibit a general idea of the bones of the cranium, I desire to premise the compendious article of the celebrated Heister. I then shall prepare myself to discuss in detail the parietal bones and the frontal bone which enclose the brain, and likewise the sutures or commissures, reserving for a future occasion the discussion of the sphenoid bone and the rest.

174. Heister, concerning the bones of the cranium in general.[2]—"The *head* is placed on the top of the vertebral

[1] This chapter is introduced here in accordance with the instructions given in Codex 58, Photolithographed MSS., vol. vi. p. 64. The title which it bears in Codex 55, Photolithographed MSS., vol. v. chapter ii. is, "The Bones of the Cranium in general, the Frontal Bone, the two Parietal Bones, and the Sutures in particular."—Editor.

[2] *Compendium Anatomicum*, Amsterdam, 1748, pp. 18-25.

column, and is generally divided into the cranium, and the face or the cheeks, to which may also be added the so-called hyoid bone. The *cranium,* which is also called the skull, is that part of the head which constitutes that large bony cavity which among other things includes the cerebrum; on this account all those bones which enter into the structure of this cavity are called the bones of the cranium. In it we generally notice its oval shape; its external convex and its internal concave surfaces; its size and thickness, which are irregular; its substance, consisting of two tables or plates, an interior and an exterior, together with an intermediate diploë or centre-piece; its composition of different bones; its connection by sutures; its uses. Its bones are eight in number, namely, the frontal bone, the parietal bones, the temporal bones, the occipital bone, the sphenoid bone, and the ethmoid bone. The frontal bone,[1] which is also called the os coronale, is the first bone of the cranium. It is double in infants, but mostly simple in adults; sometimes, however, it is bifid, or cleft into two parts, and, indeed, down to the nose. In it we notice its situation, its irregular shape, its connection, thickness, internal surface; where depressions and eminences may be observed, to which the longitudinal sinus of the dura mater is attached. There are further to be noticed its external surface, with the places where are situated the frontal and temporal muscles, and where is attached the cartilaginous pulley of the musculus obliquus major of the eye; seven apophyses or processes, six of which join in the formation of the orbits, and the seventh sustains the bones of the nose; and, finally, the frontal sinuses, with their use and various size and constitution in adults, and their wonderful origin and genesis in children (nos. 60-65).

175. "The parietal bones, called also ossa bregmatis, ossa verticis, or the bones of the sinciput, constitute the second and third bones of the cranium. There we notice their almost square form, their size, connection, thickness; their external surface, where is

[1] In the English renderings of the Latin anatomical terms here, as everywhere else, we follow the terminology used in Quain's "Anatomy."—Editor.

situated a part of the temporal muscle; their internal surface, where furrows representing little trees are impressed by the arteries of the dura mater, and grooves for the reception of the longitudinal and lateral sinuses, as well as for the Pacchionian glands. Finally there is to be noticed the spot called *bregma*, and in infants *fontanelle* or *fons pulsatilis*, with an account of its generation (no. 66).

176. "The temporal bones, also called ossa squamosa and petrosa, constitute the fourth and fifth bones. There we notice their very irregular shape, their connection, their squamous and petrous substance; four processes, the zygomatic, the mamillary or mastoid, the styloid, and the petrous; the place where they are articulated with the lower jaw; the meatus auditorius; the place where the ligament of the ear is inserted near the mastoid process; the sigmoid grooves where the lateral sinuses of the dura mater are situated; the incisure under the mastoid process where the biventral muscle originates; the hole in which the sinus of the jugular vein lies hidden; the sinuses in the mastoid process which often expand into the cavity of the tympanum. There finally remains to be noticed the state in the fœtus of the petrous and squamous part and of the bony circle or ring, on the edge of which the membrane of the tympanum is formed, and which ring in the course of time in a wonderful manner is expanded into the meatus auditorius (no. 67).

177. "In the temporal bones, and especially in their petrous portion, there must still be noticed the *cavity of the tympanum*, and the little bones of hearing, which are generally reputed to be four, and also as many notable foramina. The first of the little bones is called *malleus* (or hammer); where are to be considered the head, the neck, the handle, which are joined with the membrane of the tympanum; two apophyses, the longer of which, improperly called Raviana, serves for the insertion of the external muscle of the malleus. The second is called the *incus* (or anvil), where we may notice the head, the groove for the articulation with the malleus, and the two crura; the longer of which is joined to the third little bone, called *stapes* (or stirrup). In this

may be noticed the head, which is joined to the longer leg of the incus; the basis which is fixed upon the fenestra ovalis of the labyrinth; and two lateral parts, the internal surface of which is furrowed. What by many is numbered as a fourth little bone of hearing, situated between the incus and stapes, and what they call os orbiculare, in my opinion is no particular little bone at all; but it is simply an epiphysis of the longer leg of the incus. Among the foramina, the first, situated at the basis of the stapes, is called *fenestra ovalis,* the other which is near it is called the *fenestra rotunda.* The latter leads to the cochlea, the former to the vestibule. The third foramen ends by a canal in the mouth, and goes by the name of the Eustachian tube or duct; some are able by this tube to discharge through the ear tobacco-smoke drawn in by the mouth; through this tube also deaf persons, by keeping the mouth open, are able to hear better. A fourth foramen, however, opens into the cells of the mastoid process. All these are of use in hearing. The *inmost part of the ear,* on account of various wonderful passages, is called the *labyrinth.* There we must notice the cavity which constitutes the middle of the labyrinth, and is called the *vestibule;* on one side of it there are three *canals,* called the largest, the middle, and the smallest *semicircular,* which open into the vestibule by five orifices; on the other side is the *cochlea,* which accomplishes two spiral windings and a half; the nucleus and the tube of it are divided into two parts by a spiral lamina; the upper one of these, which opens into the vestibule, is called by Vasalva the scala vestibuli; the lower one, however, which by the fenestra rotunda has respect to the cavity of the tympanum, is termed by him the scala tympani. Finally, there is the canal of the auditory nerve, (1) the general and wider one in which are little openings leading to the labyrinth; (2) the proper, narrower, and longer one, which terminates generally either by a small opening in the cavity of the cranium, or in the aqueduct of Fallopius (nos. 68, 69).

178. "The occipital bone is the sixth bone of the cranium. In this we have to observe the situation, the figure, which is

irregular, and the state of it in infants, in whom it is usually composed of four pieces or fragments. After this we have to regard its connections; its substance, which is very thick; its three processes, two of which are condyloid, and which serve for its articulation with the upper vertebra of the neck, and for a support of the whole head: the third is extended to the sella turcica. In the internal surface of the bone, in adults, there is the figure of a cross, and to this adhere the sinuses and processes of the dura mater; and within this there are also four fossæ, in which the hinder lobes of the brain and the cerebellum lie. In the external superficies, at the back of the great foramen, there are several superficial eminences and depressions to be observed: these serve for the insertion of several of the muscles of the head (no. 70).

179. "The seventh bone of the cranium is the sphenoid bone, called also the *os cuneiforme* and *basilare:* this is fixed in the manner of a wedge, among the other bones of the cranium, and serves as a basis as it were for supporting several of them, and also some of those of the upper jaw. The figure of this bone is very irregular:[1] [in its upper part is seen the *sella turcica,* under which there is a sinus, called the sphenoidal sinus; this is sometimes double, and opens into the nostrils: sometimes it is totally wanting. The sphenoid bone has thirteen processes; six of them are internal, and are placed near the sella turcica; and the other seven are external: four of these, namely, the *pterygoid* furnish the origins of muscles; the two *styloid,* which are very small, serve to certain muscles of the uvula in the capacity of a pulley; and the seventh is placed under the vomer. There are also three fossæ in this bone; one in the sella turcica, two between the pterygoid processes; all of which are destined for various uses (no. 71).

180. "The eighth bone of the cranium is the ethmoid bone,

[1] Four pages, if not more, are here wanting in the original manuscript. Some of these no doubt contained the balance of Heister's description of the bones of the cranium; wherefore we supply the missing portion from Heister's work, nos. 70-76.—Editor.

or *os cribrosum*, or *cribriforme*. In this we have to observe, besides the situation, its extension through the nostrils and orbits, its figure, its connection, and its state in infants; its four processes, namely, the *crista galli*, which is the upper part of the septum narium; the two spongy bones, which are called also by some the superior and inferior *turbinated* processes: to which Morgagni has added two other smaller ones; the cribrous, cavernous, and papyraceous or plane parts, and underneath them various little sinuses, differing in figure, size, and number. And, finally, there are to be taken into consideration the uses of these various parts (no. 72).

181. "All these bones of the cranium are found to be imperfect in newly-born infants. The sinuses and the centre portion —diploë—of the bones are almost wholly wanting. The bony fibres, in the formation of almost all of them, are carried in the form of rays from the centre to the circumference; and most of the bones are not single, as in adults; but are still composed of various little pieces: nor are the sutures at that time formed. And, finally, there are often triquetrous little bones between them (no. 73).

182. "In adults, however, the bones of the cranium are mostly joined by *sutures*, which are either common or proper. The proper sutures are distinguished into the true, and the false or spurious. They are called true sutures when the bones are joined together in a wonderful manner by a multitude of unequal denticulated eminences, forming an appearance somewhat like the edge of a saw. These denticulations enter mutually into each other, and are most plainly visible externally; of this kind are those called the *coronal*, the *sagittal*, and *lambdoidal sutures*. The false or spurious sutures are those squamous ones of the temporal and parietal bones, and also of the frontal and sphenoid bones in the angle, where they unite with the parietal bones. The common sutures generally embrace the *transverse*, which joins the frontal bone with the bones below it, the *sphenoidal*, the *ethmoidal*, and the *zygomatic*, etc.; these, however, are of small significance. Some authors have seen crania entirely

destitute of sutures. Between the sutures, especially the lambdoidal and the sagittal, there are found in many crania certain small bones. These are called by some *triquetral bones*, from their figure; by others ossa Wormiana, though they were known to Galen; they are uncertain in their figure and situation, and are joined to the others by sutures. The use of the sutures is: (1) that the dura mater in those places may be very firmly joined to the cranium and pericranium; (2) that in infants the head may more easily be expanded during its growth, from the fact of the several bones being at that period disunited at these places; (3) that the transpiration from the brain may be more free and easy at that time of life in which they are open, and at which also the habit is more humid; (4) that very large fractures of the skull may in some measure be prevented" (nos. 74-76).]

(The original title of the present chapter is, "Concerning the Bones of the Cranium in general, concerning the Frontal Bone, the two Parietal Bones, and the Sutures in particular." The quotations from Heister are entitled, "Concerning the Bones of the Cranium in general;" a portion of these quotations, as stated above, is missing in the original MS.; this portion we supply from Heister's "Compendium Anatomicum." The remaining part of the anatomical experience premised to the present chapter was to consist of "the frontal bone, the parietal bones, and the sutures in particular." A portion of this is likewise lost, embracing nos. 40-45 of the original MS. As the description of the parietal bones and the sutures of the cranium is, however, complete, the lost portion seems to have consisted altogether of a description of particulars of the frontal bone—a description of some of these particulars, however, has been preserved. To judge from the style of the portion which has been preserved, the author of this anatomical experience was Swedenborg himself, who presented there a rational digest of the opinions of the leading anatomists on the subject under discussion. The consideration of the frontal bone in the original MS. seems to have filled eight numbers; of these, the three last, together with a portion of the fifth number, have been preserved. The subject discussed in this last number, our no. 183, seems to be "the frontal sinuses."—EDITOR.)

183. The *frontal sinuses. . . .* These cavities are larger in sheep and calves than in human beings; according to Verheyen, worms are bred there in the great heat of summer. Mucus is said to emanate by a wound reaching into these cavities; and according to the experience of some, when this wound is closed, and a volume of air is squeezed thither by the organs, it bursts out through this wound so copiously as to blow out a candle; also when a bitter liquid is trickled into it, it is felt in the mouth, and is discharged through the nose. The membrane by which these cavities are invested is mucous, and it is an extension of that which lines the cavities of the nose and the spongy bones; it is indeed glandular, and furnished with blood-vessels, but with fewer than in the little caverns of the nose; it is also thinner, wherefore it secretes mucus less copiously; when they are too moist, the sense of smell perishes. *Morgagni* relates that the frontal sinuses are sometimes divided into four; at other times there are two of the same size; occasionally, however, the right is larger than the left, and not unfrequently he saw the left larger than the right, as is also shown in the tables of Highmore.[1] Sometimes also of the two on the right side the left was missing, and only very rarely he found these sinuses of exactly the same size in two heads. *Gagliardi*[2] says that the frontal sinuses or cavities are not situated between the two tables of the bone, or the two laminæ of the ancients, and consequently in the central part or diploë, but between the plates of that table which is nearest to the brain; or, as is the case more rarely, they are situated between the plates of the outer table. In his illustrations you may see the frontal bone, the parietal bone, and the temporal

[1] *Nath. Highmori Corporis humani disquisitio anatomica*, Haag, 1651, fol.

[2] *J. Dom. Gagliardi Anatomes ossium*, etc., part i., Rome, 1689, p. 48. See also Manget's "Theatrum Anatomicum," vol. i. p. 73, from which Swedenborg seems to have quoted.

bone scraped down in a masterly manner, and the very bony plates or scales separated from one another, together with the little pegs by which they are fastened together, which are perpendicular, pointed, with little heads, bent, and describing an angle in passing from one plate or scale to another. Of the other sinuses which are similar to them, namely, the ethmoidal, the sphenoidal, and the maxillary, I shall treat in another place. The foramina of all these sinuses are so arranged, that no matter in what direction you may hold the head, whether inclined forward or backward, or whether bent to one side or the other, whatever, therefore, may be the position of the head, some moisture must always flow out from some one of these cavities for moistening the nose; compare Morgagni.

184. The *crista frontalis*, when present, protrudes a little into the hollow part of the cranium, immediately over the frontal sinuses or their septum. It is a certain narrow comb or ridge with a groove or furrow, but ascending upwards in a straight direction through the middle of the frontal bone towards the sagittal suture. At its root there is a certain exceedingly small, round opening, but sometimes elliptical or even square, which is called *foramen cœcum* (or spinosum); in some subjects it is peculiar to the frontal bone, in others it is common to the ethmoid bone; and thus communicates with the frontal sinuses. Here the longitudinal sinus and the falx cerebri attach themselves. A little channel or a little furrow is also sometimes hollowed out in the ridge for the above-mentioned sinus; and this runs down lower, when the ridge is wanting. Below this ridge is an important notch accommodating the ethmoid bone, the lateral parts of which are more or less cellulous; this is called the *incisura* (crena) *ethmoidalis*. Morgagni expresses himself on this subject as follows: "If any one just takes a look at this figure [in J. J. Manget's 'Theatrum Anatomicum,' lib. iv.] he will get the idea that in all subjects in the very process, or if you prefer, in the very ridge protruding in the middle of the internal surface of the frontal bone, there is dug out a very thin groove, throughout the

whole length of this ridge, for the reception of the apex of the falx. A groove of this kind, however, I have seen only twice or three times; in other cases I saw a groove across the ridge, but not so narrow; and at another time I saw it in the form of a circular foramen; most frequently, however, I perceived no depression whatever in this process, but in the interstice between this ridge and the so-called crista galli there was a circular foramen, and sometimes a square; not, indeed, of a very large size. These things, however, nature appointed rather for the conveyance of blood-vessels than for the reception of the apex of the falx. For although a part of it in the shape of an exceedingly small cone often enters into the foramen, yet it is torn out thence easily and without the application of any force, while the remaining part of the beginning of the same falx adheres closely enough, partly to the crista itself, and partly to the osseous lamina into which it is produced backwards; nor is the falx at the basis of the cranium contracted into a very narrow apex; nay, in some cases it is still so ample, that in the form of a considerable and firm septum, at a comparatively small distance, it cleaves the olfactory nerves, and the anterior part of the hemispheres of the cerebrum."[1]

185. The *crista galli* (or the *processus ethmoidalis*) receives below, above the region of the nose, the above-mentioned crista frontalis, being separated from it by the aforesaid little foramen. It protrudes pretty far, and in its shape approaches a sharp, almost elliptical, figure, or that of its two segments applied together; afterwards it subsides on both sides, and then lowers itself towards the plane of the frontal bone. It extends towards the ethmoid bone. Concerning its true shape see Morgagni in his last transaction.[2] Albinus[3] says respecting it as follows: "The ethmoid bone of the fœtus consists of three parts, two of which are bony, and the third

[1] Adversaria Anatomica, vi., Leyden, 1740, p. 38.

[2] See Advers. vi. tab. ii. fig. 3, where he gives to it the appellation, "The process of the os ethmoides, called crista galli."

[3] Albinus (Bernardus Siegfried), *Icones Ossium Fœtus humani; accedit Osteogeniæ brevis Historia*, Leyden, 1737, p. 14.

cartilaginous; this is a plate or lamina interjected between the bony parts, and which, besides constituting the larger, and indeed the upper part of the septum of the nose, forms also that part which divides the soft part of the nose, and likewise the crista galli; moreover, a part of it is spread out as a sieve. In adults, however, that part which is in the soft nose remains cartilaginous, while in the other parts the whole of this lamina or plate is bony, forming one continuous bone, which we described as the superior part of the septum of the nose, and as the crista galli."

We stated above that there are two bony parts of the ethmoid bone, and that a cartilaginous plate is interposed between them; these parts, however, adhere to this plate by the intervention of a cartilage resembling a sieve, which proceeding from the plate on both sides near the root of the crista galli incrusts the bony parts on top, and after it is turned into bone it is continued into the bones.

186. The *fontanelle* (or the *fons pulsatilis* and the *bregma*) in children: Where the coronal and sagittal sutures meet, there appears in recently-born children a place which is not yet ossified and is merely membranous. It is very apparent in some, even to advanced age, not being covered by bone, or the bone not meeting; this is especially the case with such as have been afflicted with rachitis. It is of an irregular square shape, with its angles sometimes extending to a considerable length; the greater part of it belongs rather to the frontal bone than to the parietal bones. The membrane which appears there is furnished with copious blood-vessels; two arterial vessels running over its whole length parallel with the sagittal and the frontal sutures; to these vessels belong the lateral branches, and their combined action causes a sort of pulsation and contraction which is noticed when the hand is applied to the part; besides, it suffers itself to be sensibly acted upon by the common pulsation of the dura mater. A drawing of it and of the arteries may be seen in the plates of Ruysch.[1] "In the fourth month in the cranium of embryos,"

[1] *Thesaurus Anatomicus Quintus*, Amsterd. 1744, plate ii. fig. 4.

says Kerkringius,[1] "there appears evidently above the nose a harmonic juncture which is more lax towards the fontanelle; in the fifth and sixth months it decreases. In the eighth month we are able to see through the fontanelle that the longitudinal sinus has been adjoined to it."

187. The parietal bones (*ossa bregmatis, verticis, sincipitis*) are the largest of the whole cranium. They form its superior, and also both of its lateral parts, like walls; their shape is square; their superior and posterior margin is denticulated, except a small part on their lower sides. The inferior part is squamous, except a little on the side of the occiput. They are joined together by the sagittal suture; with the frontal bone by the coronal suture; with the occipital bone by the lambdoid suture, and with the temporal bones and the sphenoid bone by squamous sutures; for its anterior upper angle terminates in the form of a little squamous tongue, which is called apophysis temporalis. Although these bones are the largest, they are nevertheless the weakest of all the bones of the cranium, with diploë between the tables around the margins. Their exterior surface is polished, their interior uneven; for many grooves and impressions of the arteries of the dura mater are imprinted upon them, which in some subjects are most conspicuous. The trunk of the arteries is sometimes found there in one little channel, and occasionally a short channel is near the lower anterior angle; besides vague and irregular excavations are there, made as it were with the fingers; also a groove for the longitudinal sinus as well as for the glandulæ Pacchioni. Near the lower posterior angle there appears a small portion of the little channel of the lateral sinus, which is rarely wanting. On both sides of the sagittal suture there are two small fossæ, in the bottom of which are several little foramina, through which blood-vessels pass; there the dura mater is

[1] See Manget's "Theatrum Anatomicum," vol. i. p. 146, from which Swedenborg seems to have quoted. The title of the original work is as follows: "Theodori Kerckringii Osteogenia fœtuum," Amsterdam, 1670; and the passage in question occurs in chapter ii. p. 216.—Editor.

so closely attached to them, that when the cranium is cut with a saw and raised up, on account of the disruptions many drops of blood infuse the dura mater. Near the superior margin, towards the posterior angle, is a little foramen, called the foramen parietale; sometimes it is only in one of the two bones, and sometimes in the sagittal suture itself; in some cases it terminates in the diploë, in others it penetrates both tables, in some it is even wanting; when the foramina are present those veins pass through them which carry off the remaining blood of the dura mater. There is also a foramen or a channel near their inferior and anterior part, through which passes a branch of the internal carotid which is distributed over the dura mater. On the external surface above the notch of the temples (*crena temporum*) appears a considerable portion of the temporal muscle (crotaphites).

188. "The parietal bones," says Kerkringius,[1] "during the first three months exhibit scarcely anything pertaining to the nature of bone except some darkish points; in the fourth month they are almost altogether bony. Near the sagittal suture, however, and also near the sphenoid bone, the temporal bones, and the fontanelle, there are still considerable cartilaginous apertures. In putting on an osseous substance, the beginning is made from the centre, and not from the circumference, as is the case with the frontal bone. In the fifth and sixth months the bony substance increases considerably, and the sutures are by degrees so closely drawn together, that in the seventh month they are joined harmoniously, but loosely. From the sphenoid bone, however, and the temporal bones they are still distant by a considerable gap, which distance is bridged over by a membrane; this gap is scarcely visible in the eighth month, and in the ninth it has quite vanished. The fontanelle, however, which consists partly of these bones, but still more of the frontal bone, remains during nine and ten months, nay, with children it sometimes remains to their fourth and fifth years, and in some men to their

[1] See Manget's "Theatrum Anatomicum," vol. i. p. 146, and likewise "Th. Kerckringii Osteogenia fœtuum," Amsterdam, 1670, chapter iii. pp. 217, etc.

old age. Midwives declare a child to have lived when they find that the membrane of the fontanelle which had previously been sustained by the motion and the spirit of the cerebrum, has collapsed." Albinus expresses himself on the mode in which the cartilage changes into a bony structure, as follows:[1] "At first the cartilage is thin and very soft, and similar to a cartilaginous membrane. In its middle by-and-by the bone begins as a small plate, very thin and tender, which, however, soon manifests itself by a few grosser filaments. In other cases there is an appearance as if the cartilage itself passed over into such osseous filaments. These filaments grow, and form a certain kind of little net. This produces through the circumference its own filaments, which by their hurdle-work more and more absorb the cartilage. From this rudiment there is afterwards produced the vitreous table; and likewise the diploë —may I be allowed to use this word, by which is understood the substance interjected between the two more solid tables in the bones of the skull?—from that the external table. For although the filaments of the above little net coalesce on the outside, they, nevertheless, erect among one another little plates of various size, figure, and position, from which arises the diploë; this has its beginning in the middle of the little net, and thence creeps around—soon, however, this formation is repressed; for the tops of the little plates of which the diploë consists are as it were beaten down, and then they coalesce; plates from all directions flow together inclined like scales, so as to produce the appearance of one unequal table. This is at first here and there interrupted by gaps. Such then is the genesis of the exterior table. In this manner also nature begins its work in the middle of the bone, and prosecutes it in every direction. Meanwhile this first little net in the interior pours out the diploë; but this is soon repressed and consolidated into the vitreous table. Each of the two tables in the course of time becomes thicker and more solid;

[1] Albinus (Bernardus Siegfried), *Icones Ossium Fœtus*, etc., Leyden, 1737, pp. 6, 7.

for both the filaments and the little plates swell, and new crusts are added. On this account the intermediate gaps become smaller, and at last in their stead remain openings or foramina; these themselves gradually contract, so that many of them are obliterated, and the tables themselves become more and more continuous with their parts. Through all the changes of age, however, the parietal bones (ossa verticis) remain simple."

189. The *sutures of the cranium:* The *coronal suture* crosses from one temple to the other, and joins the frontal with the parietal bones. Palfyn[1] mentions a case where there was no trace of such a suture on the left side. The *transverse suture* proceeds from the exceedingly small angles of the eye through the bottom of the orbits and the root of the nose, often to the canthus of the other eye; whence some take it as a continuation of the coronal suture. The *frontal suture* divides the middle of the frontal bone either in part or wholly. The *sagittal suture* starts from the coronal suture and in a straight line passes through the middle of the sinciput and the crown of the cranium to the lambdoidal suture, connecting the two parietal bones. Eustachius[2] states that he has seen fifteen skulls where this suture was missing. In the occipital bone, especially of infants, some variety is observed, and also in the case of those with whom the back part of the head is broad; for in some cases the upper part of the bone is divided in a transverse direction by a genuine suture, when there arises between it and the lambdoidal suture a bone of a triangular shape. The *lambdoidal suture* connects the occipital bone with the two parietal bones. Palfyn mentions that in one case he saw this suture double, the two sutures being placed at a distance of three fingers, and preserving this distance until meeting with the other sutures.[1]

[1] Palfyn (Jean), *Nouvelle Ostéologie, ou description exacte des os du corps humain,* Paris, 1731, p. 84.

[2] *Tabulæ Anatomicæ Bartholomæi Eustachii, quas publici juris fecit J. M. Lancisius,* Coloniæ Alobrogum, 1716, p. 32, fig. 5. In Manget's "Theatrum Anatomicum," vol. ii.

The *sphenoidal suture* passes around the bone of the same name, and separates it from the frontal bone, the temporal bones, and the occipital bone. The *ethmoidal suture* encompasses the ethmoid bone. The *zygomatic suture* is so called because it divides the zygomatic process as it were into two parts. The *spurious* or *squamous* sutures—the denticulations of which form a conjunction, but are not visible externally. The *squamous* suture is formed by the application of the temporal bone to the parietal, occipital, and sphenoid bones. A similar suture joins the frontal with the sphenoid bone. In some crania sutures have been observed in places where there ought not to have been any; in others they are far apart, as is said to have been the case with Pascal's skull; it is less credible that such is the case with those who are subject to epilepsy, megrim, headache, and similar pains. Eustachius in his fig. 3[1] exhibits the sagittal suture continued to the very root of the nose; he also shows in the zygomatic process (os juguli) a simple line in the place of a suture, as in the case of apes; and, besides, he exhibits the peculiar form of a diseased suture, where one suture is led across the middle of the head from the right to the left ear; and another from the foramen magnum longitudinally through the head to the root of the nose—consult his figures 1, 3, 4, 5, 6, 7, 9, 10, 12, 17, 19. Vesalius[2] observed that the superior sutures are not serrate or denticulated, as in the convex surface, but are connected by simple lines, more or less irregular; also that some sutures cannot be separated without breaking them apart, their teeth verging in an oblique direction towards the concave surface, and the interstices terminating at the internal margin of the cranium. He observed further that exteriorly between the bases and roots of the denticulations there are notches of some length in an oblique direction in respect to the substance of the bone, so that the teeth of one bone enter into those of another, and arrange themselves into

[1] See Eustachius' Tables in Manget's "Theatrum Anatomicum," p. 32.

[2] Vesalius (A.), *De corporis humani fabrica, libri vii.*, Bâle, 1543, fol., Leyden, 1725.

notches. In a certain figure of Gagliardi [1] we may see how the filaments of a bone extend towards the sutures. For the sutures allow a passage to the blood-vessels and fibres of the dura mater not only towards the interior substance, the cellules and diploë of the cranium, but also into the very pericranium.

[MODERN AUTHORS.

189*a*. LUSCHKA.[2]—"The human cranium is endowed with a considerable degree of elasticity, by virtue of which it is able to escape many a fatal injury, and is fractured only when the limits of its elasticity are transgressed. This property enables the cranium, while yielding to a certain degree to the influence of violent forces from without, to alter somewhat its shape, in order after the withdrawal of these forces to assume again its former shape. This fact appears of the greatest importance in judging of certain disturbances in the activity of the brain, which are likely to ensue after the infliction of external injuries, which apparently leave uninjured the osseous basis of the cranium. According to the experiments instituted by Bruns,[3] in which he endeavoured with the aid of a vice to compress the head, it can be compressed considerably in any direction, and its diameter may thus be shortened without causing any fracture. In this case, however, the head is enlarged in its other dimensions. These experiments have shown that the skull is endowed with a very variable degree of elasticity, which does not depend altogether upon age: for the skull of an adult in its transverse diameter could be shortened 15 mm. before breaking, while the skull of a boy twelve years old broke in its base after its dimension in the same transverse diameter had been reduced only 5 mm. (p. 51.)

[1] Gagliardi (D.), *Anatomes Ossium*, etc., table ii. fig. 1, see explanation on p. 110.

[2] Luschka (Dr. Hubert v.), *Die Anatomie des Menschen*, etc., vol. iii. sec. ii.; "Der Kopf," Tübingen, 1867.

[3] Bruns (V. v.), *Die chirurgischen Krankheiten und Verletzungen des Gehirnes und seiner Umhüllungen*, Tübingen, 1854, p. 204.

189*b*. "The *external table* of the cranium—*tabula externa*—is of variable thickness, decreasing in general from the crown to the base, and amounting on an average to $1\frac{1}{2}$ mm. Its exterior surface exhibits an immense number of least pores, which must be regarded as the orifices of an equal number of Haversian canals. These little canals, which are intended to receive the least vascular branches of the pericranium, make up a coarse reticular texture, the irregular meshes of which, in their greatest diameter, run parallel with the surface of the cranium, and terminate finally in the interstices of the diploë. The periosteum which adheres to the surface of this osseous table—*the pericranium*—is a thin, but proportionably firm, fibrous membrane, the tissue of which, without any interruption, passes over into the so-called cartilago sutarum, so that in the neighbourhood of the sutures it adheres more closely to the cranium than elsewhere. The numerous blood-vessels which run through the pericranium originate partly in the external cranial arteries, and partly they consist of rami perforantes of the meningea media which pass through the sutures. They are resolved into a fine network consisting of very irregular meshes, out of which proceed the shoots for the Haversian canals (p. 53).

"The *inner table* of the cranium—*tabula interna s. vitrea*—is generally thinner than the external; on an average its thickness amounts only to a $\frac{1}{2}$ mm.; not unfrequently, however, it equals, nay, sometimes it surpasses in thickness the outer table. It has been established by much experience that the inner table is more brittle and friable than the external; for it is cracked and broken under the influence of many forces, which do not cause any interruption in the continuity of the tabula externa. . . . (p. 54).

"To the *porous substance* of the cranium—*diploë*—is chiefly due its thickness; wherefore it occurs in a variable quantity between its compact tables. Its boundaries are not distinctly marked in respect to these tables, but it gradually arises as it were from a loosening of their substance, which is resolved into numberless leaves. These thin lamellæ combine in the most manifold fashion, producing thereby a close, but rigid, wicker-work, not unlike the structure of a sponge, the roundish spaces of which, sometimes smaller and sometimes larger, intercommunicate. In a fresh, normal state the diploë is of a more or less intense red colour, which is due to the contents of its interstices. For in addition to attenuated arteries and veins they contain a certain quantity of a reddish, pulpy marrow. . . . The bony substance of the diploë in all directions is ploughed through by arborescent canals—*canales diploici*—the trunks of which on an average are of the size of 2 mm., but sometimes they reach a width of 9 mm., and occasionally they undergo considerable enlargements. They have no independent parietes, but are bounded by the neighbouring osseous substance condensed, with the medullary spaces of which they communicate by numerous pores. These canals terminate in the external as well as in the internal surface of the cranium by roundish openings, the size of which is proportionate to that of the canals themselves. These openings accordingly perforate only one of the two tables, and in distinction to the emissaria Santorini, must be characterized as *foramina diploica.* The above canals, the first accurate knowledge of which we owe to Breschet,[1] contain very thinly coated veins which are entirely destitute of valves, and of every organic muscular texture, and the coating of which consists merely of pavement epithelium and an external layer of connective tissue intermixed with fine elastic fibres. These *venæ diploicæ,* which, with their roots, move freely in the marrow, are not closely embraced by the diploic canals, but by a thin medullary layer they are separated from the interior surface of the canals; although, on the other hand, they coalesce firmly with them around the edges of their foramina (p. 56).

189*c.* "In the sutures, no matter what their nature may be, there is ever inserted between the edges of the bones a thin layer of a thin, whitish substance, very much like cartilage—*cartilago suturarum*—which is continuous with the external

[1] Breschet (M. G.), *Recherches anatomiques sur le système veineux,* Paris, 1829.

and internal periosteum, but which does not possess the least trace of a cartilaginous texture. This intervening substance consists of closely woven cellular fascicles intermixed with fine elastic fibres and a number of oblong nuclei. This organical cement contributes not a little to the great tenacity of the sutures, and it admits of their separation in a longitudinal direction, only with a great deal of difficulty" (p. 98).

189*d*. CRUVEILHIER.[1]—*Internal Structure of Frontal Bone.* The vertical portion and external orbital processes of this bone are very thick; its horizontal part is very thin, and hence the facility with which instruments can penetrate the cranium through the roof of the orbit. It contains large cavities, *frontal sinuses*, which open in the ethmoidal notch, and add greatly to the thickness of the bone at its lower part. They are separated by a septum, which is often bent to one side, and is generally imperfect. The capacity of these sinuses is very variable; they often extend throughout the whole of the orbital plates almost to the edge of the sphenoid. The study of these sinuses, which are connected with the organ of smelling, is of great importance in determining the facial angle.]

[1] "Descriptive Anatomy," vol. i., London, 1841.

ANALYSIS.

190. The animal microcosm is a kingdom by itself, separated from all similar ones with which it is associated. Its viscera are so many provinces, and the parts of the viscera are municipalities. The palace, however, where the ruling queen resides, is the cerebrum; there also is the court and the tribunal. The kingdom itself is engirded by a certain membranous fence or skin; but the palace or the cerebrum is fortified by a double and triple rampart, *i.e.* by the cranium and the dura mater. By these walls it repels all hostile assaults, no matter how many may be made against it from without; by their means also it accomplishes its vital motions, secure from internal foes; it performs its intellectual function, and rules all things in particular, as well as in general, by the aid of counsel and of nature.

191. This bony fortification or cranium is so constructed, that singulars with common consent protect their universal, *i.e.* each part every other part, the parts themselves their integrals, and these again their general. This rule of union and of love prevails in universal nature; it is deduced from, and is seen in, the connection of all things, whence results a mutual relation: for every part from its circumference has relation to a certain centre, the centre of one part has relation to that of another, and all things together have relation to a certain general centre; these general centres, however, have relation to one which is most general. In the centres are collected all the forces which arrive from the rays and the circumferences; the circumfluent forces, therefore, avail just in proportion as they in due order conspire towards a most general centre. The cranium itself consists of seven bones, the bones again consist

of their tables, and these of smaller plates, leaves, scales, and finally of particles. From the genesis of the bones in infants, and their articulation in adults—but the origins and connections of the parts themselves we must take for granted—it appears, from what strikes our senses, that such an arrangement prevails everywhere. There are three general centres of the seven bones or of the cranium : The *first* is between the crista frontalis and the crista galli, where there appears usually a foramen. The frontal bone, which defends the cerebrum, and encloses its front face, produces in its middle a ridge or crista. From this, as from a small terminus of motion, or as from a centre of rest, of gravity, or equilibrium, everything which acts upon the cerebrum issues; here begin the sinuses and processes of the dura mater, and even the sinuses of the very bones themselves; here terminate the cortical and medullary convolutions of the cerebrum; and here, as it were, is an asylum and portico of all motions, or of all the solid and soft substances which are in a state of motion. The *second* centre is in the middle of the occipital bone; for there in a meeting of roads, as it were, where the torcular Herophili is situated, all the larger and superior sinuses, that is, the longitudinal sinus, the two lateral sinuses, and also the straight or fourth sinus, with the inferior sinus of the falx cerebri, meet together, and are concentred. The *third* centre appears in the middle of the sphenoid bone, or in the sella turcica, where lies the pituitary gland, the complement of all the functions of the cerebrum; for the individual bones communicate only with the sphenoid bone, and the parts of that bone with the sella in the middle, and indeed in such a manner that all the concussions inflicted upon the brain meet there inevitably, and are reduced there to a state of rest, and are thus extinguished. The very cerebrum also is traversed, as it were, by a certain axis, which from the straight sinus, or from the umbilicus, that is, from the meeting-place of the sinuses and the falx cerebri, is continued through the third ventricle and the infundibulum into the same gland, called pituitary, which is placed on this sella. These three centres are the general centres of the seven bones of the cranium; the rest must all be regarded as situated so to say in the circumferences and in the rays which from their most particular centres tend so unanimously towards these general centres, that in them they behold themselves bounded, fixed, quieted, and protected, and conspiring towards, and devoted to, the general welfare, while caring for their own particular wellbeing. Within the cranium there are three bodies agitated by diverse motions, namely, the cerebrum, cerebellum, and medulla oblongata. In order that the motions of these three bodies may conspire, it is necessary that in the cranium itself, which is their common envelope, there should be three centres, or three boundaries from which they emanate, and whither they tend. The centre proper of the cerebrum is near the crista frontalis; in the middle of the occipital bone is the centre which is common to the cerebrum and cerebellum; but in the sella turcica is the most general of all the centres, or that which is common to the three, that is, to the cerebrum, cerebellum, and medulla oblongata; for these three bodies extend the sphere of their activity as far as this centre. Which are the circumferences, and what their number and quality, is taught by the sutures, which bound the spheres of activity of the individual bones. For the vibrations and tremors communicated to the cranium are continued only to these interstitial margins of each bone; and if they are transferred to the neighbouring bones, they are diffused there more gently, as in another field; in the frontal bone they are thus propagated to the coronal suture; in the parietal bones they are carried as in a circle to the sagittal suture, and finally to the lambdoidal, and to the remaining smaller and spurious sutures. They are thus carried about, and at last they enter the centres, where they are extinguished.

192. The substances derive their various states of activity and inertia solely from the forms. The superior forms, which in the subsequent Part on the Doctrine of Forms [Part II. chap. ii.] we shall call celestial, vortical, spiral, are so arranged, that the singulars which determine these forms cannot help

being moved from a least beginning; the circular form, however, which is lower than the three here mentioned, and posterior, is most active in its rays and circumferences; but in its centre where the rays meet, it is most quiet, and altogether inert. The lowest form, however, or the angular, manifests the forces and powers of its substances in each point, and as it were binds them. Whenever an active nature desires to put on a passive nature, or whenever it desires to pass from a state of mobility into its state of rest, it passes off by degrees into circular, and finally into angular [forms]. This course it follows in the formation of the bones; for it has been observed that in the softish membrane circles are first delineated, and that these are gradually bound together by transverse lines; and that in this wise angular forms are excited, in which there is such a direction that each part resists every other part, and prevents the motion which has once been initiated from being continued. This is the reason why at first the most mobile membranes are called into existence, which becoming less soft in cartilages, are finally rendered hard in inert, passive, resisting, and frigid bones. This follows from the mere direction of the parts; that nevertheless in each substance or part there remains the former nature of acting, which is simply checked by opposing determinations, appears in the first, middle, and last ages of the bones; for the bones grow and expand even until the riper age of man, but they decrease as man verges towards old age, and yet they sustain and preserve the original state scarcely otherwise than the most active remaining substances. This would not happen if they were at once to coalesce into a certain hard substance. It hence appears manifestly why the bones of the cranium partake of hardness and softness in a similar degree; and why being rendered elastic in the highest degree they receive percussions, and repel them, *i.e.* reject them towards their centres. If they were too hard, they would resist and not yield; and if too soft, they would yield and not resist; in the former case, like pottery ware and glass, they would easily break, like diseased, emaciated, and dead crania; in the latter case they would continue the least concussions or blows into the sacred precinct of the cortex of the brain itself, as in embryos and infants. In order, therefore, that our skulls may be most powerful, they consist of separate circumferences and centres, of many scales, pegs, plates, with intervening sinuses, passages, pores, which again are filled with diploë, vessels, fibres, and fluids. Nature, which produces its effects from the inmost causes, and from the hidden principles of the sciences and arts, has so constructed the cranium that there cannot be anything more firm and more perfect. Yet inasmuch as the question is here not about the beginnings and the causes of the bones, but about the cranium, it is better to treat here of those effects which occur visibly.

193. The cranium itself is bony, and thus being of a passive nature, is inert and hard; it is covered with a periosteum, the dura mater, which is a softer, and at the same time a grosser, membrane. This is succeeded by the pia mater with the arachnoid membrane, and with arterial vessels disseminated through it. At last comes the cortical substance, the most active of all the substances of the whole body; this also is the inmost, since it is inmostly concealed within so many envelopes succeeding one another in due order. The cranium thus in regular order decreases in hardness and inertia, and at the same time increases in softness and activity. The elasticity also increases in a similar ratio; it is least in the cranium, greater in the dura mater, still greater in the pia mater, but greatest in the cortical substances; in the same proportion also in which elasticity increases, the power and ability of acting likewise increase. There seems to be a constant analogy in these things; that is, the same ratio which exists between the cranium and the dura mater exists also between the dura and the pia maters, and finally between the pia mater and the cortical substance. From all this it may appear somewhat clearly that the cortical cerebrum is situated within its cranium and within its envelopes safe from all contingencies; or that any injury received by the cranium never penetrates thither;

but that during its progress towards the interiors in proportion to the diminution in hardness, it at last becomes equal to nothing in the cortex, where the soul has established its palace and court.

194. Besides, the whole bony system of the animal body is so connected that one bone sustains the other, and as it were feels whatever happens to the other; and thus that it receives in part the force brought to bear upon the other; especially if any casualty happens to the cranium. This is perceived sensibly by the vibrations and tremors arising from any blow and concussion; and likewise by the continuity of all bones by means of membranes, muscles, tendons, vessels, and fibres. For the cranium rests upon, and is conjoined with, the bones of the spinal marrow; from the bones of the spinal column, that is, the vertebræ, are continued the ribs, the sternum, the shoulder-blades, the os sacrum, the coccyx, and finally the ulnæ, the arms; the loins, and feet. Whenever, therefore, an injury is inflicted on the cranium, everything bony in the whole body claims its share, or receives some part of the injury in itself, and thus in a certain manner comes forward and proffers its help. The harmony also which begins from the head is such that there is no particular which is not carried towards a general, and no general which does not redound into its parts. Hence an immense strength accrues to the cranium, for the purpose of protecting its cerebrum.

195. At first sight the cranium appears quite irregular and unhandsome; for its shape is not circular nor even perfectly oval; but it is uncouth, bald, porous, and full of grooves; in other places, however, it is polished and smooth; it is concave. In one place it is thick, composed of many parts, it contains diploë, and is hard; in another place again it is thin, simple, tough, and more soft. With all these irregularities, however, the cranium in respect to its offices is most regular, so that it is impossible to contrive anything more perfect. Thus it is formed in accordance with every motion of the enclosed cerebrum, cerebellum, and medulla oblongata; and in accordance with the determination of the sinuses, both of those in the crown

and in the base of the head. It is likewise formed for the passage and the fluxion of the arteries, veins, and of many nerves; for the reception of the convolutions, glands, and ganglia; for gathering up the dura mater and its processes. Besides, it accommodates with hollows and envelopes the organs of sense, namely, those of sight, hearing, and smell and between both periostea it contains channels of nutrition, secretion, and communication. And, nevertheless, with such a great number of duties, it preserves in a state of the greatest distinctness its numbers, orders, degrees, measures, and modes; and this great aggregation of diverse forces it directs towards the general centres; and this, not only when the head is a large globe, but also when it is as yet very small, and is scarcely the size of a hazel-nut or a pea; for it grows continually into its harmonies, relations, dependencies. Reason constantly accompanies uses; use generates necessity, and necessity a compagination of fibres, which is derived from the inmost sanctuaries of the sciences and arts, that is, from nature in its first principles, which is the work of the Supreme Being—of Wisdom Itself. Does it not follow thence that the structure of the cranium is most regular, although it appears uncouth and unhandsome?

196. From the structure of the cranium itself we can contemplate as it were in a mirror the quality of the motions which prevail and have prevailed in the two brains, in the medulla oblongata common to both, and also in the individual parts of each; for the cranium from the most tender age has been shaped into a correspondence with all the forces acting within its interior cavity; for in times bygone, or in its first formation, both were so contiguous that they acted one common cause. The larger and smaller fossæ of the bones signify and declare how far and in what manner the two brains and their appendages and parts expand. The sutures and articulations point out which are the termini, and of what kind are the spheres of motions or expansions. The protuberances, eminences, ridges, and apophyses indicate where are the centres of

motion, the equilibria, the points of attraction; the equalities, where several forces united have one and the same sphere of activity; and the inequalities, where individual forces, each by itself, have their peculiar sphere of action. The frontal bone shows that the front part of the cerebrum, divided into two bosses or protuberances, expands in an anterior direction; the coronal, frontal, and transverse sutures when they are present indicate which are the limits, the directions, and the areas of the expansions; the parietal bones show that the mass of the cerebrum underneath elevates itself and pours itself out towards the larger, and at the same time towards the lateral, sinuses; the sagittal and lambdoidal sutures that it swells downwards, and not beyond these limits. The occipital bone indicates what kind of space was left to the cerebellum for swelling; its elevation in the middle, where the sinuses meet, shows of what nature are the determination and the concentration of the motions of both brains. The crista frontalis and the crista galli, with their little foramina and cavities, and the frontal sinuses, and also the rest, show of what nature the forces are which cause a tension, and likewise of what nature in the tender brains were the alternate modes of drawing or pulling, by which these parts were made to rise and to gape open. The same is the case in the remaining eminences and elevations of the bones; for the active forces, which are those of the cerebrum, correspond altogether to the passive forces, which are those of the cranium, one being formed for the mode and the use of the other; they indicate likewise the changes of motions in the ages which succeed the first, just as actual coins or impressions. When motion, however, ceases, or changes its direction, the representations perish, and gradually the traces in the bones are obliterated; the sutures coalesce, the frontal, the transverse, and the rest; the whole opening of the bregma or the fontanelle is closed; yet the marks remain, and also the fitness and the conatus which succeeds to motion in the bony matter. In this wise it may be seen from the cranium how the cerebrum acts, almost in the same way as we may notice the workings of the animal or lower mind (*animus*) in the countenance; from the *animus* how the thinking mind acts; and as from this we may know the nature of the soul; further, how the cerebrum is bounded, and its power of acting is reduced within fixed limits. These things, however, vary in different subjects; for every one harbours a distinct nature. It is better, however, to explore these very motions and states from their efficient causes in the brains themselves than to study them from the signatures and traces in the external tables of the cranium.

197. On comparing the crania of infants with those of adults, we are able to arrive at some by no means ambiguous conclusions in respect to the difference of the motion and animation of the cerebrum. The embryonic cerebrum in its tender age is not yet covered with any cartilage, and still less with any bone, *i.e.* a cranium; but it is encompassed with a certain general membrane which is continuous, soft, yielding, united to the dura mater, and evenly spread over it, and through this membrane we see with almost transparent clearness what the nature of the cerebrum is, and what it does. It follows thence that the motion or animation of the cerebrum then is more constant, freer, less limited; and that the cerebrum yields a more perfect obedience to the desires and the will of the forming substance, or to the nature of the living soul. It is different after birth and in the ages which succeed, for then this membrane becomes fixed and hardened; it is turned into bone, and becomes a cranium. This limits the motion of the enclosed cerebrum, as the spaces around it are confined and the boundaries laid down, beyond which it may not transgress. Freedom now decreases, but for the same reason will increases; and this very often does not follow order and nature, but desires to rule over order and nature. The embryonic cranium, or rather the tender membrane which occupies its place, is in the closest proximity to the cerebrum, and constantly presses upon it; and in order that it may embrace it most closely, the position of the fœtus in the womb is inverted, so that it lies with the head downwards. From this it follows that the embryonic brain can be expanded only in a general

way, and that it is not able to perform any distinct, particular motions, except some few interiorly within its own organism. But when the cranium is beginning to be solidified, then the infant is born; and then the brain is reversed, and rests on the neck. The spaces between the dura and the pia mater, or between the cerebrum and the cranium, are now beginning to be expanded; and by this means the brain acquires the power of performing its motion not only generally, but also particularly; and subsequently also of exciting whatever muscles it pleases, and of being intent on whatever sensation it chooses. A man thus awakens, as it were, out of a certain deep sleep, and enters upon the life of his body.

CHAPTER IV.

THE DURA MATER.[1]

198.[2] The *dura mater*, or thick meninx, invests the concave part of the cranium like a convex pericranium, so that in a certain sense it occupies the place of a periosteum. This internal periosteum recedes from the external periosteum of the cranium in proportion as the intermediate bone during childhood grows thicker. In some places where the intermediate bone is thin they are but little apart; but in other places where the bone is thicker, and divided into tables, and these into plates, with intervening sinuses, diploic substance, bony fibres, and pegs, or again where protuberances and eminences are underneath, they are more distant. Long after birth they are still closely contiguous in that place between the coronal and sagittal sutures which is called bregma or the fontanelle. The dura mater penetrates into the joints of the cranium in the sutures; and by means of ligaments and vessels which pass through, it keeps up its communication with the periosteum, which was formerly so near and closely related to it. An immediate communication also remains in certain foramina; as in the foramen magnum, around the

[1] This chapter follows that on the Cranium in the plan laid down by the author in Codex 58, Photolithographed MSS., vol. vi. p. 64, and also in Codex 55, from which the anatomical experience is quoted. The title of the chapter in Codex 58 on p. 64 is "The Dura Mater and its Productions," and on p. 94 simply "The Dura Mater," which title we have consequently adopted above. In Codex 55, Photolithographed MSS., vol. v. p. 34, the chapter is entitled "The Dura Mater and its Processes."—EDITOR.

[2] Nos. 198-202, as well as all anatomical descriptions in the sequel of the volume which are not marked with the name of the author from whom they are quoted, seem to give the results of Swedenborg's own observations and of his studies of the anatomical writers.—EDITOR.

orbits, and also by means of those through which in other places nerves and veins pass out, or arteries enter. The dura mater, therefore, always adheres more firmly to the crania of infants than of adults, and to those of adults more than to those of old persons; for the filaments attenuate and become dry, and when the pores of the bones and the passages of the sutures close up, they are as it were folded up, and what before was vascular becomes tendinous; wherefore the ligaments are then easily broken, which is also the case in diseases.

199. The dura mater does not adhere everywhere equally to the walls of its cranium, nor by the same substance. Around the sutures, especially the coronal, sagittal, and lambdoidal, the adhesion is effected by filaments, either of a fibrous, tendinous, or membranous nature, which are produced from the exterior coating of this membrane—or by the ends of arteries and veins. At the base of the cranium, and also in several other places, it adheres by a kind of fungosity, pulp, papillary substance, which also contains blood-vessels, so that when the membrane is torn off, its outer surface is tinged with blood, and here and there it appears rugged, unequal, and reticular with red dots, especially under the sutures. Some vessels penetrate either into the first table of the bone, or through intermediate sinuses to the second table; these vessels convey blood, or some other liquid. The other surface of this membrane, or that which is turned towards the brain, is smooth, and irrigated with a fluid of a yellowish colour, as in the case of the pericardium, the pleura, and the peritonæum.

200. Around the parietal bone and the frontal bone, and also under the sutures, the dura mater is more loosely adjoined to the cranium; and there, according to Vieussens, it may be pressed out when the convex part of the cerebrum swells and subsides. In other places, however, around the base it cannot be torn off, because it fills up foramina, lines fossæ, and covers eminences. *Pacchioni* expresses himself on this subject as follows:[1] "The dura

[1] Pacchioni, Ant., *Opera*, editio quarta, Romæ, 1741, pp. 149, etc.; in his letter to J. Fantoni, dated Rome, April 1712, and first published in 1713, reprinted in Mangct's "Theatrum Anatomicum," vol. ii. pp. 272-280, from which Swedenborg seems to have quoted.—Editor.

mater adheres to the cranium not only by the sutures, but also by certain larger and smaller foramina which may be seen here and there in the cranium itself, and through which an entrance is granted to little ropes or threads of various sizes. These little ropes have the appearance of cords, fibres, and also of the thinnest kind of filaments; and by all these the dura mater is attached to the cranium, but unequally, the proportion of thickness corresponding to the forces and necessities of the little ropes and fibrils in sustaining the motions of the membrane. There are therefore in the cranium places where the dura mater clings to it most tenaciously, and there are others where it is attached only loosely; while, on the other hand, there are several places where it does not adhere at all; such, however, is the case in healthy persons, in diseased subjects it is different. . . . If adhesion, therefore, is effected by simple fibrils, where they are beginning to become thicker, they indeed establish the closest kind of union with the cranium, as in the whole base of the cranium. But where the adhesions are mixed, being caused by cords and fibres, or also fibrils, there indeed the dura mater is suspended more loosely from the cranium, but is more forcibly detained upon it. In this respect we have to notice concerning the exterior surface of the membrane as follows: This is attached more firmly to the cranium throughout the whole extent as it were of the falx cerebri, and chiefly near the crown of the head and the occiput; also near the concourse of the lateral sinuses where the marks of the lambdoidal suture are seen, and likewise around the foramen magnum of the occiput. But near the forehead, and near the meeting of the coronal and sagittal sutures, the connection is much more free or loose, so that it is not anywhere attached around the temples, nor in the curvatures of the sinciput. The posterior lateral fossæ which admit the prominences of the cerebrum and cerebellum are mostly free from adhesions, in order that the dura mater may retreat from them, or approach them. The tentorium, which is common to the base of the cerebrum and the upper cortex of the cerebellum, is joined deeply to the interior circumference of the cranium, and likewise to the sphenoid bone near the sella turcica, and to the internal processes of the temporal bone. The remaining expansion of the tentorium is free and flexible. The falx cerebri is fastened into the crista galli like a nail; but at the basis of the tentorium, or near the straight or fourth sinus on which it rests, it becomes more flexible; in the back also it seems a little movable, because it is there as far removed from the bone as is permitted by the suspensory ligaments, the thickness of the membrane, and the ampleness of the longitudinal sinus, which is by no means inconsiderable in the occiput. The falx cerebelli, which is opposite to the falx cerebri, is fastened on the internal margin of the foramen magnum occipitis; it is by no means immovably inserted, just as little as the falx cerebri in the ethmoid bone; but gradually, as it rises, it becomes movable to a certain degree, especially where it rises above the cerebellum, and constitutes the internal face of the tentorium lying under the bases of the falx major."

A. *The Extension of the Dura Mater.*

201. The dura mater lines the whole cavity of the cranium, and in a general way invests not only the cerebrum and cerebellum, but also the medulla oblongata and the spinal marrow; but in several places it retreats from the cranium, and forms processes; it also enters, as it were, into the cerebrum, and divides it into hemispheres. It likewise lets itself down between the cerebrum and cerebellum, and holds even the venous sinuses suspended; wherefore both the processes and the sinuses are attributed to the dura mater. It is also continued outside the cranium where nerves take their departure, and chiefly through the foramen magnum; it thus invests the whole of the spinal cord down to the last apex in the coccyx; it lines also the very foramina of the vertebral column, and accompanies the nerves into the ganglia. Nevertheless, it seems to concentrate chiefly in two places within its own cranium; namely in the middle focus of

the occipital bone, where the longitudinal, the lateral, the straight or fourth, and the small occipital sinuses meet, for which little grooves are impressed on the superincumbent bone. From this place, as from a centre, it determines itself towards the forehead as well as towards the foramen magnum, and likewise towards both sides, and at the same time towards the temples; and in a like manner through the straight sinus towards the pineal gland. Thence, however, in an opposite or downward direction it determines itself in the middle of the sphenoid bone towards the pituitary gland or the sella turcica, where is its second point of concentration. For from the anterior region which is under the frontal bone where the anterior lobes of the cerebrum repose, and which is called the forepart—*prora*—of the head, it bends and inflects itself towards the aforesaid sella in the line of the anterior clinoid processes, and thence it expatiates laterally along the so-called alæ of the sphenoid bone towards the temporal bones with a manifest appearance of separateness and elevation. Thence from both sides, or from the temporal bones where the posterior lobes of the cerebrum, or their lateral edges recline on the sphenoid bone and the temporal bones, it tends towards the cavernous sinuses. The same is the case in the occipital part, where the hinder portion of the cerebrum, as well as the cerebellum and the medulla oblongata, rest in their fossæ; thither the dura mater extends and insinuates itself along the superior and inferior petrosal sinuses in the direction of the posterior clinoid process—see Bianchi's table[1]—so that from all sides it meets together for forming the sella, and so a convenient couch for the pituitary gland. There is in addition the tentorium, a second process of the same membrane, which descends from the higher and opposite part, namely, from the occipital vault between the cerebrum and cerebellum, and around the medulla oblongata; this also lets itself down towards the same cavernous sinuses, the sella and the clinoid

[1] In Manget's "Theatrum Anatomicum," Table v. *extra ordinem* (vol. i. p. 342); for explanation see vol. ii. pp. 342-349.

processes, and connects itself with the dura mater of that region. Besides, it seems also to have desired to anticipate the way, by descending through the straight or fourth sinus towards the corpora quadrigemina, and thence through a kind of continuation by mediating vessels and a thin membrane through the third ventricle and the infundibulum towards the gland of the sella. From one umbilicus or focus it thus seems to progress as well by the circumference as by a diameter towards the other, in order in this manner to conjoin the interiors with the exteriors.

B. *The Texture of the Dura Mater.*

202. The dura mater is an exceedingly robust, thick, and whitish membrane; and because it may be divided, it is supposed to consist of two laminæ which cohere most closely. The external of these is rough, the interior as it were polished and free, and the fibres of both laminæ cohere most closely, and also intersect one another, according to Vieussens and Heister. The texture of its fibres is partly ligamentary and partly tendinous, for they seem to be independent by nature; they are indeed not muscular, because they have no similarity to fleshy fibres, nor are they purely nervous, on which account some call them tendinous. They are, nevertheless, elastic; for when the membrane is loosened from its connection with the cranium, it contracts, and chiefly that production of it which lines the spinal cord. The fibres are also sensory; for, like all periostea, they are most exquisitely sensitive to the touch, as is known from operations with the trephine. The fibres are broad on its internal surface, but small and scarcely conspicuous on its outer surface, according to Ridley. Pacchioni says: "The dura mater is a very dense and strong membrane, consisting chiefly of a twofold arrangement of fibres embracing one another crosswise, and aspiring in a certain manner to a semicircular figure. It has, besides, a reticular outermost surface, by means of which it is attached to the cranium, wherefore it is composed of a three-

fold order of fibres and muscular bands. These strata, however, on account of the greater and lesser number of filaments or muscular bands superimposed on one another, or on account of their varying thickness, are not always found alike. . . . The outermost stratum of the dura mater seems therefore to consist of papillæ produced from the subjacent fibres in a retiform order; these papillæ are unequal, and by them the membrane adheres to the cranium."[1]

203. VIEUSSENS.[2]—"The fibres intersect one another obliquely; for the external ones stretch from the anterior to the posterior parts, and the internal ones from the posterior to the anterior parts, so that both describe a semicircular figure" (p. 3).

RIDLEY,[3] on the other hand, denies that the fibres run out in an oblique semicircular manner. "On the inside," he says, "they seem manifestly to have three origins from the top part of the falx cerebri, before, behind, and in its middle; those before running in a curved manner backwards, and those behind running forwards, but bending back again in a kind of semilunar way; while those from the middle part of the falx run backwards, but are less curved than the rest. In the superior or external lamina they are extremely small, running from behind forwards. Between these laminæ"—he speaks of the falx—"the veins run, which lead back the blood from the arteries, so that the fibrous constitution of this membrane does the office of valves, supports the weight, and likewise the sinuses, which in strangled bodies generally appear ruptured or distended" (pp. 3-6).

204. PACCHIONI[4] says that this membrane, which in respect to the falx cerebri he divides into hemispheres, is composed of a triple stratum of fibres. "Among these strata," he says, "the first, which is nearest to the cerebrum, is not woven everywhere of the same orders of fibres, but they differ everywhere in a wonderful manner. Those fibres which run near the basis of

[1] Epistola ad J. Fantonum in his *Opera*, etc., pp. 137, 140, 141.
[2] "Neurographia," etc., lib. i. cap. ii.
[3] "Anatomy of the Brain," London, 1695.
[4] Epistola ad Fantonum in *Opera*, etc.

the falx, after being bent in the form of an ark, are again brought back to the base of the same falx; on which account other fibres from the edge of the tentorium do not travel in a straight line towards the front, but in an oblique direction and from a knotted beginning; there, *i.e.* in the front part, on account of approaching too closely to the longitudinal sinus, they are obliterated, whole divisions at a time, under the anterior series of semispiral fibres" (p. 139). "By the maceration of the membrane," he further says, "he learned that the agglomeration of fibres in the anterior part has no communication with the posterior one; but that the orders of the fibres are diverse, and inclining almost to opposite sides. . . . When one stratum of fibres is exhibited, immediately another one runs out, which intersects the former. These fibrils are not so elegantly woven together, but are more compact and slender, so that a microscope is required in their examination" (p. 140).

205. BARTHOLIN.[1]—"The dura mater is connected with the pia mater and the cerebrum by vessels; with the cranium by thin membranous fibres produced from itself, which pass through the sutures, and constitute the pericranium. This membrane is double like the other membranes. Its exterior side turned towards the cranium is harder, rougher, and less sensitive, on account of the hardness of the cranium which it has to touch. Its interior side is slippery, smooth, shining and bright, being more irrigated by an aqueous humour. It is fourfold where it separates the cerebrum from the cerebellum, in which place dogs have a bone in support of the cerebrum, lest it press upon the cerebellum. It is twofold, however, in the crown of the head, where it divides the cerebrum into a right and a left half" (pp. 460, 461).

C. *The Muscular Bands* (LACERTI) *or the Muscular Fibres* (LACERTOSI) *of the Dura Mater.*

206. Near the sinuses, that is, the longitudinal, and especially

[1] Bartholin (Th.), "Anatome," Leyden, 1673, 4th ed.

in the neighbourhood where it meets with the lateral and the straight sinuses, in the concave part of the membrane there appear ligamentary, tendinous, and elastic fibres, not unlike the muscular—chiefly, however, in the anterior and posterior parts of the falx. These fibres, on account of their similarity to those of the heart, resemble muscles (*lacerti*), and they seem to tend forwards according to the direction, and also to increase in thickness according to the force, of motion, or of the contraction and expansion of the sinuses; for where the action is stronger, there also they appear more robust, as may be seen in the table of Vieussens."

207. PACCHIONI.[1]—"A series of muscular bands is discovered in the interior surface of the membrane, covering a large part of it, and which contributes nothing or scarcely anything to its proper structure so called."[2] "The texture of the falx is twofold; the exterior consists of pyramidal muscles (*lacerti*), which on both ends by various interlacings are woven into its lower part; but which in the upper part are more extended, and frequently passing over the edge of the falx send their outermost portion into the hemispheres of the membrane. These muscles are thicker and longer in the posterior part of the falx, or where it is joined to the tentorium, but they are more sparse and short in the anterior part, near the crista galli. The former and lower productions of the fibres extend obliquely downwards towards the basis of the falx, but the former have an extension towards the anterior region. Those which are intermediate between the two are dispersed through the border of the falx itself, so that their extremity seems to be most intricate" (*Ibid.*, Epistolæ Physico-Anatomicæ, p. 138).

D. *THE NERVES OF THE DURA MATER.*

208. As the dura mater is elastic and sensory, and furnished with tendinous fibres, it seems also to be provided with nerves.

[1] *Opera*, ed. quarta, Romæ, 1741.

[2] Compare *Opera*, etc. (de Dura Meninge, opus academicum), pp. 3-5.—EDITOR.

These, it is said, it derives mostly from the fifth pair; since several offshoots of nerves together with the carotid artery pass through the receptacles of the sella turcica or the cavernous sinuses. Thence, it is thought, the fifth pair sends off some shoots to the dura mater, the branches of which accompany the fibrils. Besides, a certain fibrous net is sometimes seen around the pituitary gland in human crania; this, however, in calves and other quadrupeds appears sanguineous. It is also thought that this membrane borrows a few branches from the hard auditory nerves; for interiorly in the temporal bone are minute foramina, one of which, according to Heister and Valsalva, deflects a branch of the above-named nerves. It is also mentioned that some nervous stems from the common fascicle of the eighth pair, as well as from the accessory spinal nerve, are deflected into the dura mater, where they pass through the foramen of the jugular veins; likewise some from the tenth pair.[1]

209. PACCHIONI.[2]—"The dura mater receives nerves from the fifth pair. Valsalva says in his work on 'The Human Ear:' 'The hard portion of the auditory nerve enters the cranium through the dura mater, and scatters its offshoots through the trunk of the fifth pair' (p. 145). . . . This at least I can candidly declare, as having been observed by me more than once, that around the beginning of the spinal marrow, nerves which have been brought inside the cranium at the same time with the blood-vessels, creep along on both sides through the dura mater, being thoroughly attached to it. Portions of these nerves I have often loosened with a very thin and sharp instrument; and this seems to agree in every respect with the observations of the sharp-sighted Lancisi. This is perhaps the same pair which

[1] The remaining portion of no. 208 (no. 70 in the MS.) is attributed by Swedenborg to Manget, whose "Theatrum Anatomicum," which is a kind of Anatomical Encyclopædia, he seems to have largely utilized. This passage, however, was written by Pacchioni; and, indeed, in connection with what Swedenborg quoted from that author in no. 209: wherefore we introduce it there as in its proper place. It seems from this as if Swedenborg had not had access to the original work of Pacchioni, but quoted him from Manget.—EDITOR.

[2] Pacchioni (A.), *Opera*, 4th ed., Rome, 1741.

Verheyen calls the tenth, where he says, 'The tenth and last pair of nerves of the head departs from the sides of the medulla oblongata, as it is about to pass into the spinal marrow; and although it makes its way into the dura mater in that place where the vertebral arteries ascend into the cerebrum, according to Willis, it nevertheless does not emerge out of the boundaries of the bone until below the first vertebra.'" The author adds that "he recently saw the productions of nerves burst out of a cranium of considerable thickness joined to blood-vessels, and through four foramina direct their course towards the dura mater; two of which foramina were engraven into the anterior part of the cranium on both sides of the sinciput, and the remaining two into the summit of the process of the temporal bone. Of the second kind of nerves which are proper to the dura mater of the cerebellum, some have relation to the outer, and some to the inner, surface; of the former a great part is derived from the hard branches of the auditory nerve (p. 147). . . . Most minute little shoots of the auditory nerve, besides, spring out below from the interior face of the temporal bone, not far from the edges of the grooves which the lateral sinuses of the dura mater have impressed upon the cranium; these continue straightway into the dura mater, and are dispersed through it. Sometimes," the author says, "he observed between the pathetic nerves and the motor nerves of the eyes most minute nervous filaments proceeding from the sides of the medulla oblongata, and being inserted in an oblique direction in the border of the oval foramen of the dura mater, and adhering to it most intimately by penetrating into it—yet not in all subjects. Besides," he says, "the nervous filaments which arise from the beginning of the medulla oblongata, and which in company with the blood-vessels creep into the pia mater, here and there rise to the dura mater, so that the tentorium which covers the cortex of the cerebellum is abundantly supported by them" (p. 148).

E. *The Glandules of the Dura Mater.*

210. Sometimes minute tubercles and grains appear along the longitudinal sinus, which are thought to be glands; but there are more in one subject than in another, and in the sinus itself they are more apparent; concerning these, however, I shall treat below.

211. Pacchioni.[1]—"These glands succeed in a wonderful manner on both sides of the falx from its apex to its base in the back part of the head; they rest upon the back of the muscular bands; and partly by their fibres, and partly by those which emerge from the cords, they are fixed and mutually attached to them, so that they cannot be disjoined thence, unless they are torn off with a needle. Their shape is roundish, and it varies repeatedly by their mutual compression. In membranes which are not macerated they appear like the eggs of silkworms; but if a dura mater is first steeped for a month in water, and afterwards kept in vinegar, this kind of glandules swells to the size of a grain of millet, and sometimes they exceed this. In old persons, however, and in such as have been suffering for a long time from disease, they are so conspicuous that they may be detected without the help of maceration, or of the microscope, not only in the interior part of the sinus, but also in the intervals of the muscular bands, where they have respect to the pia mater and touch the same; so that if you should attempt to tear away the membrane, most of these glandules would adhere to the pia mater. Each of them is invested with flesh-coloured fibres, whence they assume the appearance of a pale flesh-colour. In old persons, however, in whom the fibres of this kind are enervated and too much relaxed, so as almost to disappear, these glandules are seen of a whitish colour, and are more swollen; this, I believe, may be observed in cases of hydrocephalus and coma, etc. They are furnished with little arteries by small branches creeping through the interior surface

[1] *Opera*, etc., Romæ, 1741.

of the dura mater, not far from the falx; and at no great distance from the veins tending towards the sinus, with which they are sometimes associated. These glandules are only discovered near the sides of the longitudinal sinus, and never, or only rarely, in the lateral sinuses, where they begin to incline downwards (pp. 126, 127). These glandules adhere less to the sinus, and more to the membranes, so that they retreat sometimes to a distance of three or four fingers' breadth from the sinus, and sometimes are dispersed still lower down; in some cases they are also attached by a thin membrane to the cerebrum." Pacchioni continues that "from these glandules innumerable filaments emerge which are as many excretory vessels. These lymphatic vessels," as he calls them, "being most intimately associated with, and folded into, blood-vessels, are implanted from the dura in the pia mater, and adhere to it most firmly, not only by means of blood-vessels, but also by means of many fibres proceeding from the dura mater. . . . A great many of these glandules seem also fastened upon, and as it were ingrained in, the pia mater. These vessels too when torn pour out a liquid (p. 128). . . . Least clusters of least conglobate glandules are situated on the back of the muscular bands on either side of the sagittal sinus; these clusters are enclosed in their own very thin membrane as in a little bag, and are agglutinated most tenaciously to the interior surface of the dura mater; sometimes also they are placed between the fibres and spaces of the pyramidal muscles in such a manner that they may easily be seen; they are also connected with the pia mater underneath. . . . From these glandules emerge the thinnest kind of lymphatic vessels, which scattered through the pia mater, and associated to the blood-vessels, pervade with them the tortuosities of the cerebrum. . . . The muscles (*lacerti*), glandules, and lymphatic vessels are most visible where the lateral sinuses meet with the longitudinal, both occupying the whole of that space on which the posterior prominences of the cerebrum and the cerebellum rest" (pp. 138, 139).

212. Fantoni declares that he discovered three glandulous

bodies between the forehead and the occiput, of various shape and size; neither of these rose much above the external plane of the membrane, wherefore they were most remarkable by breadth. They were easily visible on both sides of the membrane, and consisted of a congeries of least glandules. He observed also three others which differed but little from the former; they filled up the substance of the dura mater, as the membrane itself was wanting there, and they were attached only by little tendinous muscles which were produced from the falx. These were not raised above the surface of the membrane, wherefore they cannot be called tubercles. The remaining two agglomerations were sustained by a thin lamina with the assistance of nervous muscles. Upon pressing this substance a liquid oozed out in several places in the form of little drops.[1] He said he saw lymphatic vessels swollen with a limpid serum, of which he could not trace either the origin or the end; but other close observers also affirm that they never saw any kind of lymphatic vessels in the dura mater of a healthy brain.

In some persons suffering from apoplexy, however, whose brains secrete lymph, Pacchioni observed repeatedly that the pia mater had increased to three times its usual thickness; almost all connection between the vessels had been destroyed; and transparent hydatids were seen here and there inside it, each like a minute varicose vessel of lymph.[2]

Ettmüller, on the authority of Hertodt in his "Crocologia" (p. 282), mentions the case of a boy who died of hydrocephalus in whom the lymphatic vessels of the cranium were partly swollen and partly ruptured.[3] For a liquid is distilled when the elastic power of the membrane is exhausted, as in old and effete persons, and likewise in some persons afflicted with epilepsy, or in lunatic and insane persons.

On making a post-mortem examination of the body of a man,

[1] Letter to Pacchioni, dated June 1728. See Pacchioni, *Opera*, etc., pp. 107, 108.

[2] Pacchioni's Letter to Schrokius. See his *Opera*, etc., p. 129.

[3] *Michaelis Ettmulleri, Opera Medica*, Frankfort, 1708, vol. ii. part ii. p. 698. See also Pacchioni, *Opera*, etc., p. 130.

sixty years old, who had suddenly died, Littre found numerous tubercles, most of which he met with near the sinuses and the larger blood-vessels of the dura mater, where they were contained in the contexture between its fibres; some being more prominent on the outer, and some on the inner, surface, where excretory passages opened which by pressure yielded some serum.[1] There are many examples where the dura mater appeared pale, whitish, and soft, and where a space which was filled with water opened between it and the bony part of the cranium.

FANTONI says that in a certain subject he found the dura mater swollen like a bladder from which a great quantity of water was discharged when it was torn; and in another body he discovered a bladder of the size of a pigeon's egg, which was filled with a lymph, partly thin, and partly thick and gelatinous.[2] When the dura mater is otherwise pressed, like the pericranium, the pleura, and the peritonæum, lymph issues out of innumerable pores, and the same takes place again when it is macerated. After maceration the pores appear still more open in the dura mater; and when it is wiped clean, and the pressure is repeated, very many drops, and of considerable size, issue forth. It is thought that the gelatinous concretions, the tubercles, pustules, and serous tumours which are observed in the heads and brains of persons who suffer from concussion, derive their origin thence.[3]

213. HEISTER.[4]—"In the sinuses of the dura mater, and out of them at the sides, there are found a number of the small glands described by Pacchioni. Others are sometimes met with in the foveæ of the frontal bone, and around the division of the vessels, between the dura mater and the arachnoid

[1] Littre's papers appeared originally in the Memoirs of the Academy of Sciences in Paris. He was quoted thence by Fantoni in his letter to Pacchioni, dated September, 1712. See Fantoni "Opuscula Medica et Physiologica," *Dissertatio* I., *ad A. Pacchionum*, p. 14; and also Pacchioni, *Opera*, etc., p. 179. Swedenborg probably quoted this passage from Manget's "Theatrum Anatomicum," where Fantoni's letter is reprinted in vol. ii. pp. 280-285.—EDITOR.

[2] In Pacchioni, *Opera*, etc., p. 111.

[3] *Ibid.* pp. 109, 110.

[4] "Compendium Anatomicum," etc., vol. ii.

membrane. Sometimes also I have seen clusters, as it were, of the same sort of glands in the foveæ of the parietal bones; which, not far from the longitudinal sinus, are often imprinted upon those bones. These also, as Santorini writes of others in the foveæ of the frontal bone, were not covered with dura mater; but this membrane was deficient, and as it were perforated in that part. Such glands seem to be for the purpose of secreting a fluid for moistening the dura mater" (no. 381, pp. 21, 22). [Concerning the modern results in respect to the "Glandulæ Pacchioni," see nos. 244 *i*, and 244 *j*.]

F. *The Arteries and Veins of the Dura Mater.*

214. The vessels of the dura mater derive their blood chiefly from the external carotids, and also from the vertebral arteries; and afterwards they send it either into the bony substance of the cranium, or even into the external periosteum, or finally into the sinuses of the dura mater. It is worthy of remark that the cerebrum and the pia mater seem to share their blood only most prudently and cautiously with the dura mater, and *vice versa*, and dare to do it only in some places, near the outermost parts, and especially near the sinuses themselves. The carotids are born from the ascending arch of the aorta; the right chiefly from [the lower part of] the subclavian artery [called the innominate artery]; and both trunks, like a pine without knots, rise in freedom on high, near the sides of the trachea and the larynx. Finally, near the foramen, where the sympathetic nerve either departs or enters, they divide into the external and internal carotids. The former of these is nearer to the larynx which it irrigates, and around the integuments of the external head and of the muscles it breaks up into larger and smaller branches; thence it is everywhere most thoroughly distributed into the substance of the bones, their medulla, sinuses, and cavities. After the internal carotid has entered the cranial cavity through the carotid foramen, it sends off a certain little branch into the dura mater; but the trunk twists

itself in its whole volume into the receptacles of the sella turcica, or into the cavernous sinuses, and there sends off into the dura mater a number of shoots like the threads in a spider's web, and even further towards the pituitary gland, and indeed in such a manner that they present the appearance of a net—this, however, is different in the brains of different animals. Some also maintain that near the orbits a branch is deflected from the internal carotid into the dura mater. The vertebral arteries act in a similar manner, where through the foramen magnum they ascend into the medulla oblongata and into the cerebellum; for on entering they send one or several branches into the dura mater. These are said to be the principal arteries which out of the lower region of the occiput press into this membrane. The principal artery of the dura mater, however, is derived from the external carotid through the foramen spinosum of the sphenoid bone; this also originates sometimes from one of the three branches of the internal maxillary artery. This principal artery of the dura mater, as it is called, occupies its middle region, and at a short distance from its origin is divided into three considerable branches; the largest and middle of which bends in an oblique direction towards the straight or fourth sinus, or where the longitudinal coalesces with the lateral sinuses, and by degrees in its oblique descent or ascent it is diminished and obliterated. By shoots which are sent out in every direction, it, nevertheless, communicates with the second branch, and also with the third; as may be seen in the plate of Ruysch,[1] where the infantile cranium is exhibited with a drawing of the arteries of the dura mater. As this branch in an oblique direction tends towards the longitudinal sinus, it applies itself by a moderate inclination to its side, and seeks then in a straighter direction the region of the above-mentioned torcular (straight sinus). The second or lower branch of the same trunk, almost immediately from its starting-point, flows in a still more oblique direction towards the lateral sinuses, and communicates with

[1] "Thesaurus Anatomicus Quintus," Amsterdam, 1705, plate ii. fig. 3.

the above branch. The third or higher branch of this trunk runs away from the first branch under the parietal bones to a small distance from the place of the fontanelle; and under the coronal suture bends upwards, and being thus inclined under the frontal bone it is carried upwards; in that region it is obliterated by throwing out shoots. All these branches, however, intercommunicate with one another by little branches. They flow differently, indeed, in one subject from what they do in another; and they run out and communicate in a different manner over one hemisphere of the same cerebrum from what they do over the other. This is the artery which leaves impressions of itself on the parietal bones, the anterior, lower angle of which impressions, according to Winslow, exhibits a considerable groove.

215. All these arteries, as said above, intercommunicate, so that no artery having the way opened only by one foramen should so be deprived of blood and become tendinous; just as it is in the case of the pia mater and the cerebrum, as we shall see hereafter. The arteries of one hemisphere also cross over the longitudinal sinus into the other hemisphere, and commingle their liquids. Besides, they, or their veins, as I believe, insinuate themselves into the falciform process and into the tentorium. Hence also, as may be seen in the table of Ruysch mentioned above, some arteries seem to arise which run along the length of the suture, and even of the fontanelle. As these arteries occupy the place between the two laminæ of the dura mater, this membrane, according to Ridley, acts the part of a valve, especially in the falx, on which account the fibres cross each other in an infinite number of places; and thus by a kind of compression, when each lamina is moved and pulled, the blood is forced out towards its exits.

216. The arteries of the dura mater are not like those of the body in discharging their contents into veins which afterwards increase into a trunk; but arterious vessels run forwards, as it were, towards their exits. The exits are not open for them in the same way as entrances. Sometimes, how-

ever, apertures (foramina) are discovered engraven in the parietal bones in the angles of the lambdoidal suture where the sagittal suture terminates; sometimes there are two, sometimes only one, and in some subjects there is none. When they are present, then sometimes they lead the blood which is sent out there, into the pericranium, and perhaps mingle it with the venous blood of the external head. There is also a foramen, and sometimes there are two, near the foramen magnum of the occiput; and sometimes there is only one on either side, frequently, however, none; but when these foramina [the condyloid] are open, then some vertebral vein is carried out; thither also some blood of the dura mater of this region seems to be transmitted. The principal venous or expiratory ducts, however, are near the coronal, the sagittal, and the lambdoidal sutures, where the blood penetrates through the cranium in innumerable places; for thither are carried not only membranous tubuli and tendinous cords, but also little blood-vessels, as appears when they are separated from the cranium. These penetrate chiefly into the bony substance, partly into the exterior table, and partly they pass through both tables into the external periosteum; and when these little channels are all taken together, they are equivalent to one large trunk. Their transit is more free when the sutures with the intervening passages are more widely open, as in infancy, and also when the bones for other reasons are further apart. The ratio also of the discharge of the blood around the sella turcica under the pituitary gland does not differ; there too filaments of blood-vessels lead into the sphenoidal sinuses, as they do in other places besides.

217. The greater part of the blood, however, is discharged into the sinuses of the dura mater themselves, that is, into the longitudinal and lateral sinuses; for ducts are open which are continued even into the walls of the sinuses. According to *Winslow*, however, they do not immediately penetrate into the sinuses. "The apertures into the sinuses," he says, "are the orifices of veins, the smallest of which are for the veins of the

dura mater, and the larger ones for those of the cerebrum."[1] "Hitherto," he adds, "it has been commonly believed that the arteries of the dura mater discharge immediately into the sinuses, because injections of liquids and inflations, or a hog's bristle thrust into them, have been found to pass into these sinuses. But on a more close examination it has been discovered that the injections pass from the arteries into the veins, and from thence into the sinuses through the small orifices already mentioned; and that the hog's bristle has pierced the sides of the artery, which near the sinuses are very thin."[2] He continues: "This mistake gave rise to another, that the dura mater had no veins; but the arteries of the dura mater cover the veins so entirely that the edges of the veins are hardly perceivable on either side of the arteries. There are, however, some places where the veins being broader than the arteries, their two edges are seen on each side of the arteries like capillary vessels. These veins, for the most part, are branches of the sinuses, and the small trunks of some of them open into the internal jugular vein. We may easily be satisfied that the arteries on both sides of the dura mater communicate with each other above the large sinus of the falx."[3] As, therefore, a great part of the blood, especially when the vascular fibres under the sutures become tendinous, by chance insinuates itself into the processes of the dura mater, it follows that the arteries transmit also some blood by that way into the inferior longitudinal sinus, and likewise into the superior and inferior lateral sinuses. The experience of future ages will perhaps collect information respecting additional places for the discharge of the blood from the arteries.

218. VIEUSSENS.[4]—Four shoots of the carotids, namely, two on each side, pass into the dura mater. The two thicker ones, after entering into the cranial cavity through the sixth pair of

[1] "Exposition," etc., section x. no. 35.
[2] *Ibid.* section x. no. 36.
[3] *Ibid.* section x. no. 37.
[4] "Neurographia," etc., lib. i. cap. vi.

its foramina, insinuate themselves first of all between the double membrane of the dura mater itself; and after dividing into many branches, they irrigate almost the whole of it. The two smaller arteries which irrigate the anterior part of the dura mater penetrate both laminæ of the membrane. They are produced from the carotids, while they are still concealed in the fourth pair of foramina drilled into the base of the cranium; and after having advanced on both sides towards the anterior portion of the membrane, they are divided into many shoots, which are inserted almost exclusively into that part of the dura mater which embraces with its circumference the front part of the base of the cerebrum. As to the venous offshoots which accompany the arteries that have thus far been described, they terminate in the internal jugular veins, and into their cavities they discharge the blood which they carry away. . . . Two branches of the vertebral arteries which are attended by veins terminating in the vertebral veins, furnish the posterior part of the dura mater with blood" (pp. 30, 31).

219. RIDLEY.[1]—"The arteries belonging to the dura mater are three branches on each side. The first and foremost of which are sent out from the carotid artery, whilst it remains in the fourth foramen of the cranium, and are propagated chiefly through the anterior part of the bottom of the dura mater. Dr. Willis was mistaken in describing it as a small branch of the carotid artery that runs between the two first lobes of the cerebrum, which instead of coming out of the os frontis, as he would have it, goes into it without lending any branches to this membrane at all. . . . The second branch of arteries ascends into the dura mater by the sixth foramen of the cranium, together with a branch of the internal jugular vein, and is dispersed laterally all over the anterior portion of this membrane, as far as the longitudinal sinus, which, however, it does not enter. The third branch of arteries climbs into the dura mater by the eighth foramen of the cranial cavity, together with a small reductory branch of the vertebral vein, where the lateral sinuses enter the internal

[1] "The Anatomy of the Brain," etc., chap. iii.

jugular, and the eighth pair of nerves passes out of the cranium; which passage of this artery is not hitherto described by any author that I know of. . . . It arises from the external branches of the vertebral artery according to Vieussens, but Bartholin makes it to be a slip of the carotid artery, calling it the lesser branch thereof. As to the veins, Riolan, and after him Willis, seem to say this membrane has none. . . . Vieussens indeed allows veins to this part, and says that they all along accompany the arteries, and afterwards terminate, according to Vesling, in the internal jugular; on which subject he afterwards discusses in a different manner" (pp. 20-23). In our author's second plate there are sketched minute ramifications of arteries; one around the crista galli, which it encompasses from below like a tiara, spreading out towards its upper portion. In the description of the plate he also mentions three arteries in this region, besides the two frontal ones.

220. BOERHAAVE.[1]—"What other blood is sent into the cranium belongs to the dura mater of the cerebrum and cerebellum, and is brought thither chiefly by two arteries which spring from the external carotids and enter each through a distinct foramen into the cranial cavity, distributing themselves laterally. To these add the branches which come from the internal carotids, through their canalis osseus, and spread themselves on the anterior part of the dura mater, with those from the external vertebrals, entering through the bony duct of the jugulars, and expanding themselves on the back-part of the dura mater; all of which has been demonstrated by the accurate repletion of these vessels with wax injection, by [J. Jac.] Rau, who was well versed in that artifice. On account of these arteries the dura mater is furnished with strong fibres next the cerebrum, to break off and sustain the impulse of the blood in its arteries, and protect the cerebrum against it. Lastly, from the whole of this membraneous cavity is exhaled a kind of serous or lymphatic dew to prevent its adhering to the pia mater (no. 234). The dura mater, the internal periosteum of

[1] "Institutiones Medicæ," etc.

the cranium, is the basis in which these arteries are disposed in an orderly manner, and from whence they insert their small twigs into the bones themselves of the cranium, upon which they are every way spent in very minute branches. But these small arteries being distributed between the thin bony plates of the cranium, meet with others from the pericranium, and form with them very fine plexuses, by which the nutrition, warmth, and secretion of medulla in the diploë, with the growth of the bony cranium in proportion to the increase of its contained parts, are all performed; but having accomplished this, the blood speedily returns by the veins" (no. 304).

221. J. F. CASSEBOHM.[1]—"Not far from the conjunction with the squamous lamina of the petrous part the dura mater has in infancy a foramen, through which a branch of the artery that cares for this membrane is carried to the substance of the bone; of this in adult age not a vestige remains."

222. It must be added here that the arteries of the dura mater, which run over the hemispheres of the cerebellum in a forward direction, direct their course also towards the torcular Herophili or the straight sinus; for they have relation to this with their last branches, as may be seen in Vieussens' figures and in Cowper's anatomical plates.

G. *The Connection of the Dura Mater with the Pia Mater and the Cerebrum underneath.*

223. The connection is chiefly established in four cardinal places; namely, in the middle of the occipital bone, where all the upper sinuses of the brain, as well as the straight sinus which proceeds from the lower part of the organ, meet together. Here as many little grooves as there are sinuses are engraven on the occipital bone; and to these passages the dura mater is attached, and at the same time it holds the straight sinus suspended from all sides, and thus the cerebrum as far as the pineal gland, nay, even farther by means of plexuses and con-

[1] "De Aure Humana," Hallæ, 1734, 1735.

tinued membranes. On the opposite side around the pituitary gland the dura mater is also connected with the pia mater, and through the medium of this gland with the medullary substance of the brain. In the anterior part near the crista galli and the lamina cribrosa, into which both the dura and the pia mater enter, a connection is effected with the fibres of the olfactory nerves. In a general way, however, there is a connection in the foramen magnum of the occipital bone, where the dura mater in front is most closely bound together with the pia mater, under which the medullary appendage is transmitted into the vertebral cavity. Where the dura mater through its processes lets itself down into the cerebrum, or between its hemispheres, there is also a certain perpetual conjunction of the dura mater with the pia mater by means of ligamentous, membranaceous, and minute tendinous cords, as well as by vessels; yet in such a manner that by virtue of their elasticity it is able to approach and to recede. Besides, on the bottom of the cranial cavity the dura mater is connected with the pia mater by means of certain muscular tissues in all those foramina, through which the nerves with a portion of the medullary part of the cerebrum, the cerebellum, and the medulla oblongata take their departure. To this must be added that the dura mater by the falx cerebri enters deeply between the two hemispheres, as far as the corpus callosum, and thus unites itself to the cerebrum. In a similar manner it enters between the cerebrum and the cerebellum as far as the medulla oblongata, and thence on both sides towards the opposite side, or the sella turcica. In the remaining places the dura mater is unconnected with the pia mater, in order that the cerebrum may expand freely in every direction, and more freely under the parietal and the frontal bones, where it is more deeply furrowed into lobes.

H. *Appendix.*

224. By way of an appendix I shall quote from Baglivi's work, "De Fibra Motrice,"[1] as follows: "On examining the dura

[1] Georgii Baglivii "Opera Omnia Medico-Practica," etc., edit nona, Lugduni, 1733.

mater, we scarcely venture to assert that the motion of the heart depends upon its motion, and that the heart itself is subject to it in every way. After making a large number of experiments upon the brain and the dura mater, Pacchioni often asserted that the dura mater is not a simple membranous web, but is composed of three different orders of filaments, of which one is spread most skilfully over the other, and which mutually intersect one another; and also that one of these orders is observed on its convex part, and the remaining two on its concave part. Besides, in the internal or concave part which covers immediately the cerebrum and the cerebellum, the dura mater is furnished with some fibrous muscles, very strong and solid, which extend into various parts of it, especially to the sides, and the anterior and posterior parts of the falx; all the orders of the fibres also terminate in the tentorium by which the cerebrum is separated from the cerebellum, and also in the other larger process by which the brain is bisected. This whole series of fibres and muscles in man differs very much from that in brutes, in whom it is distinguished with greater difficulty (pp. 272, 273). . . . After considering, therefore, in the dura mater this particular structure of fibres and muscles, the whole of which, like the fibres of the heart, seems to have been formed for the purpose of contracting and of exerting a pressure; and likewise its sinuses, cavities, and the manner in which it embraces the brain and exerts a pressure upon it, it follows that with a certain degree of justice it can be called the heart of the brain; composed of membranous villi; which villi, on crisping up and contracting, exert a pressure and constrict everything with which they come into contact; and on this account we call it the heart of the brain with a greater degree of justice than Mayow applied this term to the diaphragm (p. 273). . . . The dura mater effects these strong and regular motions not by the arteries which are disseminated through it, but by its illustrious texture, in which it competes with the structure of the heart" (p. 274).

I. *Falx Cerebri or Falx Major.*

225. The falx cerebri of the dura mater is also called the first or falciform or longitudinal process, and likewise the septum sagittale, vertebrale, suspensorium, or mediastinum cerebri, or simply the falx and the falx messoria. It extends from the crista galli to the middle of the occiput. Thus under the sagittal suture the dura mater holds the longitudinal sinus in suspension, and it thence lets itself down into the cerebrum between the hemispheres, as far as the corpus callosum; there also it holds in suspension a certain longitudinal sinus, called the inferior, which sometimes is inserted into its duplicature. From its origin it gradually increases in thickness and height until it reaches the region of the straight sinus; there it is united obliquely and in a lateral extension with the tentorium which separates the cerebrum from the cerebellum, or it is continued by it, for all processes of the dura mater are properly one continuous process. The interior lamina of the membrane on both sides concurs in the formation of this process, and applies itself to it, wherefore the sinus and veins are said to be contained within its duplicature. The superior or exterior lamina, however, spreads over the above-mentioned sinus, and is continued into that of the opposite side.

It starts from a certain small foramen between the crista frontalis and the crista galli, where in some subjects there is the appearance of a kind of septum. In the crista frontalis itself throughout its length there is a fissure for the reception of the beginnings of the falx, and this is continued further. "A fissure or groove of this kind," says Morgagni, "I have seen only twice or three times; in other cases I saw a groove across the ridge, but not so narrow; and at another time I saw it in the form of a circular foramen; most frequently, however, I perceived no depression whatever in this process, but in the interstice between this crista and the so-called crista galli there was a circular foramen, and sometimes a square, but not of a very large size. These things, however, nature appointed rather for the conveyance of blood-vessels than for the reception of the apex of the falx. For although a part of it in the shape of an exceedingly small cone often enters into the foramen, yet is it torn out thence easily and without applying any force, while the remaining part of the beginning of the same falx adheres closely enough, partly to the crista itself, and partly to the osseous lamina into which it is produced backwards; nor is the falx contracted at the basis of the cranium into a very narrow apex; nay, in some cases it is still so ample that in the form of a considerable and firm septum at a comparatively small distance it cleaves the olfactory nerves, and the anterior part of the hemispheres of the cerebrum." [1]

226. Thence the falx follows an upward direction to the so-called torcular Herophili, or the confluence of sinuses, where it unites itself with the tentorium or transverse septum. Ridley says: "The first process (falx cerebri) arises from the crista galli, and is extended from thence backwards as far as the concourse of the four sinuses, commonly called torcular Herophili. . . . It has strict connection by certain membranous fibres with the cranium in those places which are immediately under the sutures and with the brain itself, by the intervention of the pia mater, to which it is joined by the intervention of large blood-vessels, propagated thence to the longitudinal and lateral sinuses, and by certain carnous growths, as it descends between the two hemispheres of the cerebrum, and afterwards at its approach to the back of the corpus callosum—over which that membrane is loosely expanded—both by continuity of its membranous substance, and by ramification of blood-vessels, terminating in the inferior longitudinal sinus. In fact, in a diseased brain I once saw it drawn up to the length of an inch from the said corpus callosum, in the exact form of a membranous thin production, continued to the inferior longitudinal sinus. . . . This part is wanting in many other creatures, as calves, sheep, etc."[2]

[1] "Adversaria Anatomica, vi., Leyden, 1740, p. 38.

[2] "Anatomy of the Brain," London, 1695, pp. 7-9.

227. Vieussens.[1]—"From the region of the sagittal and lambdoidal sutures the dura mater after being doubled up passes off into two thick processes; one of these, which is called falx, keeps apart the two hemispheres of the brain from their convex part down to the corpus callosum, and extends from the middle of the occiput to the anterior region of the occiput" (p. 5).

228. Pacchioni.[2]—"From a pointed beginning which is inserted near the crista galli, the falx, in shape a little arched, with a broader basis, and with its substance increasing in thickness, extends towards the centre of the tentorium above the straight sinus; there, where the beginning of the medulla oblongata emerges, a little cleft is noticed, in which an important branch from the choroid plexus terminates. The back of the falx is of considerable thickness; its lower tendinous end is thinner at the starting-point, yet it is more firm and broader at its base" (p. 137).

229. Winslow.[3]—"The falx extends along the sagittal suture to the middle of the tentorium; which it joins in such a manner that the lateral laminæ of the falx are continuous on each side with the neighbouring portions of the superior lamina of the tentorium. It is broader near this junction than near the ethmoid bone, and is thicker at that edge which adheres to the cranium than at the other which lies loose, and which is sharp, and from its resemblance to a scythe it received the name of falx. . . . The union or continuity of these two processes keeps them both very tense, so that they are able to sustain a considerable weight, and the falx is capable of resisting lateral pressures without giving way either to the right or to the left. We may be convinced of this reciprocal tension by first touching these two septa in their natural state; and again, after they have been cut one after the other in the direction of their breadth. . . . For as soon as the falx is cut, the tentorium will

[1] "Neurographia Universalis," etc., lib. i. cap. ii.
[2] *Opera*, etc., Epistolæ Physico-Anatomicæ.
[3] "Exposition," etc., section x.

be perceived immediately to have lost its tension and firmness; and the same thing will be observed in the falx as soon as the tentorium is cut" (nos. 13, 14, 17, 18).

230. The fibres which run through the falx flow in a different order from what they do in the dura mater, which is stretched out over the hemispheres of the cerebrum; yet, nevertheless, they preserve their affinity with these, and the two have mutual relation to each other. When, therefore, the fibres emerge from the falx, they spread in the direction described above. Ridley[1] says: "The fibres of the falx are of two sorts of orders; the one running straight about half the length of it, on its upper part, from before backwards; the other transverse, from the inferior longitudinal sinus to the superior, on the posterior part of the process, and are most conspicuous there, as the other are towards its anterior part." Pacchioni[2] says: "The texture of the falx is twofold. . . . Its interior (or posterior) face is covered with a dense arrangement of fibres running from the apex downwards to the base almost equally, and thus in parallel order from the back of the falx above to the edge of the falx below; and in this manner they extend to both sides of the tentorium, so that they penetrate into the other fibrous stratum of that process. It is strengthened thence by various transverse fibres, which leaving in the form of an arch the point where they are inserted, rise up on the back, yet scarcely pass beyond the middle; on the sides of the base, however, they are spread out in the form of a very thin tendon."

J. *The Tentorium.*

231. This is also called the second process of the dura mater, the septum transversale, the diaphragm of the cerebrum, the repagulum (cross-beam), the crepido, the tendo, and likewise the interseptum horizontale; but most frequently it is understood as the lateral processes, because it stretches out on both

[1] "Anatomy of the Brain," etc., chap. i. p. 4.
[2] *Opera*, etc., pp. 137, 139.

sides, and like two arms of the falx embraces the lowest portion of the cerebrum, and the highest of the cerebellum; for these two lateral processes near the straight sinus receive the falx which is above, and continue it. As the falx from the front, through the crown and following the course of the sagittal suture, extends into the occiput, so the tentorium spreads out at a right angle with it, first following the groove in the occipital bone of the lateral sinuses, and then further on towards the petrous processes; but below, beside the corpora quadrigemina or the isthmus of the ancients, around the medulla oblongata which it engirds, it tends by a shorter crossing or a more compendious route towards the same places, submitting itself almost horizontally to the cerebrum. It is in its way a most powerful bulwark, consisting rather of a fourfold than a twofold membrane, and thus furnishing a very strong couch and pavement for the superincumbent cerebrum, and at the same time a cover for the cerebellum which lies underneath; thus preventing one from impinging upon the other and inflicting injury upon it. Such, therefore, as is the external form of the cerebrum as far as the medulla oblongata, and such as is that of the cerebellum applying itself towards it, such also is the form of the tentorium. "For," according to Pacchioni,[1] "it has a double surface; namely, an upper, which serves as a support to the cerebrum, and another lower one which covers the cortex of the cerebellum. The former stretches from the occiput towards the front, and the latter is confined within the limits of the same occiput and the superior processes of the temporal bones." The latter, he says, is joined to the interior circumference of the cranium, to the sphenoid bone near the sella turcica, and the internal processes of the temporal bone; the remainder of its expanse is free and flexible. For it is fastened above, where in the meeting-place of three or four grooves in the occipital bone which sustains all the superior processes with their sinuses, the extremity of the falx terminates thus in a second focus, after having first closed in the boundaries

[1] *Opera*, etc., p. 142.

of both hemispheres of the cerebrum, and having consociated them with the stem of the medulla oblongata. Above, in the place just pointed out, in dogs, in the fox, cat, horse, and other animals, with the head inclined downwards, a certain bony partition is let down between these bodies, which is called the triangular bone, and which often reaches far down between the cerebrum and the cerebellum. By foramina skilfully wrought into it all the sinuses, according to Willis, pass through it; but in human crania there is a protuberance jutting out from the internal surface of the occipital bone. It must also be mentioned that these processes, both above and at the sides, around the temporal bones suffer themselves to be stretched and spread apart, as may be seen in Plate v. of Vieussens.[1] Such also is the case below; for as these processes advance onwards, they seem to divide as it were the inferior lobes of the cerebrum. (See Plate iv. *ibid.*[2]) But after they reach the actual base of the cranium they spread far between the very foramina of the auditory nerve, under the posterior clinoid process of the sphenoid bone, and at the same time send out on both sides small productions towards the sella turcica and its inferior wall, along these same clinoid processes. But on the sides, stretching out almost in a right angle towards the anterior clinoid processes, they receive the third and fourth pair of the nerves of the head almost within their sheath, and thus concur not only from below, but also from the sides, in the formation of the receptacles of the sella turcica, or of the cavernous sinuses. Besides, the tentorium, as if it were divided, reflects itself towards the temporal bones, and is appropriated by the cerebellum. (See Bianchi's table.[3])

232. WINSLOW.[4]—"The tentorium is fixed to the occipital bone along the grooves of the lateral sinuses, and those of the great angles of the petrous processes all the way to the posterior

1 "Neurographia," etc., p. 37.
2 *Ibid.* p. 36.
3 In Manget's "Theatrum Anatomicum," vol. i. p. 342, table v. *extra ordinem*, the explanation of which is contained in vol. ii. pp. 342-349.
4 "Exposition," etc., section x.

clinoid processes of the sphenoid bone. By this position it forms a sort of ceiled tent or level expanse, on the forepart of which there is a large opening almost of an oval shape. This septum divides the cranium into two cavities, one large or superior, and the other small or inferior, which communicate together by the great oval opening. It is formed by a particular fold of the internal lamina of the dura mater; and in the natural state is very tense, because of its union, or rather continuity, with the falx" (nos. 15, 16).

233. RIDLEY.[1]—"The tentorium, the second process of the dura mater, is that which arises so forwardly, as from the posterior process of the sphenoid bone. . . . It adheres all the way to the internal eminences of the temporal bones towards the lateral sinuses, by which means the cerebellum immediately, and all the parts from the beginning of the straight sinus, or the pineal gland to the last foramen of the cranium, that is, the stem of the medulla oblongata, with its appendices the corpora quadrigemina . . . together with the nerves proceeding out of it, are protected against any injurious pressure from the posterior parts of the cerebrum" (p. 9).

234. VIEUSSENS.[2]—"The tentorium, the second process of the dura mater, insinuates itself deeply between the cerebrum and the cerebellum, and with its body encompasses the whole upper portion of the cerebellum which is underneath the cerebrum, and thereby separates the hinder portion of both hemispheres of the cerebrum from the cerebellum. This process consists of strong, and to some extent of transverse fibres, and is much thicker than the falx, so that you might say that the dura mater is quadrupled in it" (p. 5).

235. PACCHIONI.[3]—"The shape of the tentorium in its circumference is the same as is represented by the whole internal oval cavity of the cranium, to the walls of which it is everywhere tenaciously affixed by innumerable fibres, which perforate

[1] "Anatomy of the Brain," etc., chap. i.

[2] "Neurographia," etc., lib. i. cap. ii.

[3] *Opera*, etc.

the cranium even exteriorly. It extends, however, quite from the occiput to the sides of the forehead, over the orbits of the eyes, and beyond the sella turcica, where it is cleft into two parts; for around the insertion of the falx it pervades interiorly the whole substance of the ethmoid bone, though this does not belong to the tentorium. This process is further perforated in its centre by a foramen which is imperfectly oval, and which has a very firm and tendinous border; this is placed around the beginning of the medulla oblongata, and through it that body is allowed to pass downwards. In the middle and posterior part of the tentorium is placed the basis of the falx cerebri, from which little muscles are sent out on both sides, but only into the surface; and hence it is that between the tentorium and the falx there is established a by no means insignificant connection" (p. 142). "The question now is, How great is the dimension of the tentorium? The whole of it is strengthened by innumerable, knotty little cords, which arise in the border of the semi-oval foramen in a beginning which is alike robust and knotty; by an insensible inflexion they extend as far as the hemispheres, so that with them they enjoy the greatest intercourse. Each of them is enriched by two, three, and sometimes even four knots or enlargements; and by means of these knots, which are very much like the ganglia of nerves, frequently, but unequally, one cord is attached to another, so that they are able to sustain any impetus, and at the same time any weight. If you industriously uncover with a needle the above-mentioned cords, you will find that they consist of numerous little ropes; which little ropes you will find twisted or platted like the hair of women when dressed, the little knots giving to it a very pretty appearance" (pp. 142, 143). "In other places the [fibres of the] two lateral portions of the tentorium originate in a delicate and sometimes double beginning in the sides of the hemispheres of the dura mater, between the first and second layer of fibres; and after they have gradually become stouter, they attach themselves to the walls of the temporal bone, and by degrees inclining downwards in an oblique direction, they are obliterated and become fixed between the lateral processes of the sphenoid bone, near the vaulted portion; while at the same time both wings of the tentorium at the very outset are fortified by transverse fibres from both fibrous layers of the dura mater" (p. 139).

K. *Falx Cerebelli or Falx Minor.*

236. This is also called the third process of the dura mater, or the processus spinosus or occipitalis, the septum occipitale, the tendo quartus, and caudex. It is likewise continuous with the two aforementioned processes, and runs down from the same place in the vaulted portion of the occiput, along the internal occipital crest or ridge, and the groove engraven into it, over the middle of the cerebellum, which is thereby likewise divided into two hemispheres. It consists of a duplicature of the dura mater, but is weaker than the other processes, and terminates at the edge of the foramen magnum.

237. Morgagni,[1] who first discovered its occipital sinus, says respecting it: "In the very middle and posterior part of the cranium, from the torcular Herophili to the foramen magnum of the occipital bone rises a bony process, which the dura mater embraces, and whence it is curved inwards into a process. In some cases this extends more forward, and in some less; and thereby the cerebellum is, as it were, divided into two hemispheres" (Animadversio, ii. p. 3).

238. Pacchioni.[2]—"The falx cerebelli (caudex) is the fourth tendo (process) of the dura mater, and is opposed to the falx cerebri. Its body is short, thick, and robust, and is composed of ligamentous cords mutually passing over one another. Its basis is wide, and is made firm by a strong insertion in the posterior margin of the foramen magnum of the cranium. Thence it goes upwards in a straight line almost under the straight sinus; where, being bent over the cerebellum, it is

[1] "Adversaria Anatomica Sexta," Leyden, 1740.

[2] *Opera*, etc., Romæ, 1741.

divided into oblong semicircular expansions, the exterior of which are large, but the interior gradually become smaller and more slender. In extending towards the border of the imperfectly oval foramen they occupy the greater part of the tentorium above the cerebellum. Lest, therefore, this wonderful texture should be weakened by very forcible efforts, immediately under the straight sinus it is distinguished henceforth by tendinous expansions, which like the transverse ligaments generated from the falx cerebelli, seem to cleave it as it were into two parts. What remains of the interior structure of this extense seems to me throughout its whole length to be a middle thing between fibres and little muscles; these have the same origin and progress as the falx cerebelli; they are spread asunder from the lower to the higher parts" (pp. 143, 144).

L. *Smaller Processes of the Dura Mater.*

239. There are to be added yet two small jugular or lateral plicatures, which bear some resemblance to processes; one of these is at either side of the sella turcica, stretching from the posterior clinoid process to the anterior clinoid process of the same side; and the other is underneath conjoining the two transversely.[1] By forming walls for the sella sphenoidalis these processes thus furnish fossæ for the pituitary gland and the receptacula cavernosa. These processes begin where the lateral extremities of the tentorium terminate at the base of the cranium.

240. There are also two others mentioned at either border of the sphenoidal fissure (or of the *fissura orbitalis superior*), where the dura mater is educed or produced so as to make the fossæ of the middle base of the cranium deeper. There are thus three larger, and four smaller duplicatures of the dura mater, which on account of being put forth by its interior lamina, according to Vieussens, may be called its internal productions.

[1] Diaphragma sellæ turcicæ, *Henle;* or operculum sellæ turcicæ, *Hyrtl.*—Editor.

M. *The Productions or Prolongations of the Dura Mater.*

241. The dura mater does not lie everywhere evenly spread out under the cranium, or above the convex surface of the cerebrum, cerebellum, and medulla oblongata; but where the bones either gape apart or subside, it extends into their fossæ, between their fringed edges, into the foramina, and into every interstice which deviates in the form of an eminence or a declivity from the smooth convexity of the brain, or the smooth concavity of the cranium. These extensions of the dura mater are called its productions. Among these the important production around the *foramen magnum* of the occiput, whose edge or border is invested by the dura mater, occupies that first place. This is, however, more closely attached to the pia mater around its anterior portion than around the lateral and posterior parts, so as to allow there a passage to serosities and phlegma. From the foramen magnum the dura mater encompasses the whole of the spinal cord down to the very os sacrum and coccyx. All the foramina of the cranial cavity, says Vieussens,[1] except the large one through which the spinal marrow descends, are completely closed up; for their edges are covered by dura mater, which adheres to them most firmly; and through them there is a passage either for vessels to which (whether they enter the cranial cavity or emerge thence) the dura mater adheres very closely, or to nerves encompassed by their vessels, concerning which every one knows that they are most closely embraced by the dura and pia mater, so that when any pituitous humour is collected in the cranial cavity no particle of it can escape outside by their means. The watery humours collected between the cerebrum and the pia mater cannot trickle down into the roots of the nerves of the spinal marrow, unless this delicate membrane is either corroded by their acridity, or burst by their excessive quantity, or finally, unless around the beginning of the spinal marrow it is distended beyond measure; for the tentorium on both sides encircles closely the stem of the

1 "Neurographia," lib. i. chap. iii. p. 13.

medulla oblongata. But the pituitous humour between the dura and pia mater may escape where these membranes embrace the cerebellum, and cause a species of hydrocephalus; and this is always attended by paralysis of those parts which are below the head: for this humour then descends into the cavity of the vertebral column, to which there is an easy approach, because the spinal marrow does not completely fill up the last foramen carved into the occipital bone, that is, the foramen magnum. To the dura mater lining the border of this foramen the spinal marrow adheres, through the mediation of the pia mater, only around its anterior edge, and on that account there is ample room between the internal surface of the dura mater and the posterior and lateral portions of the spinal marrow where this commences its descent into the vertebral column; there also is passage for a watery humour, as has been proved by experience. If most refined spirit of wine is poured on the anterior foveæ of the cranial cavity covered with dura mater, it is retained there for a considerable length of time in such a manner that not even the least drop escapes through the nose, for the fibrils of the first colligation of nerves which pass through the foramina wrought through the ethmoidal bone exactly fill up these foramina. Besides, if in a living dog the carotid arteries and the jugular veins are tied on both sides of the neck, and a saffron-coloured spirit of wine is injected into either carotid, until at last all the vessels of the brain are completely filled, and the liquid is pressed outside the vessels, so as to fill the entire cranial cavity—in that case, although during the whole of this experiment the pores of the parts of the head preserve their natural distention, not a drop of the injected liquid escapes from the cranium either through the nose or the palate.

242. The dura mater lines the edges of all the smaller foramina through which the nerves take their departure; these it either covers entirely, or it encloses and interpolates their branches and fascicles, and thus providing them with a sheath as it were conducts them outside the cranium. It also associates itself to a companion membrane, which occupies the

place of a pericranium around the skull. In our subsequent chapters it will be shown specifically how the dura mater is continued through the orifices of the lamina cribrosa into the nares; and how it is produced or prolonged through the sphenoidal fissure—the fissura orbitalis superior—through the temporal and zygomatic fossæ, through the spheno-maxillary fossa, and through all the remaining little foveæ and fissures which are worked into the bones for the nerves. It will also be shown in its proper place how the dura mater surrounds the pituitary gland in the sella turcica, which occupies there the most prominent position in the base of the cranium; likewise how the dura mater, like a window-pane, covers certain foramina cœca.

243. The dura mater also extends until it embraces some veins, as the jugular, and some arteries, as the carotid. These it introduces through open foramina, and afterwards passes them through vestibules and receptacles into the inner apartments, where it soon marries them to the finer membranes, nay, to the brain itself, and its constituent parts, and thus submits them to its rule.

244. HEISTER.[1]—"The internal foramina are as follows: The *first* is the congeries of the foramina of the ethmoidal bone, for the olfactory nerves. The *second* [or optic foramen] is in the sphenoidal bone, and gives passage to the optic nerves. The *third* is called the foramen lacerum orbitale, and transmits the third, fourth, and sixth nerves, and the ophthalmic branch of the fifth nerve, likewise blood-vessels. The *fourth* is in the sphenoid bone [the foramen rotundum], and gives passage to the superior maxillary division of the fifth nerve. The *fifth* [or foramen ovale] transmits the inferior maxillary division of the fifth nerve, and an artery of the dura mater [the middle meningeal artery entering in the spinous foramen close by]. The *sixth* [the small parietal foramen] admits an artery of the dura mater. The *seventh* is between the sella turcica and the petrous process or apophysis, and transmits no vessel, but is shut up by the dura mater; the carotid artery lies over it. The *eighth* is the

[1] "Compendium Anatomicum," vol. i.

carotid foramen. Through the *ninth*, which is in the temporal bone, passes the auditory nerve; through the *tenth* [the foramen jugulare or foramen lacerum posterius] pass the eighth nerve, and the lateral sinuses of the dura mater, together with the spinal [accessory] nerve. The *eleventh* is in the occipital bone [the anterior condylar foramen] for the ninth or hypoglossal nerve. This foramen is sometimes double" (no. 100).

[Modern Authors.

A. *Texture of the Dura Mater.*

244*a*. Cruveilhier.[1]—"The dura mater may be regarded as consisting of two very distinct fibrous layers: of an *external* or *periosteal layer*, which forms the internal periosteum of the bones of the cranium, and of an *internal* or *proper cerebral layer*, which though blended with the preceding throughout the greatest part of its extent, is separated from it at certain points, in order to form the fibrous canals which are called the *sinuses*, and also the several productions just described as being projected from the internal surface of the dura mater. Thus, the periosteal layer of the dura mater enters into and lines the longitudinal grooves, but the central layer passes off from it on either side; and the two laminæ thus formed by the right and left portions of the cerebral layer approach each other, so as to include between themselves and the periosteal layer lining the groove a long three-sided interval, which forms the *superior longitudinal sinus*. . . . The dura mater is evidently composed of fibrous, not, as was for a long time believed, of muscular tissue. It consists of fibres which interlace in various directions" (pp. 912, 913).

244*b*. Solly.[2]—"The dura mater consists of two layers . . . the external of which forms the internal periosteum of the bones of the skull. The separation between these two portions is perfect in the vertebral canal, though at the internal surface of the atlas the spinal dura mater and periosteum of the vertebral

[1] "Descriptive Anatomy," Engl. edit., London, 1842.
[2] "The Human Brain," etc., second edit., London, 1847.

canal meet together and adhere so as to exhibit in the skull the appearance of one membrane. Dr. Knox in the *Lancet* of the 19th October 1839, remarks that in some animals the vascularity of the external layer is very striking, as in certain Cetacea—the Rorqual, for example—where there is a perfectly distinct vascular layer between the dura mater, properly so called, and the calvarium" (p. 143).

244*c*. CAPPIE.[1]—"The circulation of the brain itself is almost entirely capillary. Its substance is penetrated by scarcely a single blood-vessel of size. Its arteries ramify external to the organ; and *in the dura mater they subdivide to such a degree as to convert that membrane into an extremely fine and close network.* . . . In like manner, the veins, which are seen disposed everywhere over the surface of the brain, and which are of considerable size, have their origin in vessels of extreme minuteness, which only unite after they have emerged from the nervous substance. Although this peculiarity is very striking, it does not appear to have received much attention, and so far as we are aware, no attempt has been made to assign to it a purpose" (p. 66).

244*d*. KEY AND RETZIUS.[2]—"The finer structure of the dura mater in general has been but little examined. Pacchioni, indeed, endeavoured to trace most minutely the fibrous fascicles of the dura, and to vindicate for it great peculiarities; nay, even to find in it a muscular structure. Since early times also that membrane has been searched for lymphatics. Nerves even have been discovered in it long ago, and its blood-vessels have been investigated since more minutely. But its fundamental tissue has been thus far studied but little (p. 155).

"As may be seen with the naked eye, and as has been generally acknowledged, the fibrous fascicles in the dura mater of the brain are chiefly arranged in two principal layers. Each of these principal layers, however, can be resolved into a number of thinner laminæ; for with a pair of tweezers, in many places,

[1] Cappie (James), M.D., "On the Encephalic Circulation and its Relation to the Physiology of the Brain," Edinburgh, 1859.

[2] "*Studien in der Anatomie des Nervensystems*," etc., vol. i., Stockholm, 1875.

quite a series of laminæ may be pulled off. These laminæ, indeed, are connected with one another by bundles of fibres passing from one into the other; yet often in such laminæ the cells remain in their proper position, and the preparations can be successfully used for a microscopical examination of the dura mater. The bundles of the *interior* principal layer are carried across the hemispheres in an antero-posterior direction, and at the same time from within to without. From the neighbourhood of the superior longitudinal sinus there radiates over the whole interior surface a layer of fascicles running in a more transverse direction; but this layer is somewhat scanty. It is these tracks of transverse fibres which, in the neighbourhood of the sinus, form a kind of 'cribration' of the dura mater, which will be described below. In the *exterior* layer of the dura mater the bundles of fibres are more interlaced; but their chief arrangement, nevertheless, is in a direction from without to within, and from the front towards the rear. They also follow other directions, crossing one another three or four times. The two principal layers, however, are most intimately conjoined by an interchange of fascicles, so that any separation of the two must be termed an artificial one. The chief mass of fibres in the falx cerebri radiates in the form of a parasol from the posterior and inferior angle which it forms with the tentorium cerebelli. In its upper part, near the longitudinal sinus on either side, there is spread over these radiating fibres a thin layer of bundles coming from its anterior extremity, which, however, stops before reaching the lower parts (p. 157).

"In the dura cerebralis of man we discovered, especially in some particular places, a peculiar kind of hollows or *lacunæ* which are perhaps of some importance. At all events, they are very remarkable from a histological point of view. On making a vertical section of a dura which has been well hardened in Müller's fluid or in alcohol, or still better in hyper-osmic acid—in the neighbourhood of the longitudinal sinus; and on magnifying the tissue, it is usually found more or less cribriform, that is, perforated by a system of hollows; the individual spaces of which are usually of the same shape and size, and are not filled by any organized substance, but by a clear liquid. Often this system of lacunæ is so copiously developed that the intervening partitions of the dura tissue appear like a mere thin trabecular system. In other places, again, the lacunæ are more scanty, and the dura tissue is more plentiful. They are in the exterior as well as in the middle layer of the dura, but more rarely in its interior layer. They are especially numerous in the portion which appears triangular in cross-sections, and which on either side forms the lateral walls of the longitudinal sinus; as well as farther towards the sides, and also above the sinus in its roof. . . . On examining the lacunæ under a higher magnifying power, it appears that generally they do not communicate directly, but are in mere juxtaposition; and often are separated only by thin partitions of connective tissue. Now and then, however, they are found to communicate openly; at times also several meet in one lacuna. Generally the fundamental form of these lacunæ is that of a circular or oval little bladder or hydatid which is drawn out into a point at both its extremities, so that in a longitudinal section they usually appear of a roundish or oval shape, but in cross sections of a round figure. . . . Sometimes two lacunæ are connected by their points by which they run into one another. . . . They are scattered in the connective tissue of the dura, and parallel with the longitudinal axis of the fibrous bundles of the dura. . . . After looking in vain in the interior of the lacunæ for a cellular covering, we succeeded in finding there a thin, elastic, little membrane. This membrane, which contains a large number of fine filaments, and therefore in cross-sections appears punctuated, is so closely attached to the wall of the lacuna, that it can be separated from it only with great difficulty. . . . The lacunæ occur in several places in the dura, but chiefly in the neighbourhood of the sinuses, and, indeed, in varying numbers. Hitherto we have discovered them only in man. Yet they occur not only in the neighbourhood of the longitudinal sinus, but also around the sinus transversus, where there may be a great number of them; as well as around the superior petrosal sinus" (pp. 166, 167).

244*e*. In respect to the blood-vessels of the dura mater, Messrs. Key and Retzius report that Boehm by a treatment with silver "obtained on the interior surface of the human dura mater a net of capillaries, similar to lymphatic vessels, which were in connection with veins; which capillary net is an appendage to the system of capillaries, a kind of accessory capillary system which in the direction of the interior, free surface of the dura mater is connected with intrafibrillary open spaces in its tissue, but which is charged with blood only exceptionally" (i. p. 156).

244*f*. Of Paschkewicz they report that "he found three layers in the dura; two exterior ones of considerable thickness, and an interior one which is thinner. Under treatment with silver he discovered on the interior surface a polygonal epithelium (perhaps of two strata) with stomata. He also found two nets of capillaries, of which one is superficial and the other lies more deeply embedded in the interior leaf, immediately under the epithelium. These two nets intercommunicate, and, besides, are connected with the veins, but not with the subdural space" (i. p. 156).

244*g*. From their own researches respecting the blood-vessels of the dura mater, we extract as follows: "The grosser arrangement of the blood-vessels of the dura mater has long since been treated in the text-books at sufficient length, so that we do not lose any time here in discussing them. In the dura spinalis the finer arrangement of these vessels does not offer anything in particular. . . . But in the dura cerebralis their arrangement is peculiar. For it is here that Boehm discovered the singular appendage-system of the blood-vessels, which ordinarily does not carry any blood. This system we have found to represent simply the peculiarly formed capillaries, together with the roots of the veins; for it is connected with the arteries as well as with the veins, and always carries blood. This system looks differently in different animals; with some it is composed of vessels which look like ordinary blood-vessels" (pp. 163, 156).

"On the *exterior* surface of the dura mater [which is turned towards the cranium] arterial branches are carried along in a serpentine fashion, accompanied on each side by veins, a little broader, which, with their interior boundary lines, accommodate themselves to the windings of the arteries. The arterial branches, and the veins together with them, divide in a dichotomous manner, and their twigs continue on the exterior surface in acute or right angles. The veins often communicate with other veins. The arteries also anastomose. On the *interior* surface of the dura is discovered another network of vessels, the meshes of which are usually oblong. Here and there, in the nodes of the meshes, there appear peculiar, ampullary enlargements of different sizes, which usually lie horizontally, and are of the shape of pears or clubs. These enlargements, as well as the fine capillaries themselves, in a natural state always carry blood. What is the relation of the interior to the exterior net? On carefully examining the preparations, it will be found that here and there delicate vessels in an oblique direction are carried through the dura mater from the arteries of the exterior system towards those of the interior system, pouring out their contents. These vessels are the communicating branches of the arteries, or the capillary arteries. In other places there are still larger expansions, the varying, fantastical forms of which cannot be easily described; but they may be studied in the accompanying illustrations. On examining these expansions or bags more closely, it appears that they usually occupy a transverse position in respect to the capillaries, of which they receive a number on each side; and then they pursue their course for a while on the surface; after which they dip in an oblique direction into the substance of the dura mater, in order, finally, to enter into a vein. These are the roots of the veins which connect the capillaries of the interior surface with the veins of the exterior surface. Here, then, we have the complete system of vessels before us. . . . In certain places, especially near the falx cerebri and the tentorium, the vessels are so numerous and closely crowded together, and at the same time so wide, that when they are filled with blood the tissue appears almost all red, and that only small interstices exist between the vessels. The wide roots of the veins are collected in large bundles, whence arise the larger branches" (i. p. 163).

244*h*. In addition to the networks of blood-vessels described above, Key and Retzius discovered in the dura mater also a peculiar system of little tubes carrying a kind of lymph, but unconnected with the lymphatic system of the body, and also with the subdural space within the cranium. On this subject they say: "On making injections by puncture, there are often filled in the tissue of the dura peculiarly formed *systems of little tubes.* Thus from the punctured place the injected fluid in this case shoots out in pencil-like forms which run in a parallel direction, and are in close proximity to one another. If, as happens usually, the injection penetrates into several layers of the dura, the tabular systems of the diverse layers cross one another in various angles in the direction of the fibrillæ. If the injection is very strong, the little tubes are so much crowded that the dural tissue can be scarcely perceived. The little tubes agree perfectly in their form with Bowman's 'corneal tubes.' Each tube is usually quite straight, and, as may be seen in vertical cuts, its shape is generally cylindrical, and it terminates in sharp points. Often also they become dissolved into a number of finer tubules, which either lie very closely together, or become separated from one another. In this case only a thin strip of the dura tissue is visible between the several tubules. Only rarely, however, they anastomose. As a matter of course the form and arrangement of these tubular systems depend necessarily upon the structure of the dura mater; that is, upon the arrangement of its fibrillary fascicles. The question now arises whether these spaces are naturally preformed, *i.e.* whether they are natural canals. It is indeed more than merely probable; nay, it is necessary that there should be real systems of lymph-canals (*Saftcanalsysteme*) in the dura mater. Besides the blood-vessels, the above are the only canals which can be demonstrated by methods of injection; therefore it is also highly probable that the above tubular systems represent the lymph-canals (*Saftcanäle*)," that is, canals or tubes conveying the cerebro-spinal liquid or the nervous juice. "The natural existence of these tubules receives a strong support from this circumstance, that under a very mild pressure a large system of them is filled by an injection of the blood-vessels of the dura. . . . If the injection, especially with Richardson's blue fluid, is carried further, the whole tissue is at last imbued by the fluid, so that the tubes can no longer be discerned. In this case the mass at last infuses also the fibrillary fascicles, *i.e.* it becomes interfibrillar (pp. 165, 166).

B. *Glandulæ Pacchioni.*

244*i*. Quain.[1]—"Upon the external surface of the dura mater, in the vicinity of the longitudinal sinus, are seen numerous small pulpy-looking elevations, generally collected into clusters, named glands of Pacchioni. The inner surface of the calvarium is marked by little pits, which receive these prominences. Similar excrescences are seen on the internal surface of the dura mater, and upon the pia mater on each side of the longitudinal sinus, and also projecting into the interior of that sinus. Occasionally they are found also in other situations.

"On a careful examination of the connections of these bodies, it will be found that the elevations found on the outer surface of the dura mater, and within the longitudinal sinus, in no instance take origin in those positions, but that they are grape-like bodies which are attached more deeply, and in their growth have perforated the dura mater. Their precise origin and nature were long the subject of conflicting opinions, but it has been satisfactorily shown by Luschka that they are only an enlarged condition of normal villi of the arachnoid, and that no other structure is involved in their formation. On each side of the sinus, and communicating with it, are large venous spaces in the dura mater; into these the villi project even in new-born animals, and those which perforate the dura mater and appear on the surface have their inner parts in such spaces. Each villus is covered by an epitheliated membrane, continuous with the

[1] "Elements of Anatomy," eighth edit., vol. ii., London, 1876.

arachnoid. Outside this is another fine membranous sheath, proceeding from the dura mater, and the interval between the two is continuous with the subdural space. Within the villus is a spongy trabecular tissue, continuous with the subarachnoid tissue, and of similar tissue" (pp. 575, 576).

244*j*. KEY AND RETZIUS.[1]—"On making a more minute examination of the arachnoidal villi (glandulæ Pacchioni), we discovered[2] on either side of the longitudinal sinus peculiar accessory sinuses or hollows, in which these villi lie concealed. These hollows or lacunæ (*sinus s. lacunæ laterales sinus superioris*) are irregular, and of a very varying figure, sometimes being triangular, square, or of a rhomboid shape. . . . Their walls, as in the case of all the other sinuses, are formed of the dura. They are often connected by broader or narrower passages; and by small, roundish, or fissure-like openings, very much like the mouths of veins, they terminate in the sinus longitudinalis. As this sinus by longitudinal partitions is here and there divided into several departments, the mouths of some of the lacunæ are not unfrequently hid by such partitions. The longitudinal axis of these lacunæ is usually directed more or less transversely towards the sinus. The other extremity of these lacunæ is generally pointed and directed outwards; a branch of the venæ meningeæ usually terminates in it. Trabeculæ, or cords, pass vertically or obliquely through the lacunæ, joining the roof with the bottom. Otherwise they are commonly filled with Pacchionian villi, nay, they teem with them. These villi occupy the spaces between the trabeculæ, and bathe freely in the percolating stream of blood. In general it may be stated that most of the villi have their seat and home in these very lacunæ, and that these lacunæ are chiefly intended for the Pacchionian villi. . . . These lacunæ filled with villi exist not only in adult persons, but they occur also in children, nay, in newly-born infants" (p. 179).

[1] "*Studien in der Anatomie des Nervensystems*," etc., vol. i., Stockholm 1875.

[2] "Nord. Med. Arkiv," vol. ii., 1870.

After describing minutely the structure of the arachnoidal villi, as stated above in the extract from Quain's "Anatomy," Messrs. Key and Retzius pass to the results which they obtained by injection. They say: "On making a *subarachnoidal* injection, under a very light pressure, the liquid penetrates through the subarachnoidal spaces of the brain, and through the meshes of the subarachnoidal trabecular system which is usually found in the neighbourhood of the arachnoidal villi, it passes through the trabecular meshes in the stems of the villi, into the villi themselves; and, indeed, without entering into the subdural space of the cerebrum. After arriving in the villi, it spreads through the meshes of their tissue with the same facility with which a sponge is filled [with water]. The meshes between the trabeculæ are thereby rendered tense, the villi are erected, and by the colour of the injected fluid appear tinged. The liquid, however, does not remain confined long within the limits of the trabecular system of the villi. On the contrary, it soon passes through the layer which constitutes their surface, and enters into the subdural space beyond. This also it fills and renders tense, as well as the dural sheath which encompasses the villi. Yet it does not remain even there, but flows through the dural sheath into the venous sinus or the lacuna without, in order in this manner to mix with the blood. . . . After arriving in the venous spaces, that is, in the sinuses and lacunæ, the injected liquid usually spreads through the finer blood-vessels of the dura. Very often also we found the venæ meningeæ and their branches more or less filled to a large extent. Often, however, and indeed chiefly, we obtained a copious injection of blood-vessels in the region of the dura which surrounds the longitudinal sinus and the lacunæ; especially in the roof of the sinus (p. 183).

"On the question of the function of the arachnoidal villi, we answer, their function is certainly to effect a junction between the serous spaces, that is, between the cerebro-spinal liquid of the brain, and the system of the blood" (p. 185).]

ANALYSES.

I.[1]

245. The brain is wrapped up in several coverings, like swaddling-clothes. The first is the cranium, of which we have already treated; the second is the dura mater, which we are now discussing; and the third is the pia mater. Each covering is divided into its tables—laminæ and membranes. The cranium is twofold, so is the dura mater, and likewise the pia mater; finally, under the latter the brain lies hidden.

246. In proportion as the coverings are more remote from the brain, in the same proportion do they differ from one another in excellency, *i.e.* in force, power, and perfection. The interior which are nearer to the brain, are in respect to every quality more perfect than the exterior and more remote; for they are more universal, purer, more elastic, more active, and more constant in their modes. The cranium is the last and outermost covering of the brain; it is general, thick, hard, inert, passive, and less elastic. The pia mater, however, is thin, soft, active, elastic, and the most universal of the three. The dura mater, on the other hand, holds a middle position, and is of a middle quality; it is more perfect than the one, and more imperfect than the other. Nature in its universal world, and in the kingdoms of its world, goes and returns, *i.e.* passes forth, through an order, which reigns sole in its degrees, in its dimensions, and in the modes flowing thence: hence it also reigns in the membranes in which the brain is wrapped and

[1] This analysis is taken from Codex 55, Photolithographed edition, p. 57. Another and later analysis is contained in Codex 58. As the two seem complementary of one another, we give both.—Editor.

rolled up. By following this order, and by having nature itself for our teacher, and experience for our guide, we shall be rightly instructed in those uses, and in the quality of those uses, to which the dura mater is subservient.

247. These same envelopes, in order that they may act separately, and at the same time conjointly, and that, nevertheless, the action of all may conspire into one—must consist of laminæ, which are united as well as distinct. The cranium consists of two tables, the dura mater of two orders of fibres, and the pia mater of two membranes, the upper one of which is called the arachnoid membrane. The membranes of the brain which are thus sundered are connected in a wonderful manner with one another; and each of them has respect at the same time to the external and internal states of the brain, and they feel in their own peculiar manner what is transacted everywhere. The external lamina of the dura mater applies itself to the internal table of the cranium; but the internal lamina is attached to the pia mater by membranous filaments, muscular bands, and vessels. Both, however, *i.e.* the two associated laminæ, are closely united by interlaced fibres and arteries flowing between them. The membranes which are subordinated in this manner are thus united for general and particular uses.

248. According to series and the order of succession, the membranes also distinguish from one another the smaller, larger, and largest parts of the brain; nay, even entire and whole organs; that is, they divide the cerebrum from the cerebellum, and both from the medulla oblongata. A certain most attenuated mater invests the [individual] cortical and medullary substances. Another, which is thicker, and woven of arterial capillaries and membranous filaments, covers clusters, tori, and fascicles of the same substances. The pia mater, however, invests entire congeries and convolutions. Its superior membrane, the arachnoid, does not enter the sulci and convolutions, but spreads out smoothly over them. The dura mater, on the other hand, separates the hemispheres, and divides the cerebrum from the cerebellum; it also encircles the

medulla oblongata, and passes into the opposite part of the cranium, thus serving general, but not particular, purposes. Its superior lamina applies itself to the cranium, and covers its fossæ, protuberances, and crests or ridges. The cranium, however, in a most general manner covers at the same time the cerebrum, the cerebellum, and the medulla oblongata; its exterior table does so in a more general way than the interior; for this passes off into processes, and begins to separate the enclosed masses. In this manner nature goes forward from its centres to its circumferences, from simple to compound, from purer to grosser, from most active and purely elastic to inert and passive things; or from its most minute forces, which are those of the cortex, to the general ones, which are those of the cranium.

249. Such as is the connection and communication of the membranes, such also is the fluxion and continuation of the motions which begin in the inmost parts of the cerebrum, that is, in the cortical substances, and terminate in the outermost parts of the brain, that is, in the cranium. The pia mater sustains, governs, and limits the particular motions of the brain; the dura mater the more general, and the cranium the most general ones. The motion itself is alternate, and is called the animatory and systaltic motion of the brain; it is conspicuous in the brain itself, and also in the membranes, but it is stopped, and expires in the cranium; a conatus of the parts towards motion nevertheless remains, and is represented there.

250. From the contiguity and connection of the pia mater and of the brain with the dura mater, it appears very manifestly how the dura mater is stirred and as it were drawn into motion. The cerebrum or its pia mater is contiguous to the dura mater in those places where this membrane in the form of a process descends between the two hemispheres, and also between the cerebrum and cerebellum, and where it swells into a sinus or trough; there are also muscular bands [*lacerti*] and ligamentous cords twisted in the form of muscular fibres, and likewise glands and vessels, by which both are connected.

Besides, the venous vessels of the brain cast themselves there in great number into the larger sinuses, and when they are filled and expanded, the dura mater in whose duplicature these sinuses lie cannot help being expanded and swollen in a similar manner; for its texture is continuous with the walls of these very sinuses. (Heister and Winslow, however, declare that the only connection between the two maters, or between the dura mater and the brain, is established by the veins; this will be examined in the Chapter on the Pia Mater.) This motion of the dura mater is called its *expansile motion*, and arises solely from the brain. The fact of this motion is proved by ocular demonstration, and is pointed out by its membranous texture, which both in the individual fibres and in general is elastic. The spaces between the dura mater and the brain in this covered region also confirm it. The mode in which this motion is caused seems also pointed out. When the brain expands, it folds up its clefts and interstices, and prevents the passage of the blood by the vessels into the sinuses; it likewise draws down and contracts the sinuses themselves. The effect, which is necessarily exerted thereby upon the whole circumference and the two laminæ of the dura mater, is plain. It follows hence that the dura mater in respect to this motion is passive; yet that by virtue of its elasticity, and in its capacity as a muscular tendon, it contributes in a general way to the reciprocal expansive motion of the brain.

251. It becomes necessary also to explore the form or the determination of the motion itself; for from its form motion derives the property of being constant, perpetual, and continuous of its own accord. Form, however, implies centres, radii, circumferences; all this is clearly pointed out by the vessels and fibres and their directions; for they are like so many radii or rays, and each of them is placed in the very stream of its motion, since they are unable to run counter to the general torrent. It is manifest that the expansive motion of the dura mater begins near the borders of the hemispheres and near the larger sinuses, and that it is continued thence on both

sides to the circumference; also that at a distance from its sources it becomes slower, and finally is obliterated. The most active beginning, or the general source, whence the motion spreads on all sides towards the circumference, seems to be in the confluence of the sinuses and the processes, or near the so-called torcular Herophili. For there the superior longitudinal, the two lateral, the occipital, and the straight sinuses, with the blood of the whole cerebrum, cerebellum, and medulla oblongata, flow together; strong cords similar to muscular tendons may be seen there, and at the same time papillary concretions; which may be curled up, folded together, unfolded, and accommodated to every determination of the motion.[1] Thither the fibres of the inferior lamina, after emerging from the falx into the hemispheres of the dura mater, inflect themselves, and in so doing describe a semicircular curve; thither also, as towards a common centre of motion, the arterial trunks of the dura mater, both those which cross the membrane of the cerebrum and the membrane of the cerebellum, direct their course. Besides this general fountain-head of motion, there are also innumerable particular, and so to say least springs, along the whole extent of the sinuses; but they are less important in proportion to their distance from the chief source. The very ligamentary fibres and muscular bands which emerge into the hemispheres of the membrane in an oblique direction, and also the veins which likewise enter into the sinuses in an oblique direction, demonstrate by their certain direction the same course, and consequently the same form, of motion. These are the sources or origins, but the circus or campus of the motion is the whole circumference of the membrane; the termini or goals of the motion, however, which may also be styled centres of rest, must be sought for at some distance thence. Of these there are as many as there are foramina in the superior, anterior, and inferior parts of the cranium, through which the nerves and veins pass out, and the arteries enter; for rest is

[1] Swedenborg speaks here of the *glandulæ Pacchioni*. Concerning their use and function, see footnote on p. 252.—EDITOR.

required there, the fibres retaining a mere conatus of action, the tendency of which lies in a similar direction. There are, however, general and particular termini; the former are those of the whole cranium, the other those of its particular bones. There are two general termini of the motion of the dura mater which is spread out over the cerebrum, namely, near the two orbits, where several nerves emerge, and the chief artery of the dura mater enters through a foramen called the lacerum orbitale. The general termini of the motion of the same mater as spread out over the cerebellum, and separated from that of the cerebrum by the tentorium, are also two; namely, near the so-called carotid foramina, or where the carotid arteries and the sympathetic nerves are transmitted—for the very excursions or hemispheres of the dura mater by the intervention of the falciform processes and the tentorium represent a certain triangular form; and if from the beginnings of motion we draw continuous diameters and diagonals, they coincide in these centres, as in their ultimate termini. The centres of the processes and of the sinuses, however, are different from those of the membrane itself; for the dura mater changes its determinations when it dips down between the hemispheres and the two brains. The common centre of all the processes, as well as of all the sinuses, or the fountain-head of their motions, is likewise in the middle of that terminus or confluence which has been mentioned above; but the ultimate terminus of the motion of the longitudinal sinus, and also of the falx cerebri, is that small foramen cœcum between the crista frontalis and the crista galli; for all the fibres of the falx, as so many determinations of its motion, emanate thence and tend thither. But the termini of the motion of the tentorium and of the lateral sinuses are near those fossæ in the temporal bone where the jugular veins, together with the eighth pair of nerves or the par vagum, and the spinal nerve pass out; for thither the processes of the tentorium incline, and as it were fatigued by the journey, rest in their ultimate goal. The most general of all centres, however, is the centre of rest in the middle of the sella turcica, where the pituitary gland encompassed by the carotid arteries and several nerves has its seat. The circumferences of the dura mater converge there from their particular centres both in general and in particular; the processes of the tentorium also are continued thither, and they fold themselves again around the clinoid processes, so as to form minute septa which are concentrated in the middle of the sella. If, however, I were to enter into all these particulars, I should need for this purpose a whole volume. Suffice it to say that it is a constant verity, that the more perfect forms of motion have innumerable centres; and that in the most perfect form, where motion flows to every point and determines the form, a centre of motion is represented in every one of these points whether they be in the radii or in the circumferences: as will be seen below in the Doctrine of Forms. [Part II. chap. ii.]

252. Thus far we have spoken of the expansive motion of the dura mater, or of the circulatory motion of the brain through the circumference of its meninx or membrane. Besides this, there is also another motion peculiar to the dura mater, which is excited by its own arteries, and this is called its *pulsatile* motion. For the arteries insinuate themselves from the external carotid through different foramina, and they pour themselves out, and are ramified over, the whole circumference of the membrane; and finally, they determine themselves towards the superior lamina, and discharge themselves through little openings in the sutures, through foramina in the parietal and occipital bones; and their contents are added either to the blood which courses through the bony substances, or to the blood of the external head, or of the pericranium. The arterial blood of the dura mater passes from one hemisphere into the other by crossing the sinuses, and near the bregma or fontanelle its vessels are crowded together, which is the reason that this place is called the pulsatile fountain or fontanelle, and is long kept open after birth. This motion is distinctly felt with the fingers in infants.

253. These two motions are most distinct, and originate from

different beginnings; that is, the expansive motion arises from the motion of the brain, and the pulsatile motion from that of the heart. Great care is taken that these two motions should also continue distinct; for every artery of the dura mater is introduced by special foramina from the external carotid or its branches, and communicates with the arteries of the brain, which arise from the internal carotid and the vertebral arteries, only in a most cautious and prudent manner in the processes or duplicatures of the dura mater. The former occupy chiefly the external lamina of the membrane, and the latter the internal, but only in the processes and in the falx. The former also discharge their blood into the cavities of the cranium and into the external periosteum, but the latter empty theirs into the sinuses, so that the superior lamina of the dura mater is chiefly dedicated to the pulsatile motion: but the interior to the expansive motion; yet these two intercommunicate in a wonderful manner; for the superior lamina is connected with the inferior by inserted fibres, and the very arteries with their branches run through both.

254. The cause of this phenòmenon cannot be sought for in any other circumstance than in the diversity of the motions of the brain and of the heart. That the motion of the brain coincides with the respiratory movements of the lungs, but not with the alternate motion of the heart, has been shown elsewhere;[1] for if they coincided, all the blood of the brain, and at the same time of the dura mater, would be discharged either into the sinuses, or into the bones of the cranium, and thus one of the two would be deprived of its life. Although there is a discrepancy between the periods of the expansive and the pulsatile motions of the dura mater, yet in one and the same plane they agree wonderfully; just as is the case with the pulmonary and cardiac motions in most membranes and envelopes of the body, as in the diaphragm, the mediastinum, the pleura, the pericardium, and everywhere in other places—why then should this not be so in the dura mater, the common mother of

[1] In Part I. chap. ii.—EDITOR.

membranes? On this account the dura mater is the uniting medium of the motions of the brain and of the heart; for where it has respect to the cerebrum it belongs to the cerebrum, and where it has respect to the cranium it belongs to the heart, *i.e.* to the body.

255. In the embryo, however, or in the fœtus before birth, the motions of the brain and the heart coincide; for the heart lives then constantly under the auspices of its brain, and both then conspire in the production of the general effect, that is, in the formation of the tender body; nor are the lungs then opened. In this state the dura mater being distended with an abundance of blood, acts one and the same cause with the brain and the heart; but this state is similar to one of perpetual sleep. The organs lack sensibility, and the muscles are deprived of a particular activity and determination agreeing with the arbitraments of the mind. The more distinctly, therefore, these twin motions of expansion and pulsation thrive in the dura mater, the more distinctly present is life in the organs of sense and of motion. But when the man verges towards old age the state of this membrane begins to change; for being gradually deprived of its blood, it grows pale and flaccid, and its connection with the cranium and the brain is beginning to be dissolved. Then its motions also become indistinct; the expansive motion or that of the brain remains, but it is irregular, and the pulsatile motion, or that of the heart, is obscured. Thence results an impotence of feeling and acting, and by degrees the kingdom of the heart collapses, or the life of the body closes.

256. In order that the distinction, communication, and condition of both motions may continue in a state of integrity, the arterial blood is introduced into this membrane by several foramina, with at the same time an abundant supply of nerves to accompany, construct, and reconstruct the muscular coatings of the arteries; for wherever there is an artery, there also is a nerve, and the former exists and subsists by the fibres of the latter. Besides, it has also been provided that the vessels of this membrane should pass from one hemisphere into the other

over the roof of the sinuses; and that there should be a constant communication between them, so that there should be no blood in one branch which is not common to the other; wherever, therefore, an artery flows, it can draw for the supply which it needs upon the rest whether they be neighbouring or distant. The inferior lamina also serves the purpose of a general valve; for the fibres of both cross one another, and between them run the arteries. If now the brain puts its dura mater on the stretch, the blood is urged into the upper lamina, and that which it is unable to hold is propelled towards the larger sinuses, where it mingles with the blood which is peculiar to the brain. In this wise all emergencies are cared for, and one motion is subservient to the other, or the expansile motion to the pulsatile, and *vice versa.* Besides in a diseased, or in an unnatural state, and also in old age, the ligamentary fibres and the muscular bands are dried up, and the Pacchionian glands become attached to them in the form of muscular grains, in order that the connection and the contiguity of the brain with its membrane may be preserved; for nature by a thousand similar modes makes up deficiencies and restores continuity.

257. Thus far we have treated of the functions and the use of the dura mater: now we shall say something respecting its origin. Its origin, however, is difficult to explain on account of the dearth of experimental knowledge; conjecture must supply it. We are obliged to believe that in its production vessels and fibres of the brain, as well as vessels and fibres of the body, distinctly concur. The venous vessels of the interior brain flow together towards their common sinus, namely, the straight sinus, and they form together its coating; this coating is continued into the interior lamina of the dura mater. The venous vessels of the exterior cerebrum and cerebellum, however, in like manner flow together in their sinuses, that is, in the superior longitudinal and lateral sinuses, and thus from their coatings are continued into the membranous coating of the dura mater; to these are added fibres of the cerebrum and cerebellum, which here and there emerge into this membrane. This seems to be its primitive

origin, and indeed that of its internal lamina; and as it is thus, in the first place, organized of venous offshoots, it seems to have acquired thereby a passive force and quality. But after the beginnings of the heart have been established, arterial vessels are also sent thither by the carotids; these spread themselves over the venous vessels of the brain, and weave the external lamina of the dura mater. To these are also added fibres from the body, or corporeal fibres, which will be discussed in their proper place;[1] these enter into the structure of the dura mater along the vaginal coating of the spinal marrow. In this manner this double membrane from its first formation is inaugurated, and thus is accustomed to lend its services both to the brain and the heart.

II.[2]

258. *The dura mater is the middle envelope by which the brain is enclosed, limited, and divided.* The last envelope is the cranium itself, the internal the pia mater, and the middle the dura mater. As the cranium is in respect to the dura mater, so this is in respect to the pia mater, in reference to density, elasticity, and generalness. Each of these is distinguished into two laminæ. The external is more general than the internal; such is the case with the external lamina of the dura mater which adheres to the whole cranium, and likewise with the external one of the pia mater, or with the arachnoid membrane. If a lamina is more general, it also divides less; this is so with the external lamina of both maters. It performs also the office of a general bond; see the peritoneum.[3] The dura mater performs the same use around the brain which the pleura does in the breast, and the peritoneum in the abdomen, wherefore they mutually correspond to one another; see below. The internal lamina of the dura mater encloses, limits, and divides the cerebrum; for it

[1] In Part II. chap. vi.—Editor.
[2] From Codex 58, Photolithographed MSS., vol. vi. pp. 94-101.
[3] See "Regnum Animale," part i. chap. xvi.

encompasses all its boundaries, and divides it from the cerebellum. It even encloses its appendix or the corpora striata; for on the side of the isthmus of the ancients, or the torcular Herophili, it encircles the medulla oblongata, and bends itself back in a wonderful manner. It divides the brain into hemispheres.

259. *It also sustains and protects the brain in a general way.* That it sustains the brain is manifest from the way in which it is fastened. Especially in three points, or in the extremities of its axes, which are called poles. It does so in a remarkable manner where the lamina cribrosa is situated, or at the place whence the falx runs out; likewise above the straight sinus, in the middle of the occipital bone; and finally, near the pituitary gland, in the middle of the sphenoid bone. In a like manner it is fastened in points in the middle, which, as it seems, have likewise reference to the axes; as between the pole of the forepart of the head, and that of the occiput; but there it extends into a process, and is attached to the brain by little vessels and filaments. The same is the case between the pole of the occiput and that of the base, *i.e.* the pituitary gland, where the tentorium is; there also it is attached to the brain by filaments and little veins. From the pole of the base to the pole of the forepart of the head it is folded in a wonderful manner, and forms the cavernous sinuses; and then by a manifest folding passes to the pole. Along this line it is not attached to the brain in a like manner, but only by the trunk of the carotid which thence ascends into the brain. In this wise, then, the dura mater is attached to the brain, and in this wise it sustains it. In the remaining places it is free, and kept away from the brain. It thus protects the brain against any shock received by the cranium. All blows are directed by the dura mater in a most regular manner to every part of the brain, and because the brain by its very form is protected, therefore a blow which is thus received does not alter anything in it; but according to the form of its determination it passes out by the poles. The bones of the cranium on this account are also so connected that there should be centres

of the bones where the centres of the brain are; and in this wise the effects of a blow die off when they are concentrated thither; for there are the most quiet places, and thus places of support and of protection. The effects are also directed to the fourth pole of the brain or to the isthmus, where the pineal gland is; they are conveyed thither by the straight or fourth sinus. The dura mater thus sustains the brain in every way. Its falciform process sustains the lateral process or the tentorium, where the lateral sinuses are; for when the falx is cut through, the tentorium is contracted and becomes flaccid, as is proved by the experience of Pacchioni.

260. *The dura mater also librates or poises like a general tendon, for it reacts when it is acted upon.* That the dura mater is like a tendon is confirmed by Pacchioni and others. This is especially the case with its falciform process, which is like a tendon; and the tentorium poises, hence also the sinuses. This is further confirmed by the nature of its elasticity and reaction; for when it is loosened from its connection with the cranium, it reclines on the brain. That it is elastic is proved by experience; likewise by its being a tissue of filaments, each of which is elastic; it is also proved by the arteries which are in it. When pressed, it rebounds. Being placed between the hard and quiet cranium, and the soft and highly active brain, it sustains better the regular intervals of motion.

261. *It grants to the brain space, bounds, measure, mode and ability of swelling in alternate times; nay, as a common or general bond it permits it even to reciprocate the times of its animation; and to this it also contributes its own share.* It grants it space, because the dura mater is removed from the pia mater of the brain, except in the points mentioned above. It grants it bounds and measure; for the brain is able to swell so far, and not farther. It grants it mode according to the bounds or limitations which it prescribes, and consequently ability; for without the dura mater, or when its bonds are loosened—when, therefore, it is not embraced by the dura mater—the brain raises itself only with great difficulty; as has been observed by experience in the case

of some diseased persons. It is therefore also smoothed or polished on the side which is turned towards the brain, and anointed by a proper fluid. On this account also its vessels are imprinted on some of the tables of the cranium. Hence arises the expansive motion of the dura mater; for it has a double motion, namely, one which is expansile, and another which is pulsatile. The former it derives from the brain, and the latter from its own arteries. Reaction and elasticity are required in order that it may concur in a general manner with the motion of the brain; for when the latter has reached the extreme bounds of its expansion, then the dura mater urges it to enter upon the reciprocal period of its contraction. This appears from sneezing; see the Chapter on the Sense of Smell. How the dura mater is expanded when the brain expands, appears from the determination of its filaments and vessels. It appears from its filaments, because from the crown of the head they incline downwards, and then backwards. The individual fibres are the leaders of its motion and signs of its determinations. Besides, the muscular bands and the venous vessels themselves show the same thing. The filaments are turned in a different direction in the hemispheres, and also in the falciform process, as described by the anatomists. In the falx they run lengthwise, so that they are concentrated in itself. It also is manifest from its own arteries; for they are determined from their origins towards the straight sinus; in that direction the trunks send out their branches, as appears chiefly from Vieussens' plates. All this is for the sake of the use which the dura mater is to perform outside of itself; concerning which we shall treat in what follows; and in accordance with its accommodation to the brain, which is within, to the veins which descend into its middle, and to the sinuses into which it is to transfer the motion of the brain; and finally, to the cranium, which it must knit together, and into which and through which it is to transmit sanguineous vessels. It therefore ministers to the brain in the capacity of a tendon.

262. *It receives numerous veins of the brain in its duplicature,*

and coerces them by its fibres, as by little valves. This appears very clearly in the falx, where its laminæ coalesce into one, for they are received within that duplicature; nor are they at once intromitted into the sinuses, but they stay there and are kept there, as they are in the spinal marrow. From their determinations it appears how they are received, detained, and inserted into a sinus; see what is said in what follows concerning sinuses and veins. Each time the brain is expanded, the falx is depressed, and its fibres coalesce; but each time the brain is constricted, it is unrolled, and the venous blood is admitted. Thus the approach is closed and opened in alternate times. When the brain is compressed or constricted, the fibres of the falx are also constricted, and then they press the blood into the sinuses; and also *vice versa.* In this manner each fibre acts the part of a little valve. This follows also from the direction of the fibres in the falx; and it appears likewise most evidently from the direction of the veins towards the sinus.

263. *The blood of these veins according to every ratio of the motion of the brain, or according to the constriction and relaxation of the dura mater, is discharged into its sinus.* See on this subject Chapter vi. on the Arteries and Veins, and likewise Chapter v. on the Sinuses. The blood of the cerebrum is emptied into the longitudinal sinus; likewise into the lateral sinuses, and into the straight sinus, without mentioning the others. And, indeed, all blood is carried thither in a different direction, according to the flux of the veins. The motion of the brain is least around the pole in the forepart of the cranium, and greatest around the confluence of the lateral and straight sinuses; which appears also from the muscular bands and the robust ligaments; according to this motion is the influx into the sinuses. The direction of all vessels is according to the stream of motion. The most exact measure and equilibrium prevails in all these things. The determinations of the motion of the brain may be explored first of all from those of the fibres of the dura mater and its arteries, and in the second place from those of the veins of the brain; for it does not even transgress a

point or the breadth of a line beyond its determinations; in which case it would be all over at once with everything.

264. *The blood of the veins of the brain, according to every ratio of their state, is also tempered by the blood peculiar to the dura mater.* For the venous blood of the brain for the most part is dry, because its better portion, or its spirit, has been drained off by the substances of the cortex, and has been sent off into circulation; concerning which see above in chapter i. The quantity of this blood also, according to the degree of the animation of the brain, is sometimes greater, and sometimes less. On this account also the blood of the dura mater, according to Winslow, is carried into these very veins; and in this wise every contingency is provided against. In case, therefore, the blood of the brain on account of its sluggishness should tarry in the vessels, blood from the dura mater is sprinkled upon it;[1] and in this wise the danger is avoided. And should it pour in too copiously, it is sent off into the corresponding lower sinuses, that is, into the inferior longitudinal, and into the inferior lateral sinuses.

[1] Swedenborg speaks here of the arterial blood of the dura mater as being sprinkled upon the dry and lifeless venous blood of the longitudinal sinus, with a view of increasing its mobility. Modern science, however, shows that the sluggish venous blood of that sinus is refreshed not only by arterial blood, but also by the spirituous lymph known as the cerebro-spinal fluid. That fluid, as shown in the note on the "Cerebro-spinal Fluid" in vol. ii., circulates through the fascicles of the various nerves in the body; and after serving its purpose in the body, it is conveyed back into the dura mater of the cranium; see nos. 286*c* and 286*d*. In the dura mater, however, this spirituous lymph circulates in a system of ducts or tubes, concerning which Key and Retzius inform us that it communicates with the blood-vessels of the dura mater (see above, no. 244*h*), which in their turn communicate with the longitudinal sinus. If now the sluggish venous blood of that sinus threatens to clog up its avenues, not only arterial blood, but also a spirituous lymph, is summoned from the dura mater into the sinus. The same use also is performed by the *glandulæ Pacchioni*, but only in a more direct form. For these glandulæ, as Key and Retzius inform us, are very abundant in a number of venous lacunæ along the sides of the longitudinal sinus; and out of these glandulæ, which are elongations of the arachnoid membrane, the cerebro-spinal liquid, which is the genuine nervous juice, distils into the venous lacunæ; so that in these lacunæ, which are in the closest proximity to the longitudinal sinus, there is ever an abundant store of a highly liquid, spirituous lymph, which at the shortest notice can be introduced into the sinus in order to vitalize its sluggish blood.—EDITOR.

Perchance also it passes through the membrane encompassing the sinuses; and becoming mixed with the blood of the dura mater, it is discharged through the foramina of the cranium. A similar economy in the management of the blood may be observed everywhere in the body; as, for instance, in the liver, where the hepatic artery is; and likewise in the lungs, where the bronchial artery is: and, indeed, for a similar purpose altogether; so that a comparison may be instituted, and the use of the one may be found out by the use of the other.

265. *The dura mater also encloses as it were with a capsule the sinuses, or the venous receptacles of the brain.* For the sinuses are contained within the duplicature of the dura mater; concerning which see the authors. Its interior lamina covers the sides of the sinuses, and the upper or exterior lamina forms the roof. The sinuses, therefore, depend altogether upon the dura mater and upon its motion or action. On this subject, however, see Chapter v. on the Sinuses; and, besides, consult the authors.

266. *And the motion which it receives from the brain it transfers to the sinuses.* This follows from their connection. It is also confirmed by Ridley; but see Chapter v. on the Sinuses.

267. *And according to the modes and periods of this motion it urges their dry and almost lifeless blood towards the outlets, and, finally, into the jugular veins.* On this subject see Chapter v. on the Sinuses. In respect to the blood, however, this is dry; because its better essence has been absorbed by the cortical and medullary substances of the brain. This is evident also from the appearance of the blood itself; for it does not seem to be of the same vigour and colour as that in the arteries. I noticed that the blood in a male brain was coagulated, while in other parts of the body it was florid. In proportion, therefore, as the action of the brain increases, the volume of blood, and the capacity of the sinus, especially of the longitudinal, likewise increase.

268. *The dura mater also receives the arterial trunks, or the internal carotids, at the threshold of the cranium; it encloses them with a sheath, and transmits them into the chamber of the brain.*

On this subject see Chapter vi. on the Arteries. It transmits them through tortuous windings and around corners. They are likewise covered by the dura mater with a sheath.

269. *It also involves them in a certain duplicature, and leads them through an annulus or ring.* Consult Chapter vi. on the Arteries, and Chapter xx. on the Cavernous Sinuses. For after the carotid artery has emerged through the clinoid processes, in a duplicature of the dura mater it passes to the sides of the sella turcica or of the pituitary gland; and expands itself there. It soon leaves it, however, and sometimes through an annulus.

270. *It surrenders them to the government of the pia mater and of the brain, and thus inaugurates them into the motion of the brain.* See Chapter vi. on the Arteries; how it introduces the arteries from the motion of the heart into the motion of the brain. This is done first in a most general manner by the dura mater; and there is thus caused a correspondence between the motion of the arteries and of the veins, or of the carotids and sinuses. This motion is communicated in a general manner to the dura mater, which encloses in its duplicature not only the venous sinuses, but also the arterial trunks; and in this manner it communicates to both a similar animation.

271. *The dura mater is the general membrane of the brain; as the mucous membrane is that of the head, the pleura that of the chest, and the peritoneum that of the abdomen; these intercommunicate for the same reason for which the enclosed viscera likewise act in conjunction.* See the Chapter on the Peritoneum, and also that on the Pleura.[1]

272. *The dura mater is therefore conjoined with the mucous membrane and the pleura by means of nerves,* without mentioning their conjunction by means of the jugular veins. For the dura mater involves all the fascicles of the nerves; and accompanies them far into the sphere of the body, as their general envelope. On this account it is also united to the mucous

[1] See "Regnum Animale," part i. chapter xvi., and part ii. chapter v.

membrane by the olfactory nerve. And besides, in the tongue. On this account also certain nerves, as the sympathetic, and the eighth pair of the head, likewise the carotid artery and the jugular vein, are enclosed in a general capsule. This capsule, or this ultimate coating, the nerves do not lay aside, except in the general integument of the muscles, or of the organs of sense, or of the viscera. In this manner the brain by its dura mater acts as a general cause in the body. The pleura also involves the nerves with a certain sheath, likewise the peritoneum. In this manner, therefore, the general membranes are continued.

273. *These membranes, however, are mutually conjoined with the brain by the arteries; for the former are of the brain, and the latter of the body.* For, as said above, the carotid artery is led to the threshold of the cranium. There the dura mater receives it on its arrival. The same is the case in the spinal cord; wherefore this is not peculiar to the brain. It is, however, peculiar to the brain that it encloses several nerves of the head with a general capsule in the cavernous sinuses, and that it accommodates its membrane to the olfactory nerves on their departure; likewise to the motory nerves of the eye, and to the fifth and sixth pairs; for these pass out of the region of the brain, near the orbits.

274. *More immediately, however, the dura mater communicates with the orbit of the eye, where the external sight is, which corresponds to the internal sight of the brain.* Thus it lines the orbit of the eye; nay, it communicates even with the coatings of the eye itself by means of fibres; see the Chapter on the Eye. That the external sight corresponds to the internal sight, which is called imagination, may be seen in the Chapter on the Eye, and it will also be more extensively proved below. They are thus engaged in the same cause. This appears also from the eyes of birds and fishes, which are like succenturiate brains. This is the reason why the general membranes, and also the fibres, communicate more immediately and more manifestly. There is also a very close communication of the ear, especially of the membrane of the tympanum, with the dura mater; see the

Chapter on the Ear.[1] Thus the hard (*portio dura*) and soft (*portio mollis*) nerves let themselves down from this tremulous area into the ear, which is in close proximity through the aqueduct of Fallopius. Besides, the most general modes of the senses, especially of the ear and its modulations, have an immediate communication with the dura mater.

275. *The dura mater, by its internal lamina, distinguishes also the regions of this sphere, that is, the highest which is that of the cerebrum, from the lower or middle which is that of the cerebellum; and both these it separates from the lowest which is that of the spinal marrow. For between the cerebrum and cerebellum it erects a certain barrier, and interposes boundary streams, namely, the tentorium and the lateral sinuses.* That the dura mater is divided into two laminæ, see the authors. Likewise, that its superior lamina is more general than the inferior. The same is the case with the laminæ or tables of the cranium; likewise with the two laminæ of the pia mater. Thus the arachnoid membrane is more general, and does not enter the sulci and convolutions; neither does the dura mater. Its interior lamina passes off into processes, and dips down between the hemispheres; but the superior lamina is attached to the cranium. As the membranes themselves, so also their laminæ increase in generalness according to their distance from the brain. It forms a certain tent (*tentorium*) between the cerebrum and cerebellum, which is its lateral process. This tentorium inclines toward the anterior part of the cranial cavity, in order to form the cavernous sinuses; and thus it encloses regularly the whole cerebrum with its corpora striata. It hence appears that the sphere of its activity, like that of the operations of the cerebrum, is distinct from the sphere of the cerebellum. These very distinctions show this manifestly; and they likewise show the quality of this sphere of activity; for the membrane, which is like a general band, completely accommodates itself to it.

276. *The dura mater, however, conjoins these regions by means of its external lamina; it thus separates as well as unites the*

[1] In the unpublished work on the Senses.—EDITOR.

viscera of its sphere. The external lamina is closely attached to the cranium. It crosses the sinuses, and thus passes into the region of the other sphere. Its extent is similar to that of the internal lamina or table of the cranium. How the two laminæ separate will be seen in Chapter v. on the Sinuses.

277. *The dura mater also knits together the bones of the cranium which have been joined by sutures, and it unites with them in the character of an internal periosteum.* It does so by its external lamina, as was said above. Unless they were thus knit together, the bones might easily come apart near the sutures. By its attachment to the cranium, and also by its elasticity, it causes the cranium to yield a little, though insensibly, to a strong motion of the cerebrum; the bones of the cranium derive this property from infancy, when the brain is plainly seen to palpitate. In general, the more junctions there are, the greater is the elasticity, and the more powerful and certain are the effects; this may be observed everywhere. In order that it may serve this purpose of elasticity, the external lamina is thinner, and around the sutures it is interspersed with a great number of arterial branches. The bones themselves, according as they grow harder and stronger, likewise become more fragile, as is the case with the other bones; so that they are easily broken by blows. *By its elasticity, therefore, the dura mater imparts to them strength, and power of resisting.* This has already been shown.

278. *The dura mater, especially, unites the brain to the centres of the cranium, and the cranium to the poles of the brain.* On this account they all cohere in a wonderful manner; and thus it is made evident that the centres of the bones of the cranium and the poles of the cerebrum cohere thoroughly. There are chiefly three general centres of the bones of the cranium; namely, *first,* in the frontal bone, or where the crista galli is situated; *secondly,* in the middle of the occipital bone; and *thirdly,* in the basilar process, where the sella turcica lies. All the centres of the bones have respect to the poles. And these three centres of the cranium correspond altogether to the three

poles of the brain which have been specified above; so that the poles of the brain correspond to, and are united with, the centres of the bones by means of the dura mater. For the poles of the brain are situated, *first*, where the falx cerebri begins; *secondly*, where the straight sinus emerges; and *thirdly*, where the pituitary gland is placed.

279. *The action of the brain, therefore, has respect to those places where the cranium is strongest; and shocks received by the cranium are directed to the most tranquil places, and thence they are communicated to all points of the whole brain; and on this account both are perfectly protected, and remain without any fear of danger or injury.* For the most tranquil places of the cranium, and also of the brain, are there. Blows received by the cranium from without tend towards these places, and meet there; wherefore also all motions run to the poles of the brain. Blows received by the cranium, after being conveyed to these poles, are dispersed thence in every direction to all its substances; and indeed in a most regular manner, according to every particular of its form, so that no injury to the form need be feared. Thus the brain protects itself by its own form; because whatever flows or runs in accordance with the form, never injures or violates the mass. But if anything runs counter to this form, or in a different direction, then it causes an injury. Whatever alters the form is foreseen or forefelt by the brain; but if any motion or shock is in accordance with the form, then the brain does not receive a sensation from it.

280. *The dura mater also feeds the bones of the cranium, and especially its interior lamellæ, with blood and juice.* For in certain places of the cranium it adheres to it in such a manner that a kind of spongy substance intervenes between them. Near the sutures also it transmits veins. Larger veins it sends out entirely through the cranium, *e.g.* near the angle of the parietal bones. In other places it simply inserts them into the cranium; so that the interior lamellæ of the cranium receive some nutrition from its internal periosteum, just as they receive some from its external periosteum. Thus the

periostea impart nourishment to their bones, as is the case everywhere. As to the manner in which it adheres, see Pacchioni.

281. *The dura mater also conjoins the motion of the heart, or the pulsation of its arteries, with the motion of the brain or the animation of its fibres, for it undergoes a twofold motion; namely, one which is pulsatile, and which it derives from its own arteries, and another which is expansile and constrictive, and which is imparted to it by the brain.* Concerning these two motions Pacchioni, and also some others, have already treated. They may indeed be discerned plainly. Its pulsatile motion is mainly in the fontanelle of infants, where all the arteries meet. That it is possible for these two motions to exist together in one and the same membrane, appears clearly everywhere in the body; especially in its general membranes, namely, the pleura, the peritoneum, and the diaphragm. In the pericardium also it is shown that two motions may thus exist together most conjointly; nay, even in the heart, and in all its arteries, as has been shown repeatedly. This agreement of two motions may also be demonstrated mechanically. See what has been frequently stated on this subject. For the motion of the brain coincides with that of the lungs.

282. *On this account also it receives its arteries from the external carotids by special foramina, and it distributes them between its double lamina.* The arteries of the brain and of the dura mater are not commingled anywhere, except in the poles of the brain, or in its most quiet places; as, for instance, around the crista galli, where offshoots of the internal carotid even penetrate outside. Likewise around the pituitary gland. The reason of this is that they differ in the times of their pulsation. Unless they differed in this manner, the arteries of the brain would pass into the dura mater, and *vice versa* those of the dura mater into the brain. This also is a sign of their diversity of motion. Where the motions are quiescent, as in the poles, there they are also coincident. Whence does the dura mater introduce its arteries? In fact, from the external carotids.

On this subject consult the Authors cited. This indeed is the reason why, according to Baglivi, the motion of the dura mater is like that of the heart.

283. *Nor do the arteries of the dura mater mingle with those of the brain, except near the poles, where it is most quiet.* This has already been stated. There they may commingle, because there is the most tranquil place, and because their motions do not differ. For the blood-vessels are launched into the stream of motion. Where there are diverse motions, they do not flow together, even though they be of the same origin. They may be said to be far from each other, just in proportion as their motions disagree with each other.

284. *These arteries it not only distributes throughout its plane, according to the direction of the motion, but it transmits them also into the very sinuses, and especially into the superior lamina above the sinuses, nay, also into the other hemisphere, in order that it may equalize the condition of both.* That it distributes its arteries over the sides of the sinuses, appears from the continuity; namely, for the purpose of enabling the coatings of the sinuses to form also their interior coatings, and other similar things which are in harmony with their motion; for into the very sinuses it transmits portions of its own arterial, and perhaps also of its venous blood; especially does it do into the superior lamina above the sinuses, where many and innumerable vessels flow together, which have been delineated by Ruysch. And as they meet there together and are collected from all sides, their pulsation is especially felt there, and not so much in the hemispheres themselves. This is the reason why the fontanelle in infants is a source of pulsation. Baglivi, and also others, have treated of the fact. This is the cause of the opinion that the motion of the brain is similar to, and agrees with, that of the heart. Besides which, it also renders the condition of both hemispheres equal; for the dura mater consists in a great measure of arteries, and only of a few fibres. This appears sufficiently from a strong and subtle injection, like that used by Ruysch. If the vessels are even emptied of blood, they

are still continuous with blood-vessels. It is thus that the elasticity of the whole dura mater is preserved. For there are a great number of cases where one hemisphere suffers more than the other, and where it is either inflamed by the blood, or deprived of it; in which case it is assisted by the other side; for it is a rule that everything in the body is common to the neighbouring and remote parts whenever use and want demand it.

285. *Besides, the dura mater conveys to the cerebrum the more general modes of certain senses, wherefore it is also furnished with nerves, and is itself sensitive.* As is the case in hearing; for indeed it becomes tremulous by sonorous modifications, because the membrane of the tympanum communicates with the dura mater. See the chapter on the Ear.[1] The same is the case with the sense of smell, because the dura mater descends into the mucous membrane in company with the olfactory nerves. It may be inferred that something of the sense of sight also strikes it, on account of the membranes; for as the cerebrum refers the general mutations of its state to the dura mater, therefore also the general states refer themselves altogether from the external sensory organs to the cerebrum. There is nothing which does not contribute some share to the mutations of state of the cerebrum, consequently does the dura mater; wherefore it may be said that the dura mater in conjunction with the pia contributes that which is common or general in modifications of sense, even as they do the same in respect to motion; for the same help which it proffers to the one, it does also to the other. But so far as they are general, they are also obscure. That nerves enter into it, appears from the description; consult the Authors. That it is sensitive appears from bare skulls and from the case of other periostea; and it is so much the more sensitive, because it communicates in a most regular manner with the cerebrum, and every one of its parts.

286. *It appears hence that the brain performs its functions in a more perfect manner in proportion as this membrane is in a*

[1] In the unpublished work on the Senses.—EDITOR.

higher state of integrity, and more closely united to the cranium. Its integrity consists in the preservation of its elasticity by a proper distribution of its arteries and its attachment to the cranium; and likewise by the preservation of its connections [with other parts of the brain]. From diseases we learn what state is induced on the brain by an inflammation or a relaxation of the dura mater; thus by a dissolution of its connections; or by any other injury which it may have suffered. On this subject observe cases of apoplexy, paralysis, and other diseases. For as the brain depends upon its membranes, as upon its common bonds, so also the dura mater depends upon the brain; the state of the one easily affects the state of the other; whether a portion of it be worn, loosened from its connections, thickened, deprived of its reactive and elastic faculty, or distended by an intervening humour and in a manner separated from the brain. See Part IV. on the Diseases [of the Brain].

APPENDIX TO CHAPTER IV.

FROM AN EARLIER ANALYSIS OF THE DURA MATER.[1]

286*a*. *Nature of the dura mater.*—It is an elastic and passive membrane; for it does not at all act from itself, but is acted upon by the cerebrum. It consists of arteries, veins, and fibres almost tendinous, which when they are acted upon relapse into their former position. From many indications it is plain that this membrane suffers itself to be acted upon by the brain itself; and that while it is acted upon, by virtue of its elasticity, it reacts and recovers so as to become like a wide-spread tendon (p. 283, no. 54).

286*b*. *The uses of the dura mater* are manifold.—1. It reacts upon the sinuses, when they are acted upon by the cerebrum, so that they are dilated after being constricted by the cerebrum. 2. It admits the nervous juice on its arrival. 3. It likewise admits the arterial blood on its approach. 4. It transmits the venous blood of the cerebrum, together with its own, into the sinuses. 5. It also transmits its own venous blood into the bones of the cranium, and into the external pericranium. 6. It transmits the nervous juice when it arrives. 7. A part also it causes to transude, in order to be irrigated by its moisture. 8. It clothes the nerves about to depart from the cranium. 9. It clothes also the arteries which are proper to the cerebrum (p. 283, no. 54).

286*c*. *Texture of the dura mater.*—As far as the dura mater is concerned I hold that it consists of a double membrane. 1. That its exterior or superior lamina is vascular in a threefold

[1] From Codex 57, Photolithographed MSS., vol. vi. pp. 276-310. Dated Jan. 14, 1740.—EDITOR.

degree; that it is consequently a continuation of vessels of every kind, of fibres namely, and vessels of white and red blood. 2. That its interior lamina is a peculiar membrane which is a vehicle for the lymph impregnated with spirit which is set free when the nerves are distributed over the muscles and periostea.[1]

That the exterior lamina is vascular appears plainly from the arteries which flow into it, and also from cases of inflammation. Especially also from infants, where it is very red. For this reason also its fibres are compact. That the interior lamina consists of ducts or tubes which convey the nervous juice, appears from their composition, for they are grosser and larger. They also transmit a copious supply to the periosteum; and if there is no passage granted for it there, it is transmitted between the meninges.

It follows thence that the dura mater is elastic, and that when it is stretched or extended it recovers itself spontaneously. For not only does it receive new juice, but that which is contained in it cannot be discharged; and hence arises the reactive power of the membrane. The interior lamina seems to be chiefly elastic, for it is that which conveys the above nervous juice. Its filaments, consequently, cannot be called fibres, or vasa, or vascula; wherefore it possesses an intermediate character, and is called tendinous, when yet it is properly membranous. The interior membrane is required to be most elastic, in order that it may poise the motion of the sinuses, and by virtue of its elasticity may react, and at the same time act upon the inflowing and outgoing vessels. For when its elasticity is impaired the effect also perishes.

The exterior or upper lamina is indeed elastic, but not to the same degree. It is finely elastic; but in order to produce an effect, it must be grossly elastic (p. 290, nos. 75-78).

286*d*. *The motion of the spinal cord and the cerebrum cause the superfluous nervous juice to return from the body, and to be propelled and pumped towards the dura mater, and at the same time towards the pericranium.* This becomes most evident if this

[1] See the note on the Cerebro-spinal Fluid in vol. ii.—EDITOR.

membrane is examined in the spinal cord, where in its front part it is conjoined with the ligamentary coating, especially in the neck and near the first vertebra where it is articulated with the occipital bone. But as the experimental data are not premised, we cannot enter here upon a further confirmation. But that the nervous juice is propelled further by the cerebellum and cerebrum, appears from the fibres of the dura mater, which are as it were muscular, from the muscular bands, the muscular grains [Pacchionian corpuscles], and several other adscititious forces whereby the dura mater is moved when the cerebrum is in a state of motion. In this manner, then, that juice is propelled.

The road which it takes seems to be from the foramen magnum towards the middle of the sphenoid bone, and laterally upwards into the dura mater itself, where it is loosely adjoined to the cranium. In the upper part of the dura mater it seems to be carried along the canal [the longitudinal sinus], where there is also a duplicature of the membrane [the falx cerebri], which when it is acted upon on both sides, propels the juice forwards, and thence towards the whole circumference. The greatest portion of the nervous juice, however, insinuates itself first into the tentorium, and thence upwards into the cerebrum, and likewise into the falx cerebri, and thus upwards in exactly the same direction which is taken by the fibres. Thus every part of the dura mater obtains its supply. All this appears manifestly from the direction of the fibres of the dura mater (p. 291, no. 81).

286*c*. *Glandulæ Pacchioni.*—From the whole description of these so-called glandules it appears that they are small elevations chiefly of the pia mater and the arachnoid membrane. For as between the longitudinal sinus and the pia mater there are vessels, muscular bands, and little cords, it must needs be that by the continual action there should arise this kind of grains or miliary corpuscles. Wherever, indeed, the arachnoid membrane is joined to the falx cerebri, on account of some viscosity or for some other reason, that membrane, which in itself is cellular, is raised up in this fashion, and by the continual reciprocal movement these peculiar little tumours are produced. Likewise on account of the muscular bands, among which they are seen to be strewed; to these also they serve as roots. In some brains also there are folds. All of which is a common enough occurrence everywhere in the body where there is any adhesion, and yet a continuous expansion and subsidence; as in the lungs, and in other places.

This is the reason why they are more conspicuous near the longitudinal sinus, and near the region of the straight sinus; for the greatest pulling and spreading apart takes place there, and not so much near the lateral sinuses, where the posterior lobes apply themselves most closely, and where the parts are not so much drawn apart. Hence also these corpuscles are more numerous in diseased conditions. For when the pia mater does not apply itself properly to its sinus, but strives to remove from it, then muscular bands are constructed, and then also it adjoins itself closely by this kind of glandulæ, as they are called. . . .

Such being the case, it follows that into these peculiar little tumours there are opened ducts from the arachnoid membrane and the pia mater, through which there is instilled a liquid or a refined lymph. For there is a connection of causes, and from remote parts there is constantly derived thither a lymph; and hence they are supposed to be lymphatic vessels.[1] . . .

The above theory is confirmed by experience; for throughout the whole cerebrum no lymphatic vessels proper have been discovered (pp. 293, 294, nos. 89-92).

[1] From the experience adduced from Key and Retzius (see above, no. 244*j*), it appears that most of the Pacchionian glands are contained in venous lacunæ, on either side of the longitudinal sinus, and that the refined lymph which is conveyed to them by the arachnoid membrane oozes out through the surface of the Pacchionian glands, thus mixing with the venous blood which empties into the longitudinal sinus. —Editor.

CHAPTER V.

THE SINUSES OF THE DURA MATER.

287. The sinuses of the dura mater are receptacles and capacious troughs of venous blood, which flows in from the cerebrum and cerebellum, and which is conveyed by them to the jugular veins. The ancients, who did not examine every corner of the brain like the men of the present times, were acquainted with, and acknowledged only, four or five sinuses; their number has increased at this day, and probably will increase still more.[1]

A. *The Superior Longitudinal Sinus.*

288. This first sinus of the dura mater by some is called the third, the sagittal, and the superior sinus of the falx. It starts from the crista galli and its osseous lamina, where it is slightly bent back, and where also the falx cerebri is fastened. A little particle of it, like a diminutive cone, also enters the foramen cœcum, which separates the crista galli from the crista frontalis; as an impervious little body it is born there, not merely from the incisura ethmoidalis, and then it traverses the ridge of the crista frontalis. Under it, in some cases (according to Morgagni), there is a groove across in the form of a circular foramen. Thence it advances forth, opening out more widely, and in a moderate falciform shape follows the arch of the cranium; and while increasing constantly in size and thickness in proportion as it absorbs little affluents, it pursues its way above, and at the same time between, the two hemispheres of the cerebrum almost to the middle of the occipital bone, above the torcular Herophili,

[1] See on this subject Trolard's researches in nos. 328*d*, 328*e*, and 328*f*, and also Henle in nos. 328*k* and 328*n*.—Editor.

where four sinuses, with the contents of all the remaining family of sinuses, meet together. The shape of the longitudinal sinus is almost triangular as it is let into the cranium, and drawn into a point on being stretched downward, and as it is carried along the interior surface [of the cranium]. Besides having interiorly some small cavities and by-ways for the blood, or some little blind cells, and also foldings in some places, it is furnished with seven or nine smoothly-turned ligaments or fibres in the form of little ropes, which run transversely in an oblique direction; and further, with certain membranous processes running off into anfractuosities from one wall to the other. To these are to be added a congeries of granular little bodies, which are very much like miliary and conglobate glandules, and which are hidden under the interior coating of the dura, between the expansions and roots [which are there]. These glandular bodies creep from the head of the sinus to its bottom, or throughout the whole extent of the sinus, according to Pacchioni. As the sinus grows thicker on its approach to the torcular, it is interwoven and strengthened by a number of seemingly fleshy fibres which tend from behind a little forward. There also its exterior walls are fortified by ligamentary bonds and fibres which are arranged in bundles and cross one another; some of these are seen to pass from the dura mater into the falx cerebri, and others to start from the falx itself. After the sinus has thus started from its beginnings in the crista galli, and pursued its way under the groove impressed on the cranium, following the course of the sagittal to the lambdoidal suture; and after it has sent out threads and vessels through the sutures; it inclines downward a little, first in a straight direction, and immediately afterwards deflecting sidewards, it is continued to the middle of the occipital bone. There it becomes forked and flows into the lateral sinuses, the right and the left; or else it flows only into one, either with a simple or a double orifice, with its lips more or less drawn apart. The veins which convey the blood from the cortical substance back into this sinus, in the back of the head are a little inclined from behind forward, and in the forepart of the head they are a little inclined from the front backwards—quite differently from what is the case in the animals whose heads are bent downwards. These veins are inserted on the sides, and also from underneath. The apertures or cellules through which the blood is introduced are smaller on the sides, but they are large and valvular in the bottom. The vessels which irrigate the dura mater, frequently and at various intervals enter into this receptacle, and this, by introducing their blood into the above-named veins near their mouth.

289. WILLIS.[1]—"Within the cavities of the sinuses, and where the interstice between the cerebrum and the cerebellum is situated, are found many fibres, or as it were larger nervous cords, such as we have observed stretched out in various fashions in the ventricles of the heart. Within the sinuses there is constituted from the various processes of the membrane a cavity full of turnings and windings, and manifoldly partitioned as it were into many little cells. . . . But besides these intricacies and little cells of the membrane, there may be observed in the heads of quadrupeds throughout the whole cavity of the sinuses very many cords, as it were ligaments produced everywhere from one side to the other. . . . That these peculiar interior processes of the sinuses, and as it were transverse cords, are conducive to the more convenient return of the blood, we gather also from this consideration, that in draught animals, whose brain (because they feed and move with their heads inclined forwards and downwards) is in greater danger of inundation by the blood, these processes are very large" (pp. 46, 47).

290. VIEUSSENS.[2]—"The longitudinal sinus is furnished with transverse ligaments, and also with several membranous ligaments which pass off into windings and intricacies; this is not the case with the other sinuses. Where it passes into the lateral sinuses, it is of extraordinary thickness, and there only

[1] "Cerebri Anatome," London, 1664, cap. vi.
[2] "Neurographia," etc., lib. i. cap. ii.

it appears interwoven with quite a number of fleshy fibres, which are interiorly inserted into both its sides, and a little obliquely inclined from behind forward. Its lateral parts are besides furnished on the outside with very many ligamentary fibres arranged into fascicles and intersecting one another crosswise; some of these fibres seem to start from the falx, and others to pass from the dura mater into the falx. . . . The veins which convey the arterial blood back into the sinus tend from behind forward with the exception of two or three. In animals with their heads inclined forwards and downwards they all verge from the front backwards" (pp. 6, 11). See his plate i. and ii., and also Ridley's figure 4. But the manner in which the veins that convey the blood collected from the brain wind and bend, is seen chiefly in Ruysch's and Bidloo's plates; they are, in fact, inflected and reflected in a semicircular form, and yet they do not constantly preserve this direction.

291. RIDLEY.[1]—"As to the ligaments of the sinuses which are in some places round and cord-like, and in others broad and membranous, in the longitudinal sinus chiefly, they are in concurrence with the cruciform ligamentous fibres, taken notice of by Vieussens on the under and outside of this sinus, from whence the fibres belonging to the falx cerebri seem to have originated (p. 51). . . . As to the veins entering this sinus, about one-half insinuate themselves from behind forwards, the other half from before backwards—differently from what is remarked by Vieussens, who makes them enter with their orifices from behind forwards, with the exception of two or three (p. 52). . . . The longitudinal and lateral sinuses have many transverse ligaments which the other sinuses have not, and the longitudinal has many small cavities or blind cells which the lateral have not. I have seen in many skulls that the blood burst open the sides of the sinuses, and found its way between the duplicature of them, so as even to make a fovea or cavity in the cranium itself (p. 56). . . . The sinuses have no pulsation other than what is

[1] "The Anatomy of the Brain," chap. vi.

communicated to them from the subjacent brain (p. 50). . . . It is worth noting, that while the blood-vessels are all full, so as to keep the dura mater upon its full stretch, the pulsation is not visible at all, or at least very faintly; but after a depletion of the vessels, the beating becomes very visible, equally in the sinus and the membrane too" (p. 51).

292. PACCHIONI.[1]—"When the longitudinal sinus is gently opened on top with a knife, it displays its interior surface, which is at first found covered with membranous and unequal expansions, extending so far that at a distance from the apex of the sinus of about six fingers' breadth, they are formed into small cells. These little cells are found in greater abundance and more ample from the exposed sinus upwards towards the crown, and they are dispersed unequally through it. Most of them are empty, and they have orifices standing open almost in opposite directions; they are covered with a membrane which has the shape of a semilunar valve, but which does not cover the whole cavity. The remaining cellules represent simply impervious little pits or depressions. The cellules which are situated along the sides of the above-named longitudinal sinus, receive the blood, as appears from their swelling out upon being inflated, or when a pencil is inserted into them. They seem to be formed for this purpose, lest the blood should too easily pass back from the sinus into the vessels; as appears from this consideration, that no valves are found where the sinus is more capacious, and where it is in a descending position, because the blood runs down there more swiftly by its own weight. The hindermost part of the sinus, however, consists for the most part of a texture simply of unequal membranous expansions, as of so many fringes. And here it must be observed that this membranous expansion is not only strong, but that it lines the cavity of the sinus not straight across, but almost always in an oblique direction; and that it adheres to it most tenaciously. Under this lining are situated the ligamentary cords of Willis, which being propagated from the

[1] *Opera*, etc., Rome, 1741.

centre of the cavity of the above-named sinus, are led obliquely upwards, and are there seen to be interlaced in a certain net, with which they occupy the remaining part of the cavity of the tube. These cords also borrow many fibres from the muscles of the falx cerebri, on whose back they mostly rest, and to which they are joined; and thence they are able to summon forces for their own uses (pp. 124, 125). . . . When this covering is drawn away [the author speaks here of the lateral sinuses]—which is done by cutting the sinuses open longitudinally, and carefully tearing it away—little cords appear to the sight, more simple than those mentioned above, which cross one another, and which rise up from one extremity to the other (p. 125). . . . In the longitudinal sinus, immediately under the membranous expansions, and in the little areas around the cords of Willis, nay, even upon these very cords, are situated innumerable little conglobate glands, enclosed as in a bag by a peculiar delicate membrane. These glandules for the most part meet in clusters; only rarely they are arranged separately by themselves. These glandules proceed in a wonderful manner on both sides of the falx cerebri from its apex to its base in the back part of the head; they rest upon the back of the muscles; and partly by their fibres, and partly by those which emerge from the cords, they are fixed and mutually attached to them, so that they cannot be disjoined thence, unless they are torn off with a needle (p. 126). . . . It is worthy of being noticed that these glandules are only discovered near the sides of the longitudinal sinus, and scarcely ever, or only rarely, in the lateral sinuses where these begin to incline downwards (p. 127). . . . A great many of these glandules also, upon dissolving the connection between the dura and pia mater, seem fastened upon, and as it were ingrained in the latter membrane. . . . I noticed that both are further conjoined by some thin filaments, which emerge from the glandules of the dura mater. These are lengthened out to a certain distance, and are then broken off; upon touching them with the tip of the finger it is moistened by a transparent humour" (pp. 128, 129). In the author's figure 1 the longitudinal sinus is laid open, and on its internal surface are seen at a glance the membranous processes, the cords of Willis, and the above-named glandules, which are concealed throughout the whole tract of the sinus under the aforesaid processes or membranous expansions. In their natural state they are usually of the same bulk and form; in the plate we only obtain a back view of them; while on the opposite interior side they send out their filaments, which he calls lymphatic vessels, to the pia mater. In his second figure are exhibited the smaller cellules along the sides which admit the blood inside the sinus; and also the larger vascular cellules which are situated near the bottom of the sinus, the orifices of which have a mutual relation to one another; and lastly, also the impervious little foveæ (pp. 227, 228). The little valves, however, he says, he delineated in his letter on the glandules of the dura mater, which, however, I have not yet succeeded in seeing.

293. Ruysch.[1]—He exhibits a human dura mater preserved in a suitable liquid. "On opening the longitudinal sinus, there come into sight little round or roundish corpuscles, shaped like grains of millet, which have been discovered by Pacchioni. They scarcely exceed in size the head of a common pin, unless they are examined under the microscope; or unless they consist of two corpuscles. I examined also another human dura mater, in which the longitudinal sinus was laid open, but where scarcely a single one of these corpuscles could be discovered. But outside of this sinus, from the interior surface of the dura mater, there hangs down a membranous portion, with heaps of this kind of corpuscles; from none of these, however, the least lymphatic vessel could be seen proceeding." Ruysch produces also the dura mater of a gigantic girl dissected by himself, in whose longitudinal sinus he discovered some corpuscles of this kind, yet very small, considering the size of the whole body; sometimes they scarcely exceeded the size of a small pin-head (p. 10). Thus, although they are

[1] "Thesaurus Anatomicus," vii. nos. 34-36, Amsterdam, 1727.

of various sizes, and are found in various localities, they nevertheless are found in all human subjects.

294. WINSLOW.[1]—"The sinuses are in the duplicature of the dura mater, but this does not prevent their cavities from being lined on the inside by particular, very thin membranes. . . . The cavity of the superior longitudinal sinus is not cylindrical, but triangular, having in a manner three sides, one superior, parallel to the cranium, and two lateral, inclined to the plane of the falx cerebri. The upper side is formed by the external lamina of the dura mater, and through the middle of its breadth a kind of fine suture runs from one end to the other. The two lower or lateral sides are productions of the internal lamina, which having parted from the external, are inclined toward each other, and then unite; forming first the sinus, and afterwards the duplicature of the falx. This sinus is lined interiorly by a fine proper membrane, which forms likewise a kind of suture along the bottom of the sinus, that is, along the union of the two lateral sides. In this sinus we observe several openings and several ligamentous cords. The openings are orifices of veins, the smallest of which belong to the dura mater, and the larger to the brain. The veins of the brain enter the sinus, for the most part, obliquely from behind forward, after they have run about a finger's breadth in the duplicature of the dura mater. . . . Its internal cords appear to be tendinous, and to be designed for the purpose of preventing the too great dilatation of the sinus by the blood. They vary, however, in different subjects, and do not always reach from one side to the other. It is likewise believed that little glands have been discovered there; but we ought to be careful not to mistake for such certain small corpuscles which are the products of diseases" (nos. 29, 33, 34, 35, 38).

295. MORGAGNI.[2]—"The blind cavities or diverticula of the longitudinal sinus are said to serve the purpose of moderating the too rapid or violent flow of the blood. This purpose, I hold,

[1] "Exposition," etc., section x.

[2] "Adversaria Anatomica," vi., Leyden, 1740.

also certain other open cavities fulfil. For in certain longitudinal sinuses, sometimes in several, otherwise only in one particular place, I observed that in its interiors for some distance an additional peculiar wall was added on either side, or that the sinus sometimes for the distance of two finger breadths was doubled. I remember to have noticed this also once in the straight or fourth sinus" (Animadversio, vi. p. 8).

296. BARTHOLIN.[1]—"There are four cavities or sinuses, or receptacles of copious blood and spirit. Galen sometimes calls them the ventricles of the dura mater; others ducts. . . . The superior longitudinal sinus is the longest; for it is continued throughout the whole length of the head down to the nose. Galen sometimes calls it a vein, because it contains a large quantity of blood" (p. 462).

B. *The Inferior Longitudinal Sinus.*

297. The lower or smaller sinus of the falx, by some also, when it is present, called the third or fifth sinus, arises almost from the prominent crista in front of the ethmoidal bone, from which the superior and larger longitudinal sinus arises. It runs along the lower edge of the falx cerebri to the straight sinus, which is the common trough of the blood of the interior brain, into which it enters at a short distance from its root, sometimes a little further up; so that it may be almost considered as a branch or muscular band (*lacertus*) continued from this sinus. As it passes on it constantly increases in size, although it is narrow, and almost flat. It collects the veins from the interior texture of the cerebrum, and also those which stray about in the falx cerebri, and which communicate there with the superior longitudinal sinus. These veins enter into it in an oblique direction tending from before backwards. A drawing of it may be seen in Ridley's figure 4,[2] where it is exhibited together with the superior longitudinal, the lateral, and the

[1] "Anatome," etc., Leyden, 1673.
[2] "Anatomy of the Brain," Appendix, London, 1695.

straight sinuses, and where it is shown that the veins enter into both the superior and inferior longitudinal sinuses in an oblique direction. The author also represents a notable vein on either side of the former sinus, which originates at about one-third of its distance from the crista galli; the superior longitudinal sinus, however, he calls the third, the two lateral the first and second, and the inferior longitudinal sinus the fifth. This sinus, however, does not run between the duplicature of the dura mater, but between that of its inferior lamina, and it differs in this respect from the superior sinus; on this account also it is classed by some authors among the veins.

298. WINSLOW.[1]—"The inferior longitudinal sinus is situated in the lower edge of the duplicature of the falx cerebri, being very narrow, and as it were flattened on both sides. It communicates immediately with the straight sinus, and in some subjects appears even as its continuation. It likewise communicates with the superior longitudinal sinus by small veins which pass from one sinus to the other, and consequently with the veins of the cerebrum" (no. 39).

299. HEISTER.[2]—"The inferior longitudinal sinus seems to me to have the least claim to the title of a sinus; its coats are thin like those of the other veins, and its shape is not triangular like that of the before-mentioned sinuses." [Demonstrators in anatomy declare that this sinus is often wanting.][3]

C. *The Lateral Sinuses.*

300. The lateral sinuses are the first and second sinuses of the ancients. They receive the blood which had been previously collected by the superior longitudinal sinus, and add to it a large supply of other blood which is furnished by the straight

[1] "Exposition," etc., section x.

[2] "Compendium Anatomicum," vol. ii. note 48, p. 94.

[3] In the edition of Heister's "Compendium" which we consulted (that printed in Amsterdam in 1748), we could not find the statement in brackets. Heister says there, "Nature often sports with the sinuses of the dura mater; for the *fourth, i.e.* the straight sinus, is not always present."—EDITOR.

sinus from the interior cerebrum, by two veins flowing in from the cerebellum, and by other sources. These sinuses also, like the superior longitudinal sinus, run in the duplicature of the dura mater under the cranium, into which from their very outset a groove is dug for their accommodation. Their shape is triangular, which soon, however, becomes somewhat elliptical, and they are lined interiorly with a fine and polished membrane. In this manner they descend from their torcular, encompassed with a firm substance and robust fibres, taking their course over the cerebellum, and soon passing down to the petrous portion of the temporal bones, where finally after a winding course, resembling the serpentine form of an alembic, they enter under the styloid processes into bony hollows or caverns, called also jugular fossæ, and likewise diverticles of the venous blood and of the sinuses. At that juncture also the blood flows in from the superior as well as from the inferior petrosal sinuses; and they are likewise joined by the vertebral vein,[1] and on the other side from the external ear through a peculiar foramen formed under the suture of the temporal and occipital bones, by the occipital vein, and also by another little vein from the tympanum of the ear. These veins discharge their contents from above, partly from the sides, and also from below, into the same bony fossa, and secrete themselves there. In this wise these sinuses enriched with much blood descend through the internal jugular veins, in company with the nerve par vagum, and its accessory spinal nerve through the foramen, which is generally divided, and enter into the superior vena cava, and thus are carried towards the right auricle of the heart.

301. Ridley.[2]—"The lateral sinuses run within a strong

[1] Concerning this connection of the lateral sinuses with the vertebral vein, says Solly in his "Human Brain," etc. (p. 145), in the description of his fig. 70: "The venous plexus at the commencement of the spinal canal communicates externally with the external vertebral veins, and with the venous plexuses which these vessels form on the transverse processes, and below with the large spinal veins; before with the transverse sinuses on the basilary process of the occipital bone; posteriorly with the posterior occipital sinuses; lastly, they terminate *in the lateral sinuses*, close to the jugular foramen."—Editor.

[2] "Anatomy of the Brain," etc., chap. v.

duplicature of the tentorium down upon the occipital bone over the cerebellum, till in their further descent, after a tortuous manner, upon the lower production of the temporal bones they wind under them in order to their passage out of the cranium at the foramen jugulare—common to the eighth pair of nerves going out, the third branch of arteries belonging to the dura mater, and the internal jugular coming in, which is through two round bony cells in the temporal bones—into the jugular vein" (p. 40). He mentions also that they are furnished with ligaments or cords, like the superior longitudinal sinus,[1] but that they are destitute of cavities and blind by-ways.

302. VIEUSSENS.[2]—"In the lateral sinuses are found transverse and membranous ligaments. On the right and on the left along the sides of the occiput they lie over the cerebellum, and by-and-by they also lie under it, as where in a winding course they enter the round caverns, which in human beings are the termini partly of the vertebral and partly of the jugular veins" (p. 6).

303. PACCHIONI.[3]—"The cavity of the lateral sinuses is not varied by so many membranous openings and cells as the superior longitudinal sinus, but it appears quite even in respect to its membranous extent, except that at their highest portion the sinuses are wont to be distinguished by certain folds, which are not very unlike those which are discovered in the terminus of the former sinus. When this covering or these folds are drawn away, which is done by cutting the sinuses open longitudinally, and carefully tearing it away, little cords appear to the sight more simple than those in the longitudinal sinus, which cross one another, and which rise up from one extremity to the other"—as is shown by this author in his plate, where these little cords cross one another obliquely, and where sometimes two or three are attached to the end of one. "Very few blood-vessels enter into the lateral sinuses, whence it seems as if their cavity served rather as a receiving vessel to the longi-

[1] "Anatomy of the Brain," explanation of fig. 4 in Appendix.
[2] "Neurographia," etc., cap. ii. [3] *Opera*, etc., Rome, 1741.

tudinal and straight sinuses. . . . Traces of glandules are discovered never, or rarely, in the lateral sinuses; and then chiefly where they begin to incline downwards, and before they leave the back of the tentorium" (pp. 125-127).

304. WINSLOW.[1]—"All the sinuses of the whole brain communicate with each other, and with the great lateral sinuses by which they discharge themselves into the internal jugular veins, which are only continuations of these lateral sinuses. They likewise disgorge themselves partly into the vertebral veins, which communicate with the occipital (small lateral) sinuses; and partly into the external jugular veins by the orbital sinuses, which communicate with the angular, frontal, nasal, maxillary, and other veins; as the lateral sinuses likewise communicate with the occipital veins. . . . These lateral sinuses represent two large branches of the superior longitudinal sinus; one going to the right hand, the other to the left, along the great circumference of the tentorium, all the way to the basis of the petrous portion of the temporal bones. Thence they run down, having first taken a large turn and then a small one; and being strongly fixed in the lateral grooves of the cranial base, they follow its course all the way down to the foramina lacera and the fossæ of the jugular veins. They do not always arise by an equal and symmetrical bifurcation of the superior longitudinal sinus; for in some subjects one of the lateral sinuses appears to be a continuation of the longitudinal, and the other to be a branch from it. This variety may happen on either side. In short, we sometimes find one of these sinuses higher or lower, larger or smaller, than the other. The cavity of these lateral sinuses is likewise triangular, and furnished with a proper membrane and with cords; and it has also the small venous openings, which indeed are common to it, not only with the longitudinal sinus, but with most of the other sinuses. The exterior surface of this cavity is formed by the external lamina of the dura mater, and the other two by the internal lamina. As these two sinuses go out by the bony fossæ, they are dilated

[1] "Exposition," etc., section x.

into a kind of bag, proportioned to the size of the fossæ where they terminate in the jugular veins" (nos. 30, 40-43).

305. MORGAGNI.[1]—"The lateral sinuses not merely descend to the base of the cranium, but proceed still further to the middle of the base; nor are they always a bifurcated continuation of the superior longitudinal sinus. For out of fourteen bodies which I dissected, there were scarcely more than four where the lateral sinuses were such a bifurcated continuation; but in the remaining ten bodies the longitudinal sinus was very far from branching out equally into the lateral sinuses. Above the torcular even it deflected most evidently towards one side, and the whole of it to that extent was continued into the sinus of that particular side. It has been observed that the sinus into which the longitudinal is prolonged in this manner is most frequently the right one; for only in one out of the ten cases mentioned above was it continued into the left. In the other cases, therefore, in the left wall of the right sinus, after it had already deflected from the longitudinal sinus, an orifice stood open which with some was narrower, and with others wider, and which in some was double and even triple, but of various width; in most cases, however, it was strengthened by being encompassed, especially on the back, with a thick substance of considerable extent, so dense and firm that it seemed to be a texture of tendinous and fleshy fibres most closely interlaced with one another. This orifice was the beginning of the left sinus. The posterior part of the torcular I saw in this manner strengthened by a firm and strong substance, even in those cases where the longitudinal sinus was bifurcated into the lateral. In two subjects even, below this division, the two sinuses communicated by a transverse channel; I remember that in the first of these cases there was some space between the place of division and this channel, and that in the second case the posterior wall of this channel was likewise furnished with the same kind of substance" (pp. 2, 3).

Compare also the author's plate, where a drawing is given of

[1] "Adversaria Anatomica," vi., Leyden, 1740.

that subject in which there was a threefold beginning of the left lateral sinus, in which, however, the right was larger than the left (p. 132). Heister also says that it must be borne in mind that, according to the observation of Morgagni, the left sinus very often has its beginning from the right lateral sinus, and not from the longitudinal, as is commonly supposed.

306. How these sinuses run out may be seen in the plates of Vieussens and others; but the curvature and the genuine figure of the right sinus with its bulb or enlargement may be seen best in Valsalva's work on the Ear. In the description of his plate he states that the internal cavity of this sinus is not everywhere curved equally, but that that part of it which is directed towards the cerebrum is compressed, and as it were flattened out, although it is generally represented as perfectly cylindrical. The ventricose enlargement at the bottom in his plate has the form of a sack; and above, it is curved first in one, and then again in another direction; and there it is joined by the superior petrosal sinus and the vertebral artery; on the other side the occipital vein which is described by the author enters into it, besides some branches which are sent thither from portions of the occiput. Winslow in his description of the internal jugular vein mentions that through the posterior mastoid foramen it communicates with the lateral sinuses; and also that this communication is sometimes by an anastomosis with a branch of the external jugular, or of the cervical vein which goes thither.[1]

307. In some subjects also there is another little *transverse sinus* between the two lateral, not far from the place where the longitudinal and straight sinuses join the lateral; by this transverse sinus the two lateral communicate their blood to each other. Heister had an exact drawing made of this communicatory sinus, with the declaration that Rivinus makes mention of this transverse sinus.[2]

[1] "Exposition," etc., section v. no. 108.

[2] "Compendium Anatomicum," vol. ii. note 48, p. 94.

D. *The Inferior Lateral or Occipital Sinuses* [i.e. *the Lower Arms of the Posterior Occipital Sinus*].[1]

308. As there is a superior and an inferior longitudinal sinus, so also there are sometimes corresponding inferior sinuses under the lateral ones ; *i.e.* such as are embedded in the tentorium in the same manner as the inferior longitudinal is in the falx cerebri. Generally, however, they are wanting. "Near the posterior occipital sinus" (discovered by himself), says Morgagni, "I saw also two other sinuses flowing into the torcular, which, I think, ought to be described, although I have not discovered them often. I have not the least hesitancy in believing that they were real sinuses for several reasons; and among others for this one, that their cross-sections were by no means circular, but of that form altogether of which Valsalva speaks in the dissection of other sinuses."[2] Vieussens says, "Each lateral sinus has sometimes a small one under it; mostly, however, it is absent; when it is present it never terminates in the jugular vein, but always in the superior lateral sinus."[3]

E. *The Posterior Occipital Sinus.*

309. The posterior occipital sinus, or the posterior longitudinal sinus of the dura mater, was first discovered by Morgagni; his words respecting it are as follows :[4] "In several subjects, wherever the straight sinus was missing, I discovered another one near it, which terminated in the same place, and which to my knowledge has never been described before. On account of the place which it occupies, I call it the *posterior* sinus. In the middle and posterior part of the cranium from the torcular to the foramen magnum arises a bony process which is encircled by the dura mater; thence this membrane is curved inwardly

[1] See Henle on the Occipital Sinus in no. 3280.—Editor.

[2] "Adversaria Anatomica," vi.; Animadversio, iii. p. 4.

[3] "Neurographia," etc., p. 8.

[4] *Ibid.*, Animadversio, ii.

in the shape of a process; in some it extends forward more, in others less, and by it the cerebellum is divided as it were into two hemispheres. Through this membranous process this posterior sinus passes, flowing in where pointed out above. It takes its origin, however, in the neighbourhood of the foramen magnum, and conveys the blood from the veins belonging to the vicinity, and again to higher places. Instead of one sinus which not unfrequently occupies one side of the falx cerebelli, I sometimes observed two, each of which pursued its way on its own side of the falx. Although among seventeen heads where I looked for this sinus, there were five in which I saw nothing of it, except small openings within the torcular, which did not admit the probe deeply; and, further, although in four heads I did not even see these orifices; nevertheless, as in the remaining eight it was conspicuous to a great distance, I did not see any reason why I should omit its description, especially as the praises of the inferior longitudinal sinus are occasionally sung by the anatomists, which, as I have said, is by no means constant, and throughout its greater part is narrower than this posterior sinus. Another feature of its conformation must be mentioned; for I frequently saw that the interior cavity of one sinus was not conical, but that its sides were conjoined in an angular form, and that it is fortified sometimes also by certain membranous ligaments which run across it, as in some of the larger sinuses" (p. 3).

F. *The Straight Sinus.*

310. The straight or fourth sinus of the dura mater, which was also called torcular by Herophilus, runs out from the region of the pineal gland, where an interstice is formed between the corpus callosum, the corpora quadrigemina, and the cerebellum; or, in other words, it has its beginning and passes on from the inmost corner where the falx cerebri and the tentorium are, near to the medulla oblongata. After it has thoroughly claimed to itself, and absorbed in itself, the veins, and often the

double choroid plexus; and after having adjoined to itself the inferior longitudinal sinus where it exists, it emerges into daylight as it were out of a crater, or out of the centre of the cerebrum. In this manner, then, this sinus, charged with all the blood of the interior cerebrum, and reclining on the cerebellum, after having adjoined to itself two or three superficial sinuses, runs out in an oblique direction, and empties the blood which it conveys, either into the end of the longitudinal sinus, or into the one arm of it which inclines towards either of the lateral sinuses, or finally into one of these two sinuses.

311. VIEUSSENS.[1]—"The straight sinus carries the blood back from the interior portions of the cerebrum; and its orifice appears where the longitudinal sinus passes off into the lateral sinuses. It receives the inferior longitudinal sinus which occupies the base of the falx cerebri. . . . The little venous channels which are led down from the grey interior substance of the cerebrum, and from its lateral ventricles; and in like manner also those which after having been brought from the fourth ventricle, climb over the convex part of the cerebellum—all these tend towards the straight sinus, and form the same" (pp. 6, 8).

312. RIDLEY.[2]—"The straight sinus comes from the lower part of the falx cerebri, at that point where it becomes continuous with the tentorium; and a large double vein belonging to the choroid plexus, together with the inferior longitudinal sinus (when there is one), enters it at an interstice made between the end of the corpus callosum, the corpora quadrigemina, and the cerebellum; from whence having first passed over the cerebellum, it at last arrives with the other three sinuses at that place of union, which from its first discoverer has ever since retained the name of torcular Herophili" (p. 42).

313. WINSLOW.[3]—"Near the concourse of the superior longitudinal and the lateral sinuses we observe the opening of the

[1] "Neurographia," etc., lib. i. cap. ii.
[2] "Anatomy of the Brain," chap. v.
[3] "Exposition," etc., section x.

straight sinus, which sometimes is double. Throughout its whole extent it is enclosed in the very union of the falx cerebri and the tentorium. It does not always end directly at the extreme end of the longitudinal sinus, but sometimes opens at the beginning of one of the lateral sinuses, especially when the bifurcation is not equal or symmetrical; and in this case it often terminates in that lateral sinus which appears like an arm of the longitudinal sinus and of the other lateral sinus. . . . Its diameter is but small, and it forms a kind of bifurcation with the inferior longitudinal sinus, and with a vein of the cerebrum which is sometimes double, called vena Galeni" (nos. 44, 45).

314. MORGAGNI.[1]—"The straight sinus [in the subjects examined] ended in the middle of the transverse canal between the two lateral sinuses; in the first subject it had one, in the other subject two mouths. This one mouth, in many other subjects, I saw in the left lateral sinus near its beginning; and, therefore, I have neither seen its opening always—as Manget asserted—at the end of the longitudinal sinus, nor even in most cases . . . can I remember to have seen the straight sinus doubled, like the superior longitudinal. In this latter sinus, namely, I saw sometimes in several places, sometimes only in one place, a duplicature was caused by a peculiar wall being attached interiorly to either side, and which extended occasionally to the distance of two finger-breadths" (pp. 3, 8). The emersion of the sinus may be seen in figures 4 and 5 of Ridley, in plate vii. of Vieussens, in one plate by Morgagni, and in another by Pacchioni.

G. *The Superior Petrosal Sinuses.*

315. These sinuses have also been called the longer, but smaller and more slender sinuses of the base or of the sella turcica, those of the posterior petrous angle, and likewise the interior basilar sinuses. They extend from the cavernous sinuses of the

[1] "Adversaria Anatomica," vi.; Animadversiones, i. and vi.

sphenoid bone to the petrous part of the temporal bone, and terminate in the lateral sinuses, where they are twisted into the tortuous shape of an alembic. They, therefore, derive their blood from the cavernous sinuses, and at the same time, by the insertion into them of many veins, from the inferior or anterior part of the cerebrum; this takes place by many orifices. They also pass forth in a somewhat triangular shape through the duplicature of the dura mater.

316. VIEUSSENS.[1]—"Four sinuses open into the receptacles of the sella turcica (cavernous sinuses). These sinuses are situated in that part of the dura mater which is spread out over the base of the cranium. . . . The superior sinuses, traces of which are slightly impressed on the temporal bones, by those ends which are turned towards the sella turcica, open into the cavernous sinuses; by their other ends they terminate in the lateral sinuses; once, however, I found a portion of them impervious" (pp. 6, 7).

317. RIDLEY.[2]— "The superior petrosal sinuses which are longer and narrower, according to Vieussens, arise from the cavernous sinuses, though more truly from the circular sinus, running down from thence upon the internal process of the temporal bone, and terminating in the lateral sinuses" (pp. 42, 43).

318. MORGAGNI.[3]—"Vieussens in his plate[4] is careful not to represent the part of the superior petrosal sinus nearest to its end, wider than the rest. I also in six heads, which I carefully inspected, could not see it enlarged, except in one single sinus, and this was partly obstructed by some fibrils, as it were woven into nets, ascending. In five heads, however, and also in many others, so far from its being larger, I really found it smaller; nay, in two of them the end was actually blind or impervious. The other end, however, which is inserted in the wall of the lateral sinus, in one case I found consisting of two small orifices, and in another of one only, but the opening of which was a little

[1] "Neurographia," etc., lib. i. cap. ii.

[2] "Anatomy of the Brain," chap. v.

[3] "Adversaria Anatomica," vi.; Animadversio, xxviii.

[4] Plate xvii. p. 93.

larger. This was the way of the blood into the lateral sinus; on which account I am inclined to believe that such also must have been the case with Vieussens' subject in which he found one of the two sinuses impervious at the same end; which, as he says, happened to him only once" (p. 35).

319. BIANCHI.[1]—"The narrower and longer of the sinuses placed in the base of the cranium derive their immediate origin from the cavernous sinuses almost under the angle which arises from the meeting of the productions of the dura mater. They run out thence in an oblique direction over the petrous portion of the temporal bone, into which, on that account, is imprinted a groove corresponding to their passage. Although this sinus measures a considerable length before reaching the top of the petrous portion, it, nevertheless, falls down again, and inserts itself into the lateral sinus, where this is first bent over the temporal bone in its progress towards the beginnings of the jugular veins." See his plate in Manget's "Theatrum Anatomicum;"[2] and especially also Ridley's second plate, where he deduces its origin from his circular sinus;[3] likewise Vieussens' plate xvii.[4] This represents the continuation both of the superior and inferior petrosal sinuses by the curve where the sixth pair of the nerves, together with the carotids, crosses the cavernous sinuses. Morgagni declares that "in seven heads he observed most clearly that the fifth pair does not pass over the beginning of the superior sinus, but, on the contrary, that the beginning of this sinus passes over the trunk of the fifth pair."[5]

H. *The Inferior Petrosal Sinuses.*

320. These sinuses, which are also called the inferior, interior, larger but shorter, petrous sinuses of the sella turcica, or those

[1] "Demonstratio Anatomica, F. M. Nigrisolio conscripta," 1715, in Manget's "Theatrum Anatomicum," vol. ii. p. 347, nos. 8.8., and 10.

[2] *Ibid.*, vol. i. p. 342, Tabula v., *extra ordinem.*

[3] "Anatomy of the Brain," Appendix, figure 2.

[4] "Neurographia," etc., p. 93.

[5] "Adversaria Anatomica," vi.; Animadversio, xxi. p. 27.

of the crura of the sella, start from the sides of the cavernous sinuses or of the receptacles of the sella, or, according to Ridley, from the circular sinus; and they run out thence between the sphenoid and temporal bones. They become larger on the way, and being but slightly bent, seek those petrous cells into which the lateral sinuses discharge themselves with a view of entering the jugular veins. These sinuses, together with the superior petrosal sinuses and the bent portion of the lateral sinuses, separate that part of the cranium which tends towards the temporal bone, almost as an island from the remaining continent, and also from the occipital and sphenoid bones. In this island the seventh pair of nerves of the head, the auditory nerve, leaves the cranial cavity and enters the temporal bone. Thither also reaches the extreme end of the tentorium, and thence as from a fixed station it expands towards the sella turcica and the cavernous sinuses.

321. VIEUSSENS.[1]—" The inferior petrosal sinuses, whose traces are deeply imprinted upon the temporal and sphenoid bones, with one of their extremities open into the cavernous sinuses, and with the other enter into the jugular veins, where the lateral sinuses pass into them, and from these they are separated partly by a bony and partly by a membranous partition" (p. 7).

322. RIDLEY.[2] — " The inferior petrosal sinuses, which are much shorter and wider than the others, descend from the same place as the superior, between the temporal and occipital bones, down to the aforesaid foramen of the cranium where the jugulars come up, and end there" (p. 43).

323. BIANCHI.[3] — " The inferior petrosal sinus derives its beginning on both sides from the cavernous sinuses, exactly under the crura of the posterior clinoid processes of the sella turcica; it runs out thence immediately on the place where the sphenoid bone is articulated with the petrous process, where there is also a kind of furrow made for its passage. It

1 "Neurographia," etc., lib. i. cap. ii.

2 "Anatomy of the Brain," chap. v.

3 "Demonstratio Anatomica," etc., 1715, in Manget's "Theatrum Anatomicum," vol. ii. pp. 347, 348, nos. 9, 9 and 11.

is, however, further down than the other, almost like a serpent lying at the bottom of the posterior side of the petrous process; while the other, the superior petrosal sinus, occupies the terrace of the same process. . . . Though the lateral sinus after its first curve descends inwards towards the centre of the cranial cavity, it nevertheless is inflected there a second time, and ascends; finally, however, it descends, and leaves the cranium on both sides through an ample, open foramen. Between the petrous portion and the occipital bone, or at the base of the posterior surface of the same petrous process, it is previously enlarged into a sort of lacuna, which is received in a peculiar bony fovea, called [by some] specus rotunda. Soon it sends out backwards from the posterior side of each lateral sinus the vertebral vein which is about to enter the vertebral specus [plexus], and at last the whole lateral sinus is wedded with the beginning of the internal jugular, and runs with it into one channel. For carrying back to the heart by means of the lateral sinuses and the internal jugulars the liquids collected in the cavernous sinuses at either side of the sella turcica, and for deriving them thither, there exist thus four emissary vessels, or four sinuses which communicate immediately with these same cavernous receptacles. The former carry away from the latter their liquid contents, in order that the humours which are deposited, or which trickle into, these cavities, of which there is one at either side of the sella, and which are exhausted of their uses and therefore sluggish, may return into circulation more swiftly and easily, and without danger of delay and coagulation." See the plates referred to above, and likewise that of Valsalva respecting the ear.

324. MORGAGNI.[1]—"Vieussens was quite right in representing the sixth pair of nerves on the external side of the inferior petrosal sinuses; I only could have wished that he had drawn the sixth pair of nerves along the same external side, and as received within the cavity of these same sinuses; and passing onwards for some distance, as I have seen in many heads" (p. 27).

[1] "Adversaria Anatomica," vi.; Animadversio, xxi.

T

I. *The Circular Sinus.*

325. The circular sinus, which runs around the pituitary gland and the sella turcica almost in the form of a circle, was first discovered by Ridley, who describes it in the following words:[1] "By having first injected the veins with wax I discovered another sinus running round the pituitary gland on its upper side forwards, within a duplicature of the dura mater, backwards between the dura mater and pia mater. Here it is somewhat loosely stretched over the subjacent gland itself, and laterally in a sort of canal made up of the dura mater above, and the carotid artery on each outer side of the gland, which by being fastened to the dura mater above, and below at the basis of the skull too, leaves only a little interstice between itself and the gland, thereby constituting a cavity communicating with the aforesaid arteries, from whence the above-mentioned four small sinuses descend, by a visible continuity, on each side from a little beneath the hinder process of the sella turcica. . . . Vieussens, it may be, saw some part of this sinus where he thought that the cavernous sinuses communicated. . . . The use of this circular sinus is to bring back the blood from the pituitary gland, the sphenoid bone, and it may be also from the rete mirabile, seeing the pituitary gland appears nowhere furnished with veins to carry off the blood from this plexus" (pp. 43, 44, 47).[2]

326. Bianchi impugns and denies the existence of this sinus, observing that "the dura mater in the anterior region of the pituitary gland, or above the anterior processes of the sella turcica, is not duplicated, but simple, so that no sinus can be concealed in it. In reality, when the dura mater is scraped off in this place only very lightly, the bare bone underneath at once appears everywhere. Between the gland and the anterior elevation of the sella there is no space, nor is there any communication between the lateral parts of the sella; on the back

[1] "Anatomy of the Brain," chap. v.

[2] See Henle on the *circular sinus* of Ridley in no. 328*m*.—Editor.

of the gland, however, no space is found between the dura and the pia mater; consequently, also, no pia mater is there, and therefore this sinus has been confounded with the cavernous sinuses. The dura mater also which covers the cavernous sinuses at the sides of the glands is exceedingly thin, and by no means duplicated; and if it is but slightly dissected, it at once opens an access to the cavernous sinuses."[1]

327. Morgagni replies to these arguments thus: "Brunner in his dissertation concerning the pituitary gland wrote about thirty years ago that in dissecting the human head, with a syringe he injected red wax into one of the two jugulars, the other having been tied; that the wax penetrated splendidly as far as the pituitary gland, which on its anterior side it encompassed like a crown. This sinus also was drawn by Cowper's own hand, and in his appendix to the Anatomy of the Human Body he distinctly represented a circular sinus or a vein which encircled the gland. Litre also writes that between the thickness of the superior lamina of the dura mater which covers the sella from above, a sinus of an oval shape could be observed, by which the superior portion of the pituitary gland is encircled, and into which a portion of the veins of the same gland is derived (Mémoires de l'Acad. R. des Sc., 1707, p. 308). I myself, before removing the dura mater by which this gland is covered, observed a not obscure outline of an annular vessel, which with its blood colour shone through that part of the dura mater and around the upper circumference of the gland; and I noticed this so often, that out of nine heads there were only two in which I could not see it."[2]

J. Other Smaller Sinuses.

328. Other sinuses of less importance are also enumerated. According to Winslow there are "*six petrosal sinuses*, three on each side, one anterior, one middle or angular, and one inferior;

[1] In Manget's "Theatrum Anatomicum," vol. ii. p. 343, no. *aa*.
[2] "Adversaria Anatomica," vi., Animadversio, xix. p. 24.

the two inferior, together with the occipital sinuses, complete a *circular sinus*[1] around the foramen magnum. An inferior and superior *transverse sinus.* Two *cavernous sinuses,* one on each side. Two *orbital* or *ophthalmic sinuses* [ophthalmic veins]. All these sinuses communicate with the great lateral sinuses by which they discharge themselves into the jugular veins; they likewise disgorge themselves partly into the vertebral veins, which communicate with the small lateral or inferior occipital sinuses. They may also empty themselves into the external jugular veins through the orbital sinuses [ophthalmic veins] which communicate with the angular, frontal, nasal, maxillary veins, etc."

[MODERN AUTHORS.

328*a*. QUAIN.[3]—"The *venous sinuses* within the cranial cavity admit of being divided into two sets, viz. those placed in the prominent folds of the dura mater, and those situated in the base of the skull.

"The form and size of the sinuses are various. All of them are lined by a continuation of the internal membrane of the veins, the dura mater serving as a substitute for the other coats.

"The sinuses which are contained in the several folds or processes of the dura mater converge to a common point, which corresponds with the internal occipital protuberance, and is called the *confluence of the sinuses* or *torcular Herophili.* The form of the torcular is very irregular. Five or six apertures open into it: viz. one from the longitudinals, and one from the straight sinus; two from the right and left lateral sinuses; and one or two from the posterior occipital sinuses.

"The *superior longitudinal sinus* (s. falciformis superior), commencing at the crista galli, extends from before backwards,

[1] See Trolard on the *circular sinus of the foramen magnum* in no. 328*h*.—EDITOR.

[2] "Exposition," etc., section x. nos. 29, 30.

[3] "Elements of Anatomy," eighth edition, London, 1876.

in the upper border of the falx cerebri, gradually increasing in size as it proceeds. It is three-sided, and is crossed obliquely at the inferior angle by several bands, the *chordæ Willisii.* The veins from the cerebral surface open into this sinus chiefly towards the back part; and in such a way that the apertures of the greater number of them are directed from behind forwards, contrary to the current within it. The longitudinal sinus communicates with the veins on the outside of the occipital bone by a branch (one of the 'emissary veins,' Santorini) which passes through a hole in the parietal bone.

"The *inferior longitudinal sinus* (s. falciformis inferior) is very small, and has so much of a cylindrical form that it is sometimes named the *inferior longitudinal vein.* Placed in the inferior concave border of the falx cerebri, it runs from before backwards, and opens into the straight sinus on reaching the anterior margin of the tentorium cerebelli. It receives branches from the surface of the falx cerebri, and sometimes from the flat surface of the hemispheres.

"The *straight sinus* (s. tentorii) runs backwards in the base of the falx cerebri, gradually widening as it approaches the torcular Herophili, in which it terminates. Besides the inferior longitudinal sinus, the venæ Galeni and the superior veins of the cerebellum open into it.

"The *lateral sinuses* (s. transversi) are of considerable size. Their direction conforms to that of the groove marked along the inner surface of the occipital and other bones, and extending from opposite the internal occipital protuberance to the foramen jugulare. The sinus of the right side is usually larger than that of the left; both commence at the torcular Herophili, and terminate in the jugular veins. The lateral sinuses receive the blood transmitted from both the longitudinal sinuses, from the straight and occipital sinuses, from the veins upon the sides and base of the brain, from those on the under surface of the cerebellum, and from some of the veins of the diploë. The petrosal sinuses also join the lateral sinus on each side; and two *emissary* veins connect these with the veins at the back of the head and neck.

"The *posterior occipital sinus* is sometimes a single canal, at other times double, as if composed of two compartments. It lies along the attached border of the falx cerebelli, extending from the posterior margin of the foramen magnum to the confluence of the sinuses. It communicates in front with the posterior spinal plexuses of veins.

"The sinuses placed at the base of the skull are as follows, taking them in their order from before backwards.

"The *circular sinus* has the form of a ring, and is placed superficially in the substance of the dura mater round the pituitary body; it receives the blood from the minute veins of the pituitary body, and communicates at each side with the cavernous sinus. Sometimes it is only partially developed, the part in front of the gland being that usually present; sometimes, however, it is behind the gland.

"The *cavernous sinuses*, placed on each side of the body of the sphenoid bone, over the roots of the great wings, and stretching from the sphenoidal fissure to the apex of the petrous portion of the temporal bones, are of considerable size, and of very irregular form. Each receives the ophthalmic vein at its forepart, and communicates internally with the circular sinus, and posteriorly with the petrosal sinuses. In the wall of each, separated by the living membrane from the cavity of the sinus, pass forward the third, fourth, and sixth cranial nerves, the ophthalmic division of the fifth nerve, and the internal carotid artery.

"The *superior petrosal sinus* is a narrow canal running along the upper margin of the petrous part of the temporal bone. Commencing at the back part of the cavernous sinuses, it is directed outwards and backwards in the attached margin of the tentorium cerebelli; and descending a little, ends in the lateral sinus where this lies upon the temporal bone.

"The *inferior petrosal sinus*, wider than the upper, passes downwards and backwards along the lower margin of the petrous bone, between this and the basilar process of the occipital bone. It opens into the lateral sinus near its termination, or into the jugular vein.

"The *anterior occipital* or *transverse sinus* (sinus basilaris) is placed at the forepart of the basilar process of the occipital bone, so as to establish a transverse communication between the two inferior petrosal sinuses" (vol. i. pp. 481-484).

328*b*. Trolard.[1]—"The *superior longitudinal sinus*. . . . On removing the top of the cranium there appear several tumours of a blackish colour, which are situated one behind the other, on either side of the superior longitudinal sinus. Their upper wall, which is formed of the dura mater, shows very often one or several open spaces, across which pass the Pacchionian corpuscles. These tumours are not always of the same size. The largest among them always correspond in size to the middle part of the sinus. They lodge in the osseous depressions, which are noticed in the surface of the parietal bones above them.[2] If an incision is made into the dura mater to the bottom of these tumours, they are found to be real cavities. Their bottom wall is formed by the Pacchionian corpuscles; while their upper wall, as already stated, is constituted of the dura mater; fibrous tracts, which decussate in such a manner as to form an areolar cavity, pass from one wall to the other. The upper wall is smooth, probably lined by the internal membrane of the veins. When there are any openings in that top wall they communicate with other openings, which are noticed at the bottom of the depressions in the parietal bones. These latter openings or orifices belong to venous canals. . . . There exists thus at the sides of the longitudinal sinus a series of sanguineous lakes, of small cavities which are of an areolar structure. Their number is variable. They reach sometimes from the concavity of the

[1] Trolard (Dr. P.), in charge of the course of anatomy in the school of medicine at Algiers, "Recherches sur l'Anatomie du Système veineux du Crâne et de l'Encéphale." In "Archives Générales de Médicine," vol. xv., Paris, 1870.

[2] In order to get a proper idea of these cavities, they must be examined in the skulls of aged persons.—Trolard.

frontal bone to the torcular Herophili; at another time they only extend as far as the parietal suture. These cavities communicate with the cerebral veins. . . . In fine, these sanguineous lakes communicate with the superior longitudinal sinus either indirectly through cerebral veins, or directly through openings in the lateral edges of the sinus" (p. 260).

328*c*. "The *inferior longitudinal sinus*.—This vessel, which may be regarded either as a vein or a sinus, exhibits this remarkable peculiarity, that it has no collateral vein. Nevertheless, I have sometimes noticed little veins coming from the anterior portion of the corpus callosum and the neighbouring convolutions, which entered into its anterior extremity. I have also observed anastomoses whereby the two sinuses were united. In case the circulation in either of the two is stopped, it may be re-established through these anastomoses. I look upon the inferior longitudinal sinus as a prolongation of the straight sinus, and a diverticle which at a given sign may receive the venous blood of this latter sinus. Suppose the circulation in the straight sinus or in the lateral sinuses is retarded by some obstacle, and suppose there is a continual afflux of blood from the veins of Galen, in this case it may pass into the inferior longitudinal sinus, the walls of which are capable of distention, and which besides does not receive any collateral veins" (p. 261).

328*d*. "The *superior petrosal sinus*.—Towards the middle of this sinus there empties into it a vein to which I apply the name of the *great anastomotic vein* (grande veine anastomotique). This vein sometimes takes its rise at the sides of the superior longitudinal sinus; but most frequently it arises from a junction of veins which anastomose on the middle part of the convexity of the cerebral hemispheres. After the trunk of this vein has thus been formed it directs its course downwards from behind forwards. It passes through the fissure of Sylvius, fastens itself to the sharp edge of the small wing of the sphenoidal bone; and being embedded in the dura mater, it crosses the spheno-temporal fossa in order to enter the superior petrosal sinus. During its last course, as is very plain, *it is a real sinus*, and its volume is considerable. . . . As this vein is voluminous, and establishes an extensive communication between the veins of the base and those of the roof of the cranium, I propose to call it *the great anastomotic vein*" (p. 263).

328*e*. "The *inferior petroso-occipital sinus.*—On examining the base of a skull, on the level of the petro-occipital suture, there is noticed a groove running from the foramen lacerum anterius to the foramen lacerum posterius. This groove, which sometimes is very marked, is occupied by a sinus. This sinus is semi-cylindrical. Its base rests on a thick couch of fibrous tissue. Its direction is from within outwards, and from before backwards. Its anterior extremity is not always circumstanced alike. At one time it communicates immediately with the cavernous sinus, in which case it crosses the foramen lacerum anterius. At another time it does not go as far as that foramen. . . . Its posterior extremity terminates in the anterior condylar foramen. This sinus is not very large, although sometimes it equals in size the inferior petrosal sinus. Nevertheless, I regard it as of considerable importance, because it establishes a connection between the anterior intra-cranial sinuses and the exterior veins. From its position I propose to call it the *petro-occipital sinus.* Like the inferior petrosal sinus, it rests on the suture bearing the same name; and as this latter sinus is far from being *petrous* or petrosal, since it is situated almost altogether on the occipital bone, I am of the opinion that it ought to be called the *superior petroso-occipital sinus;* the name of the new sinus in this case would be the *inferior petroso-occipital sinus*" (p. 267).

328*f*. "The *anterior condylar confluent.*—In an interior direction from the foramen lacerum anterius, and outside of, and a little ahead of the condyle of the occipital bone, there is a hole called the *anterior condylar foramen.* This bony cavity, at the bottom of which there opens the posterior condylar canal (*canal condylier posterieur*), is very deep. It is often one and a half centimetres long, and one centimetre in width. This cavity harbours a regular venous confluent. Five veins or sinuses empty into this venous confluent, namely:—

"(1) Anteriorly and interiorly there is the inferior petroso-occipital sinus.

"(2) Anteriorly and a little exteriorly there is the superior petroso-occipital sinus (viz. the inferior petrosal sinus), that is, the vein which continues this sinus.

"(3) Posteriorly there is a vein which comes from the anterior spinal sinuses, and crosses the anterior condylar canal. Breschet has pointed out this vein, which may be called the *anterior condylar vein.*

"(4) Posteriorly and interiorly there is a vein which proceeds from the vertebral vein, between the atlas and the occipital bone. It passes behind the internal jugular vein, and is contained in an osseous canal. It is not always present.

"(5) A small vein which applies itself to the anterior atloido-occipital ligament, and which across this ligament, communicates with the internal sinuses of the spine" (p. 268).

328*g*. "The *cavernous sinus.*—From the lower portion of this sinus there departs a sufficiently voluminous vein which places itself about the inferior maxillary branch of the trifacial nerve; with that nerve it passes into the foramen ovale and terminates in the pterygoid plexus. It may be called the *vein of the foramen ovale.* It communicates sometimes with the meningeal veins.[1]

328*h*. "The *transverse occipital sinus.*—Three times I came across a sinus which came from the interior spinal sinuses. It passed through the whole basilar groove, in order to enter the transverse occipital sinus" (p. 265).

328*i*. "The *circular sinus of the occipital foramen.*—The interior spinal sinuses which anastomose in the anterior part of the foramen magnum in its median line, do not meet behind; and yet it is these sinuses alone which started the belief in the

[1] This vein is described by Henle (Gefässlehre, 1868, p. 341) as follows: "The cavernous sinus despatches through the foramen ovale a few veins, which after joining some branches of the venæ meningeæ, encompass the third branch of the trifacial nerve in the form of a plexus, and terminate in the venous plexus of the inferior temporal fossa, according to *Nuhn* ('Untersuchungen und Beobachtungen aus dem Gebiete der Anatomie,' etc., Heidelberg, 1849, no. i. p. 6). More rarely the second branch of the trifacial nerve is accompanied too by venous twigs from the sinus cavernosus."

existence of what has been described under the name of the *circular sinus of the occipital foramen.* This sinus, therefore, ought to be considered as exploded" (p. 265).

328*j.* On the basis of his experiments Trolard holds that both the carotids and the vertebral arteries, before entering the cranium, are bathed in venous blood. In respect to the carotids he says that they have their venous bath before entering the cavernous sinuses, and, indeed, while they occupy what he calls "*the carotid sinus.*" Concerning this sinus he says, "The carotid is bathed well in venous blood before plunging into the cavernous sinuses, and this venous blood is conveyed to it by this latter sinus. It is carried off by the inferior petroso-occipital sinus, and by one or two little veins which come from the vein of the foramen ovale, or from the meningeal veins. . . . The venous blood circulates around the carotid in little areolas; wherefore a real sinus is there which may be called the *carotid sinus*" (p. 264).[1]

In respect to the vertebral artery he says: "Fastened anteriorly and interiorly to the osseous wall of the vertebral canal for about one-fourth of its circumference, as to the remaining three-fourths of its circumference it is surrounded by the vertebral vein. The enclosed spaces between the venous and arterial walls give to the vessel an areolar appearance." In the "inter-transversary spaces," Trolard says, the vertebral artery is completely surrounded by the vertebral vein. In conclusion he says: "Should our researches be confirmed, this law would hold good. The arteries which enter the encephalon are bathed in venous blood; the carotids from the moment when they enter the carotid canal; the vertebral arteries from the moment of their entrance into the vertebral canal" (p. 269).

[1] Concerning this *carotid sinus*, says Henle (Gefässlehre, 1863, p. 341): "Into the carotid canal there extends a continuation of the sinus cavernosus (*pars intra canalem caroticum* of the cavernous sinus, Rektorzik) along one side of the carotid artery; and at a variable distance from the inferior orifice of the canal it passes over into a net of very fine veins which engird the carotid artery, and which after being united into one or into several venous stems enter into the interior jugular vein" (*Rektorzik*, "Ueber das Vorkommen eines *sinus venosus* mi canalis caroticus," Wien, 1858).

328*k*. HENLE.[1]—"The lowest or basal layer of sinuses begins at the anterior edge of the middle cranial fossa with the *sinus sphenoparietalis* of Breschet (sinus alæ parvæ), which is 3 mm. wide; and, under the cover of the lateral point of the great wing of the sphenoid bone, takes its origin from a meningeal vein, and in a shallow furrow of the lower plane of this wing moves in a medium direction. It enters the anterior point of the cavernous sinus" (p. 333).

328*l*. "The *sinus cavernosus* is an irregularly bounded bay or inlet between the leaves of the dura mater. Threads run through this receptacle, which is situated along the lateral declivity of the sphenoid bone, above the roots of the great wings of that bone. In addition to the internal carotid artery it contains the abducent nerve, and the plexus of the great sympathetic nerve which encircles the carotid" (p. 333).

328*m*. "The sinus cavernosi of either side are connected by one or several canals, which run along the anterior and posterior walls of the sella turcica, or at its bottom, and which are called the *anterior and posterior intercavernous sinuses.* These intercavernous sinuses, together with that part of the sinus cavernosus which is situated between their origins, form an ample venous ring around the stem of the pituitary gland, which has been called the *sinus circularis.* The canal at the bottom of the sella turcica is identical with Winslow's *inferior circular sinus.* Among the two intercavernous sinuses the one in front is the more powerful one, while the one behind is more frequently absent" (p. 33).

328*n*. "In addition to the superior and inferior petrosal sinuses there are some other canals which originate in the cavernous and intercavernous sinuses, and which in the part of the dura mater covering the cranial declivity form a more or less copious net, which laterally is connected with the interior petrosal sinuses, and in a downward direction empties into the venous plexus of the anterior wall of the foramen magnum.

[1] Henle (Dr. J.), "Handbuch der systematischen Anatomie des Menschen," vol. iii. section i., "Gefässlehre," Braunschweig, 1868.

This net is the *basilar plexus* of Virchow,[1] which is analogous to the venous net covering the posterior plane of the vertebræ. In aged persons the venous spaces are not unfrequently amplified into wide lacunæ, similar to the cavernous sinuses, through which run delicate, reddish trabeculæ" (p. 335).

328*o*. "The *occipital sinus*, which is enclosed in the falx cerebelli, descends either from the point of union of the longitudinal and lateral sinuses, or from the longitudinal sinus alone, or from one of the lateral sinuses. It is either single or double. Sometimes it is wanting altogether. In some rare cases it is a mere channel of communication with the venous plexus of the posterior wall of the foramen magnum, in which case it is of a small calibre. At other times, in the marginal sulcus, near the edge of the foramen magnum, it turns towards the foramen jugulare, either in one arm, or more frequently in two; and before reaching the foramen, terminates in the lateral sinus. For this purpose the single occipital sinus divides into two parts. Out of the angle of division, or out of either of the two arms, it sends branches, anastomoses, into the vertebral plexus of the foramen magnum. . . . When the occipital sinus is double from its origin, each of the trunks represents the string of a bow, the bow itself being described by the lateral sinuses between the centre of the occipital bone and the foramen jugulare" (p. 335).

328*p*. KEY AND RETZIUS[2]—"*The Pressure of the Blood in the Sinuses.*—Since the pressure of the blood in the veins, as is well known, is subject to many changes, and since peculiar conditions prevail, especially in the cranium, it is impossible to determine this pressure with any certainty *à priori*. That this pressure on the whole is low, follows, in respect to the pressure of the blood in the venous system, from well-known physiological laws. In order to obtain some more definite knowledge on this subject, we endeavoured to measure it directly. With the

[1] Virchow, "Untersuchungen über die Entwickelung des Schädelgrundes," Berlin, 1857, p. 48.

[2] "Studien," etc., vol. i., Stockholm, 1875.

kind assistance of Professor Christian Lovén we instituted a small series of such measurements in the longitudinal sinus of living animals (dogs). These experiments, which are always a little difficult, could not be executed without some preliminary loss of blood. Yet the figures obtained express the average value of the pressure. After the dog had been etherized—only large dogs can be used for this purpose with advantage—a longitudinal incision was made down to the bone in the direction of the central line of the cranial roof. In order to hit the wider part of the sinus, with great care as small a hole as possible was made in the posterior portion of the cranium. In doing so, there often arose a considerable hæmorrhage from the diploë, which was stanched by the application of snow. After the sinus had been laid bare to the extent of a few square millimetres, a small incision was made most cautiously into the dural roof of the sinus. The blood rose constantly from the wound in a small pulsating jet. This alone proves the *positive* value of the pressure of the blood in the longitudinal sinus. Immediately after the incision had been made in the wall of the dura, a fine canula of glass was introduced into the opening in the sinus. This canula, which was filled with a concentrated solution of soda, was connected with a manometer. At first, in the beginning of the experiment, a continuous low pressure was indicated, probably on account of the hæmorrhage which just then had happened. Gradually, however, the pressure increased, until at last it reached a value which remained. In order to give an idea of the values obtained, we communicate as an example a series of figures representing the results of one of our experiments. The first numbers express the value of the pressure in millimetres in the commencement of the measurement; the following numbers, however, give the gradually increasing height of pressure. The first column records the height during inspiration, the second during expiration.

Inspiration.	Expiration.
5 Millimetres.	8 Millimetres.
5·5 ,,	9 ,,
6 ,,	9 ,,
7 ,,	9 ,,
8 ,,	10 ,,
8·5 ,,	11 ,,
9 ,,	10 ,,
9 ,,	10·5 ,,
10 ,,	12 ,,
12 ,,	14-16 ,,

"From these figures an idea may be obtained of the gradual increase of the pressure. During inspiration it rose from 5-12; and during expiration from 8-14, and at last to 16. After this height had been reached, the pressure remained. The entire change thus moved between 5 and 16. On account of the coagulation of the blood in the canula, the measurement in this, as well as in all the other experiments, could not be extended over half an hour. . . . Similar results were obtained in the other experiments.

"The results of these experiments may be summed up as follows:—

"(1) There is a *positive* pressure in the longitudinal sinus in its normal condition; which pressure amounts to about 10-14 mm. of mercury.

"(2) By respiration a variation is caused to this effect, viz. during inspiration a lowering of the mercury from 0·5-1-2-3-4 mm.

"(3) A small arterial pulsation could also be observed simultaneously in the manometer."]

ANALYSIS.

329. BEFORE entering analytically or from experience upon an investigation of the nature and the uses of the sinuses, we shall have to premise some universal statements respecting the generation of the blood, and the causes of its circulation; for there is a continuous connection of causes.

330. In respect to the *generation of the blood.* The cerebrum, by its own power, brings up from the body, or from the kingdom of its heart, a blood of a better description; that is, a blood which is lighter, softer, more fluid, and more easily resolvable into its constituent parts. The spirituous essence which is extracted thence by the cortex it transmits into the medullary fibres; but the residual blood, that is, that which is heavier, hard, sluggish, and more terrestrial, it consigns to the sinuses, chiefly the longitudinal. This blood the cerebrum forwards as far as the receptacles or winding trunks of the lateral sinuses, where it restores and vivifies it with new spirit, and sends it full of alacrity by the jugular veins towards the subclavian vein and the superior vena cava. There at the first threshold of the body it is received and welcomed by the new chyle, rich with saline and other terrestrial elements drawn from the vegetable and mineral kingdoms, which is brought thither by the thoracic duct. This chyle is poured on the blood which arrives freighted with spirit, and is taken thence into a large chymical vessel where the fluids for the composition of the blood are prepared, namely, the right chamber of the heart. Thence the whole blood is diffused over the lungs, in order that it may imbibe still purer material elements floating in the bosom of the atmosphere. From the lungs it is conveyed back into the left chamber of the heart, more florid and liquid, and thence it is distributed through

the universal arteries of the body. These vessels separate the lighter from the heavier, and the purer from the grosser, and they remove out of circulation the antiquated and hardened blood-globules and the refuse matters. It hence appears that in investigating the natural things of the kingdom of the soul we have to proceed from the source to the streams, and back again from the streams to the source; that is, we have to learn from the brain, and at the same time from the body, what the sinuses of the dura mater do, and what it is that they convey within themselves. It follows thence that for the exploration of the sinuses we require an intimate knowledge of the brain as well as of the body; otherwise we look upon the dura mater and its sinuses, as upon the gates and columns of a temple, from without, with the doors closed to the holy of holies.

331. Each of the sinuses of the dura mater from first to last conveys its own blood, of a distinct quality. The longitudinal sinus contains the grossest blood, thick, sluggish, and pituitous; for the grey matter, which in great abundance constitutes the circumference of the cerebrum, drains off the spirit and the better life of the blood, and commits it to the fibres. The straight sinus, on the other hand, holds a blood which is less gross, sluggish, and effete, because deprived of less spirit; for its blood is extracted, collected, and conveyed from the inmost sanctuary and the most hidden recesses of the cerebrum, cerebellum, and medulla oblongata, and from all their corners, fissures, passages, ventricles, and plexuses; as, for instance, the choroid. The lateral sinuses have but a small supply of veins, and attract a less gross and obtuse blood. The receptacles of these sinuses, or the portions of each of them which swell out big, and which with their curved bellies stretch towards the temporal bone, admit a few more venous streams, which are larger, and turgid with a more vigorous blood. The superior and inferior petrosal sinuses, however, convey thither from the pituitary gland and its vicinity, and from the cavernous sinuses and the circular sinus by which that gland is surrounded, a most refined virgin blood, but newly wedded to an abundant supply of spirits, which have

been distilled in the large laboratory of the brain. In this manner the blood, which but recently was indolent and torpid, is reanimated, and rendered vigorous and liquid; and in this condition it is poured into the so-called internal jugular veins, by which it is committed to the left subclavian vein, where it meets with the chyle and the lymph of the body, and also encounters the superior vena cava, which flows immediately into the right auricle and into the right ventricle of the heart. It appears hence that every sinus carries a blood of a different character; that the first or highest sinuses convey one which is dark, thick, and almost obsolete; those in the middle one which is finer; but the last and lowest a blood which is fresh, resplendent, and virginal. In this manner the cerebrum by its alternate animatory motion at one time enriches the blood—which is as it were the soul of its body—by its life, *i.e.* its spirit, and at another it deprives it of the same; and then again it recruits and revives it.

332. As the longitudinal sinus receives a sluggish and indolent blood in addition to that which it imbibes from its parent, the dura mater, it is furnished with a robust membrane and a strong bridle, *i.e.* with muscular bands, membranous expansions, ligamentary cords, and muscular grains at its extremity, which have been woven into it for the purpose of restoring its tension and the modulus of its elasticity; and in addition it is furnished with bag-like anfractuosities, folds, and impervious crypts, as is the case with the heart. It is also strengthened by its attachment to three bones, and increases in strength along its course. For the membrane or coating reveals the quality of the blood which moves within it; the one is most accurately accommodated to the other; and nature never exceeds, even by a hair-breadth, its measure, ratio, and necessity. The following are additional causes of this; namely, that the longitudinal sinus passes forth almost in a parallel line with the horizon, and that its blood does not descend by its own weight, as is shown by the brute animals which walk with their heads bent downwards. Further, the blood of the straight sinus either at its terminus, or by the orifice which is close to it, ejects its contents forcibly, and

opposes force by force. Again, the cerebrum sometimes acts placidly; and the lateral sinuses, already swollen with the confluent blood, do not admit any additional blood, unless it is powerfully injected into it. And, finally, the sphere of activity of the longitudinal sinus is very great; it extends in fact over the whole spacious dura mater, which is tightly stretched over the whole brain, and underneath so many bones, down to the basis of the cranium.

333. From the above-mentioned cause, or from the diverse nature of the blood, it follows also that the straight sinus is encased in strong coverings, muscular bands, and tendinous fibres, and encircled by a strong duplicature of the dura mater, and likewise enclosed by the hemispheres both of the cerebrum and the cerebellum, which, while they are being expanded, press upon the sinus with their united force; whence it arises that it squeezes out its blood like a torcular or winepress, and vomits it forth out of its mouth, with its lips as it were rolled back. This sinus, although it is short, and pours out a blood which is not as lifeless as that of the longitudinal sinus, nevertheless does not run out in a downward direction; but in man, with his head erect, it has an oblique, upward direction. It is also the first source of the expansile motion of the whole dura mater and its processes.

334. From the same cause it follows that the lateral sinuses are strengthened with only a few ligaments, and that the cords in them are placed more obliquely near their coating; and that after a short distance from their place of origin they terminate in their receptacles.

335. From a similar cause it follows that the superior and inferior petrosal sinuses are invested with a thinner membrane, and are not provided with those auxiliary armaments with which the higher sinuses are furnished; for they convey a purer and more liquid blood, nay, the very spirit, which by the least impulse is led to prosecute its way and to reach its goal. Its goal, however, is the extremity of the lateral sinuses, and the beginning of the jugular vein, where all the kinds of blood have

already met, and these they refresh and vivify with the new spirit of the cerebrum.

336. The receptacles or asylums of the sinus-blood, being bound by their connection with the cranium, have a coating furnished with a retiform plexus of filaments, and, besides, they creep in a sinuous course to the [temporal] bones, with the purpose, it seems, of being distended, dilated, and erected, and again of being reduced to a smaller calibre. They rest on the cerebellum, and are rolled by it; and by the alternate motion of that organ the mass of the blood within them is stirred up, and its various ingredients are mixed. Besides, in company with the petrosal sinuses they apply themselves to the temporal bones into which the ear and its tremulous tympanum are dug; for the tremor causes the lighter particles and purer essences of the blood to vibrate, and it thereby accommodates and intimately mixes them. It hence appears that animal nature does not make the least step without having use for its end.

337. In order that the quantity and quality of the venous blood of the cerebrum may be equal in both lateral sinuses, and likewise in the jugular and subclavian veins, as well as in the vena cava, a provision sometimes is made by a transverse sinus, which conjoins the two lateral sinuses; and also in other places by anastomoses within the cerebrum and the cerebellum themselves, as well as in the neighbourhood of the heart, outside the brain; for the left jugular vein communicates with the right, where it enters the subclavian. In this wise the mass of the liquid is equalized, and an equilibrium produced both in the quality and in the quantity of the blood.

338. Concerning *the circulation of the blood.* The causes of this circulation, or of the motion of the heart, are proximate and remote. The proximate cause of the diastole of the heart is the continual pressure and action of the blood of the two venæ cavæ upon the right auricle of the heart; and the proximate cause of its systole is the stretching of the nervous fibres; which yield as long as the blood acts, and which act in order that the blood may yield. Remote causes, however, are the

lungs, the cerebrum, cerebellum, medulla oblongata, and spinal marrow. The lungs by admitting the blood from the right ventricle of the heart, and diffusing it over their whole organ, and also by keeping the pericardium in the universal motion: the cerebrum by propelling its blood by its own power towards the jugular veins, and pouring upon it the spirituous liquid, and also by acting upon the muscles of the body: the cerebellum by pushing the blood, also by its own power, and thus from a living source, into the superior vena cava; and by filling and animating the cardiac nerves, nay, and even the arteries and veins, with a spirituous fluid [the nervous juice]: the medulla oblongata and the spinal marrow by transmitting blood into both venæ cavæ, and especially into the superior cava by the azygous vein. Nor is it necessary that the periods of their animation should coincide with those of the alternate motion of the heart.

339. The cerebrum and cerebellum propel the blood collected in the sinuses out of the receptacles into the jugular veins; the jugular veins determine it towards the superior vena cava, and immediately into the right auricle. The right auricle is as it were the pivot and hinge on which depends, and from which flows forth, the systole and diastole of the ventricles of the heart. From this motion, however, arises the circulation of the blood through the arteries and veins, and in this wise there is a connection of causes from the first to the last. The cerebrum and cerebellum move in the realm of the first causes or of the very principles; for they act from themselves or from causes in themselves. The heart, however, and the remaining members of the body are in the sphere of the intermediate and ultimate causes; for they do not act from themselves, but from causes out of themselves. On this account the blood of the sinuses of the brain is as it were a living source of the circulation not only of the blood, but also of the remaining fluids, which describe special circuits, subordinate to that of the blood.

340. Thence is derived the cause why the longitudinal sinus mostly opens with its mouth into the right lateral sinus, and

at the same time inclines thither a short portion of its own trunk; or why it opens into both sinuses, but by a foramen which is more open towards the right one; or again, why it diverges, but rarely, towards the left sinus: for it follows continually the stream of the blood, just as the tenor of the effects is determined by its causes. The right jugular vein, namely, approaches more nearly to the point whence the subclavian veins branch out, and it thus pours the blood by the shortest passage into the vena cava and into the right auricle of the heart. When, therefore, the auricle is in want of new blood, the nearest receptacles are called upon to supply the deficiency. These, however, are conjoined to the heart by the right jugular vein, and hence the right lateral sinus, together with the longitudinal sinus, are the nearest receptacles; wherefore from its very beginning, and when it was but a little rivulet, this latter sinus was accustomed to be bent in this direction, and thus is spontaneously drawn thither. It is to be observed that the longitudinal sinus is the first which takes its origin in embryos.

341. As the effects flow from the efficient causes by a continuous subordination, the position of the auricle itself, and the influx of the blood into it from the sinuses of the brain, must furnish the reason why the azygos vein (vena sine pari) in man presses on the right and not on the left side; why the right lobe of the lungs with the right portion of the diaphragm exceeds in bulk and extent the left; why the pylorus, together with the duodenum, the gall-bladder, and the liver occupy the right side; why the eighth pair of nerves which accompany the jugular vein out of the brain, and especially its right branch, enter into the auricles and ventricles of the heart: besides several other points which do not belong here.

342. Hence also must be derived the reason why the straight sinus throws its blood into the left lateral sinus, and thus supplies its contents to the left subclavian vein, whither the new chyle is conveyed by the thoracic duct: for that sinus is opened after the longitudinal sinus has been brought into play, and the chyle is only at a later period brought up from its

mesaraic or mesenteric glands. But when the blood of this sinus by the traction of the intermediate vessels is carried towards the right auricle, the straight sinus then discharges itself into the terminus of the longitudinal sinus. Meanwhile, lest such direction of the venous streams as has been inaugurated in early age, *i.e.* a direction more to the one than to the other side, should interfere with and injure the vital motions and the economical state of the kingdom, anastomoses have been established not only between the sinuses and the veins of the brain, but also between the veins of the neck.

343. This also furnishes the reason why the straight sinus is recumbent on the cerebellum, and not on the cerebrum; and also why the receptacles of the sinuses, *i.e.* the lateral sinuses, creep over the hemispheres of the cerebellum; for the motion of the cerebellum is constant, while the cerebrum sometimes animates unequally.

344. Thence also it follows that all the sinuses of the head converge and terminate in the receptacles, *i.e.* the lateral sinuses; and that they are capacious troughs which serpent-like wind themselves first in one and then in another direction, in order that as much blood may be stowed up in them, and by them supplied to the heart, as is required for the perpetuity and the renovation of the state and motion of both.

Thus the cerebrum and cerebellum are constantly engaged upon, and watchful over, the affairs of their kingdom, and in things general they act prudently from things singular; if, therefore, at each interval of their animation they should give out all their blood, or always the same quantity, they might easily prevent the circulation of that blood of the body which rises up by the inferior vena cava. On this account the two brains, which feel inmostly in themselves whatever happens outside of themselves, start the circles and send out the liquids, according to every use, want, and necessity of their body. This is the work of the soul, which, like a queen from its palace, or from its two brains, provides and cares for the singulars in each part, and for all things in the general. In short, the brain sends into the chamber of the heart so much blood, and of such a quality, as the heart demands, *i.e.* as the whole system of the body demands from its heart.

345. The mode also appears hence by which the brain acts upon the sinuses, and by means of the sinuses upon the dura mater. How it acts upon the sinuses. There are a kind of tendinous fibres, muscular bands—*lacerti*[1]—and little vessels which from the pia mater enter the coatings of the sinuses, and from the dura mater pass into the borders of the hemispheres, where there is as it were a mutual fitting together. Order consequently returns to and fro, from part to part. The fibres of the pia mater insert themselves into the roots of the muscular bands—*laccrti*—and of the cords which constitute the texture of the sinuses; then in addition plenty of blood-vessels adjoin themselves to these pioneer fibres which lead the way, and they enter in troops into the nearest lamina of the dura mater, or into both walls of the sinus, and the duplicature or the process underneath. In this wise they are mutually attached by a sort of network; and the brain by the pia mater acts upon the sinus from without, and also from within upon the very texture of the coating of the sinus; nay, it even acts upon the ligamentary cords in its cavity, at regular intervals, whenever it folds itself together, and unfolds itself again.

346. The ends of the muscular bands—*laccrti*—also appear sometimes interwoven with little grains, which are like little miliary glands [glandulæ Pacchioni]. By their means the tension and the lost modulus of elasticity of the membrane seems to be restored, and each individual part is adapted to the harmony of the various motions; wherefore they are not present in all subjects in equal number or size, nor are they of the same shape and in the same places. That they are muscular conglomerate bodies appears from their dissemination, when they are present, between the roots of the cords, as well in the longitudinal sinus as in the beginnings of both lateral

[1] Heister and Winslow say that the pia mater is connected with the dura mater only by means of veins; see the Chapter on the Pia Mater.—SWEDENBORG.

sinuses; for they are situated both within and outside the sinuses. And it appears also from the number of filaments which are extended from them, as well as from their structure, so far as it has been discovered. A congeries of them is said to be enclosed within a special membrane in order that a general, and at the same time a just particular ratio of expansion may return thence into the coating of the sinus, and into its cords, cellules, little valves, and interfluent little veins.[1]

347. The venous vessels of the cerebrum, however, and partly also those of the dura mater inserted into these veins of the cerebrum, introduce themselves into the sinuses from the sides and from the bottom, and they fill and expand their cavities. What a force of expanding the tubes and vesicles is contained in these inflowing little rivulets appears satisfactorily from water and air injected by means of small syringes; for the influx of venous blood and the expansion of the sinuses is rendered easy and feasible whenever the mouths of the sinuses are opened, when the little valves recede, the wrinkles unfold, and the processes of the dura mater are relaxed. The texture, indeed, of the filaments of the inferior lamina and of the duplicature of the dura mater, and likewise the insertion of the muscular

[1] Swedenborg seems to have hesitated somewhat in assigning their proper function to the *glandulæ Pacchioni.* In the first draught of his work on the Brain, written between 1735 and 1738, he considered them as muscular grains scattered through the ligamentary cords of the longitudinal sinus, and the office he assigned to them was to aid in restoring to the muscular cords of the sinus their lost modulus of elasticity (see Photolithographed MSS. vol. iv. p. 75). In a second paper on the Dura Mater, written in 1740 (*Ibid.* vol. vi. pp. 293-295), he regarded these glandules as elongations of the arachnoid membrane with the subarachnoid liquid circulating through them. On account of the deficiency in the anatomical experience of his time, he, however, failed in discovering any special use in corpuscles organized in this manner; and therefore in his final induction of the function of the dura mater, which is detailed above, he returned to his first idea in respect to their structure and function.

Modern science has confirmed Swedenborg's second induction, according to which the *glandulæ Pacchioni* are elongations of the arachnoid membrane (see above, no. 244*f*). By showing, further, that the subarachnoid liquid not only circulates through them, but also oozes out through their surface and mingles with the venous blood of the sinus, it has enabled us to assign another equally important use to these corpuscles (see footnote to no. 264).—EDITOR.

bands—*lacerti*—is such that the little veins hasten of their own accord into the sinuses, as into so many asylums of reception. The sinuses, therefore, are expanded for this reason, in addition to that which arises from the mediating tissue [between the pia and the dura mater].

348. But when the order of the motion of the brain is inverted, it exerts contrary effects upon the enclosed sinuses; the streams are pressed upon and closed up; the sources of venous blood cease; for the cerebrum then folds in its edges, and the side contracts the roots of the cords; it folds the cavernous coating, and with its valves closes the doors. The tendons running obliquely into the opposite walls, with their roots deeply embedded in the membrane, by their force contract the cavity; for, like the arteries and veins of the body, the sinuses are then reduced to their smallest calibre. On this account the sinuses are constricted, and from a cylindrical they assume a prismatic shape.

349. The descent of the blood is then facilitated, for the channel of the sinus from a slender beginning grows into a wide cavity; it increases also in strength and active forces; and, finally, it rushes in a declivity downwards, and aided by its own weight the blood actually lapses down.

350. All sinuses go through their systaltic and diastaltic motion together; one more swiftly and ahead of the others: for both the cerebrum and the cerebellum, and also the medulla oblongata and the spinal marrow, are expanded and constricted together; hence also their action upon the sinuses, and therefore the action of the sinuses themselves, is simultaneous. Their systole and diastole, however, like that of the veins of the body, lacks a sensible pulsation; and it can, indeed, be noticed with the eye, but not felt with the finger. For the pulsation of the arteries arises by a successive transfluxion in the imperceptible moments of a certain undulation, and thus by a successive elevation in each particular place of the vessels through which the transflux takes place. It is different, however, in the sinuses, and similar there to what takes place in the veins; for there is

not an undulatory stream of blood coursing through them, but they are filled and also emptied all at once. This, then, is the reason why neither the motion of the brain, nor that of the sinuses, which is synchronous with the motion of the lungs,[1] can be explored by the experience of touch; and why only the other motion, or the pulsatile motion of the superior lamina of the dura mater, which is consonant with that of the heart, is thus perceived.

351. The expansion of the sinuses happens at those times when the brain contracts, and the constriction of the sinuses when the brain expands;[2] for while the two brains are swelling, and while they fill up the spaces under the cranium, the sinuses which pass between them yield and are acted upon; and they thus have a contrary alternate motion. This is plain in the case of the straight sinus, which is situated in the middle axis of the processes of the dura mater, and is enclosed by both hemispheres of the cerebrum and of the cerebellum: when both of these swell, this sinus cannot help being reduced to its smallest calibre, since it is pressed upon on all sides, and rendered narrow. The same reason holds good with the other sinuses which are urged into their triangular form when the cerebrum and cerebellum at the edges of their hemispheres are pressed inwards. Such also is the case with the lateral receptacles of the sinuses which are extended over the hemispheres of the cerebellum; for when the cerebellum is expanded, these venous troughs are pressed into the walls of the bones of the cranium, and then the blood is squeezed into the jugular veins.

352. The sinuses are lengthened whenever they are expanded in width, and they are shortened whenever they are constricted; that is, during their diastole they increase in size in both dimensions, and during their systole they decrease in the same manner, just as is the case with the arterial and venous vessels of the body. This is indicated by their folds, sinuosities, blind foveæ, pervious mouths, and ligamentary cords; all of which

[1] See the experience related in no. 328*p*.—EDITOR.
[2] See no. 328*p*.—EDITOR.

shrink and are closed up, and fold together and corrugate the coating, when the sinuses contract; and *vice versa.* The sinuses possess a greater power of expansion and contraction at their bottom, and a lesser power under the bones from which they are suspended, but suspended in such a manner, that for the above reason they retreat from the bones somewhat.

353. *How the brain by means of the sinuses acts upon the dura mater* may be concluded from what precedes. When the two brains expand they assume a more convex and globular form; their edges, therefore, all around, and hence also near the great longitudinal fissure, become rounded as it were, and they thus press upon the accumbent sinuses. They hollow out their walls in correspondence to their own convex form, and force the appended duplicatures of the processes down, where the fissures are drawn together more closely. By this means the dura mater is stretched out, and its expansile motion caused, the origin of which is spread over as much space as is occupied by the longitudinal, lateral, and the other sinuses. The dura mater, however, by its own elasticity strives to become relaxed; when, therefore, the brain relapses into its systaltic motion, it contributes its help towards the elevation of the falx and of the other processes, whose edges have a free play, and also towards the return of the sinuses into their diastaltic motion. On this account the universal dura mater is a common tendon, and it is the impulsory cause of the reciprocal motions of the brain and the sinuses; for whenever the brain is expanded, the dura mater by means of the sinuses is put on a stretch, and whenever the brain contracts, the dura mater is unstrung. Hence there results a reciprocal action, and, as in the case of all mechanical powers, the passive force corresponds to the active force.

354. We may add here that in the first rudiments of the fœtus there appears over the brain a certain sinus swelling with blood, which is constantly beating, and which communicates immediately with the new little heart, or with the first and last vesicle of the little heart. This sinus is dependent upon the motion of the brain, and it urges the tender and delicate

chambers of the heart into their systaltic and diastaltic motion, or introduces and initiates them into it. For the lateral sinuses and the jugular vein are then not yet in existence, and the animatory motion of the brain does not yet differ in its intervals from that of the heart. All things are then concordant, attuned, and simple; the motion of the heart agrees with that of the brain; and the heart, left to itself and to the body, does not yet almost exclusively sway the sceptre, but beats safely under the auspices of the brain. At that time the entire volume of the blood of the body is taken to the brain, and the entire volume of the blood of the brain is carried back into the body, describing a simple circuit. For this purpose a passage is then granted to the blood through the foramen ovale and the ductus arteriosus; but both these passages are closed after birth. The order, however, is inverted, and the state changed, as soon as the brain awakens to the use of its own will; that is, as soon as the infant is thrust out of its uterine prison, and with the doors closed behind, is ushered into the open air and into the battle-ground of the world. A state of dependence, nevertheless, remains; for the heart is still kept under the auspices of the brain and of the sinuses, but more remotely. This is the cause of the great similarity between the superior longitudinal sinus and the heart, both being furnished with similar cords, sinuosities, lacunæ, little columns, valves, and other things, which in a like proportion are not found combined anywhere else.

CHAPTER VI.

THE ARTERIES AND VEINS OF THE CEREBRUM, CEREBELLUM, AND THE MEDULLA OBLONGATA.

355. THERE are two arteries coursing through the entire head, the carotid and the vertebral; and also two veins, the jugular and the vertebral. Those which enter the cranial cavity, or depart thence, are called internal. Each of these will be treated separately.

A. *The Internal Carotid Artery.*

356. Far down in the thorax the carotid arteries arise from the aorta bent upwards in the form of a plough-handle; the right carotid usually departs from the subclavian artery. Both trunks ascend freely near the side of the trachea and the larynx, in the form of a straight stalk, almost without any branches.

The internal carotid leaves the common trunk near the larynx, and enters the carotid canal in the petrous portion of the temporal bone. This osseous canal opens exteriorly in the middle between the basilar process of the occipital bone and the styloid process, only a short distance below the Eustachian tube; where also, between the apex of the petrous bone and the upper margin of the aperture, there is occasionally a little sesamoid bone. The artery, after having laid aside its muscular coating,[1] and invested itself with dura mater, and, according to

[1] Swedenborg in maintaining here that the internal carotid on entering the cranial cavity lays aside its muscular coating, bases himself on the testimony of Boerhaave (in no. 363). Burdach, among modern authors, expresses a similar view; for he says: "After gaining an entrance into the cranium, the arteries give up their fibrous sheath, which passes over into the filamentous coating [dura mater] of the brain; and in correspondence with the sphere to which they henceforth belong, they acquire a peculiar character: for . . . together with their

others, with periosteum as a covering, enters the cranial cavity near the side of the posterior clinoid processes, and soon continues its way to the anterior clinoid processes of the sella turcica; and after emerging through a foramen out of its cavernous sinus, it ascends to the cerebrum, and disperses itself through its substances.

Its passage through the osseous canal of the cranium, which lies almost horizontal, is angular and serpentine; its outlet towards the base of the sphenoid bone near the clinoid processes is curved; its crossing through the cavernous sinuses of the sella turcica is variously inflected and winding; and its egress out of these sinuses towards the region of the infundibulum is sinuous. There it approaches nearer to the carotid of the other side, with which in many cases it communicates by a short, transverse arterial branch [anterior communicating artery]. Here the artery divides and spreads into two or three stems, one of which, taking leave of the other, rises in an anterior direction; and after describing there a semicircle among the olfactory nerves to which it also sends out a few shoots, approaches again its companion of the other side, and is reunited with it by a short anastomosis. Soon after this they each separate into branches, of which the first [the middle cerebral artery] seeks the anterior lobe of the cerebrum, distinguishing it from the posterior; and then cleaves it, drawing furrows or

annular, muscular fibres they lose every vestige of a proper or independent irritability by becoming thin-coated" (see below, no. 383*a*). Other authors, again, while granting that the internal carotid on entering the cranium gives up its fibrous sheath, do not admit the fact of their likewise laying aside their muscular coating; and yet they agree that the coatings of the arteries in the brain become very much thinner. So Quain says: "Some arteries want sheaths, as those, for example, which are situated within the cavity of the cranium." And afterwards he continues: "Some arteries have much thinner coats than the rest, in proportion to their calibre. This is strikingly the case with those contained within the cavity of the cranium and in the vertebral canal; the difference depends on the external and middle [muscular] coats, which in the vessels referred to are thinner than elsewhere" (see below, no. 383*c*). It stands to reason, however, that when an artery "loses its annular, muscular fibres," or when its muscular coating "in proportion to its calibre" becomes much thinner, "every vestige of its independent irritability," as Burdach says, "is lost."—EDITOR.

sulci through it. The second branch [the anterior cerebral artery] goes to a lobe, which by some is called middle; another branch of it bent back in front runs backwards over the corpus callosum; this in some subjects is double or bifidous. The third branch, which is either an associated branch of the second, or an independent one, starts for the posterior lobe; so that all three are propagated in every direction into the cerebrum and its substances. The two remaining stems [the posterior branch of the anterior cerebral artery (see Winslow, no. 361) and the posterior communicating artery which produces the choroid artery, and in conjunction with the basilar artery the posterior cerebral artery] ramify in a similar manner. They are distributed in the form of capillaries over the pia mater, with which they are covered, representing creeping ivy and twig-work of blood-vessels; and at last they become lost in the cortex of the cerebrum, or in its interior substance. It is also worthy of attention that the carotids pass almost around the chiasma of the optic nerves, as well as around the region of the infundibulum; and that upwards, especially towards the front part, they divide the surface of the cerebrum almost into peninsulas, which become conspicuous with their prominences or promontories standing apart.

A notable fact in connection with the entrance of this artery is this, that the nervus vagus or pneumo-gastric nerve leaves the cranium through the same carotid foramen, or else enters through the same; and that in crossing the same it is attached to the carotid by a kind of cellular, filamentous, or membranous vagina, or by filaments in the form of plexuses creeping through its proper and its adscititious coating. These filaments which adhere to the artery are like tender shoots, of slight consistency, reddish, and sometimes mucilaginous, according to Winslow.

The carotid artery likewise communicates by the dura mater in the cavernous sinuses with several nerves, which on the point of leaving the brain first salute the carotid, but soon divide into their various branches, and are spread over their provinces. In the neck also it communicates with the highest ganglion of the sympathetic nerve, which, together with the nervus vagus (pneumo-gastric nerve), passes in the middle between the aforesaid artery and the jugular vein. The carotid too reclines upon the dura mater, where in the form of a window it closes up a certain blind foramen which does not open outwards, between the sella turcica and the petrous bone; from the cavernous sinuses also it sends into the same membrane a kind of reticular plexus, whence in some subjects there arises a rete mirabile.

Meanwhile the internal carotid arteries, not long after emerging out of the obscure hiding-places of the sella turcica, and while they are beginning to introduce themselves between the lobes, and to advance towards the interiors of the cerebrum for the purpose of forming the choroid plexuses—by throwing out an intermediate branch [the posterior communicating artery], associate themselves with the vertebral arteries, in order that from the united trunk of the vertebral arteries, which is also called the basilar artery, a transit may be established on both sides into the carotids, or from the carotids into the vertebral arteries.

357. WILLIS.[1]—"The trunks of the carotid arteries, ascending upwards, are presently divided on both sides into an anterior and posterior branch. Either pair of these, inclining towards each another, are mutually conjoined: moreover, the posterior branches so joined are united with the vertebral branches coalescing first into one trunk. The vertebral arteries emerging from the foramen magnum, at first are divided as they pass through the sides of the medulla oblongata; then they are united in its base and produce a single channel, which, upon meeting with the posterior branches of the carotids, becomes joined with them. From the place of their junction an important branch [the posterior cerebral artery] ascends on either side under the edge of the cerebrum, and after having been conveyed over the crura of the medulla oblongata is divided into very many slender shoots or capillaries, some of

[1] "Cerebri Anatome," etc., London, 1664, 16mo; chaps. i., vii., viii.

which ascend to the little glands situated near the cerebellum, but the rest constitute the arterial part of the choroid plexus. Before the anterior branches of the carotids are united they send out from themselves on either side an important branch [the middle cerebral artery], which creeping upward like a boundary stream, distinguishes either hemisphere of the cerebrum as it were into two provinces; but after the aforesaid branches are united, presently departing again from one another, they are carried to the forepart of the cerebrum, and thence bending back they advance between its hemispheres on the corpus callosum. All these arteries, before and after effecting their mutual junctions, send out shoots and little branches on every side, which not only creep through and intimately engird the outermost circumference of its sphere, but also its sanctuary and the more interior recesses (pp. 7, 8). . . . The carotid arteries of one side, in many places, are united with the carotids of the other side; and besides, the vertebral arteries of both sides are thus joined with one another, and they are also inserted into the posterior branches of the carotid arteries which have previously been united. The anastomoses of the carotids in most animals are effected near the base of the cranium under the dura mater, and indeed in different ways; with some by the vessels of a rete mirabile, communicated from one side to the other; in others an arterial channel is produced between the carotids, whereby the blood may be carried from one side to the other, and *vice versa;* . . . so that if perchance one or two passages should be stopped, there might easily be found another passage to take their place: as, for instance, if the carotids of one side should be obstructed, the vessels of the other side might provide for either province. Also as to the vertebral arteries there is the same provision made. Further, if both carotids should be stopped, the offices of each might be supplied through the vertebral arteries; and so, on the other hand, the carotids might supply the deficiency caused by a closing up of the vertebral arteries. . . . This may be proved by an experiment. I have often injected into either carotid artery a liquor dyed with ink, and presently the branches on either side, yea, and the chief shoots of the vertebral arteries, were dyed with the same tincture; nay, if such an injection, through one single passage, is repeated several times, the vessels creeping into every corner and secret recess of the cerebrum and cerebellum will become imbued with the same colour. In those heads which have the rete mirabile, the tincture being injected on one side, will permeate the retiform plexus of the vessels on either side. . . . On dissecting not long ago the body of a certain man who had died from a large cancer within the mesentery which had at last become ulcerated, I found the right carotid where it emerged into the cranial cavity quite bony, or rather stony, its cavity being almost entirely closed up; so that the influx of blood being denied to this passage, it seemed wonderful to me why this person should not have died of apoplexy before; from which indeed he was so far removed that he enjoyed to the last moment of his life the free exercise of his mind and of his animal functions. Nature, however, had substituted a sufficient remedy against the danger of apoplexy; namely, the vertebral artery of the same side, where the carotid was wanting, with its bulk enlarged, became three times as big as the arteries on the other side; because the blood which was excluded from the carotid artery, added itself to the wonted supply of the vertebral artery, and flowing with a double flood into the same vessel, had thus dilated the channel of the artery beyond measure. This man about the beginning of his illness was tormented with a grievous pain of the head towards the left side (pp. 49-51). . . . Either artery, while passing through the sphenoid bone, is so curved and twisted in its ascent, that the blood before reaching the cerebrum, by a repeated opposition of shores, as by the interposition of a bar, may be retarded and flow less rapidly. But this is not brought about in all animals by the same means; for although the ascent of the artery in all animals is oblique and winding, yet in some, for instance, in man and in the horse, where it is twisted about to a greater extent, it passes on to the cerebrum in a single and undivided trunk; in most of the other beasts, however, it passes through the skull in a smaller circuit, and presently escaping out of sight under the dura mater, it is broken up into retiform plexuses, which are called rete mirabile. . . . In the first place, we notice in man that the carotid artery enters the cranial cavity a little further back than in any other animal; namely, near that foramen through which the lateral sinus passes out on entering into the jugular vein; for with the rest the artery emerges into the cranium under the extremity or under the acute process of the petrous bone. But in the human head, after being carried about over a larger circuit, this artery reaches the base of the cranium near the fossa made by the lateral sinus in its passage, where being at once twisted, it enters the canal dug for it in the sphenoid bone, and for greater safety it is besides invested with an additional thicker coating. . . . The artery having emerged out of the bony canal, lays aside this additional coating; and being now well defended within the cranial cavity, goes forward clothed only with its proper coating, and creeps for some distance under the dura mater along the side of the sella turcica; and in the middle of the passage being depressed as it were into a valley, it emerges soon again, until it reaches the head of the sella turcica. There it is again bent and twisted in a certain manner; and after having pierced the dura mater, is carried towards the cerebrum. . . . The conformation of the carotid artery in the horse comes nearest to its structure in man; for there also the artery enters the cranial cavity further behind, making a larger circuit than in other beasts. Afterwards, its trunk being twisted over a certain compass, and then depressed a little, it proceeds to the side of the sella turcica, with its cavity still broad and distended. . . . Between the trunks of both carotids a transverse canal is formed as a by-way. . . . In addition, certain shoots are sent out from the trunk of either artery, and inserted into the pituitary gland. . . . In the sheep, calf, hog, nay, in the dog, fox, cat, and other four-footed beasts, this artery is divided into retiform plexuses. . . . In those animals where the rete mirabile is found, the carotid artery about to enter the cranial cavity is not carried over such a long circuit, but emerging near the sella turcica, is at once divided into small shoots Laterally, however, many little rivulets are derived from it in every direction. These little rivulets are partly ingrafted in the venous passages of the sella, and in the vessels on the other side, and partly they are carried into the pituitary gland, and partly, after describing a circuit, they return into the former trunk of the artery. . . . If below the skull an ink-coloured liquor is gently and gradually injected, it passes through the straight passage and is at once carried to the cerebrum, nor does it infect with its colour the lateral vessels of the plexus; but if this liquor is squeezed in rapidly and impetuously, it runs at once into the plexus, and blackens the lateral vessels of the plexus, and even the part of the pituitary gland on the other side, entering into its interior structure" (pp. 53-56). See also the author's plate to chapter vii. of his "Anatome Cerebri," where the curved ascent of the carotid is represented; namely, while ascending into the cranium, where it is enclosed in the carotid canal, and moves within the additional coating. On the same plate also is represented the ascent of the carotids in the horse, and their communication by a transverse branch, and also the manner in which they send out little shoots into the pituitary gland, and in which they divide and ascend with a double trunk. In his first, and especially in his second plate, may be seen in what manner the posterior branches of the carotids are united in a sheep's brain, where they meet the trunk of the vertebral arteries, and how, being divided, they encompass like shores all that area where the pituitary gland is situated and the optic nerves coalesce, and whence they send out an important branch sidewards into the middle of the bulbous surface of the olfactory nerves; and, finally, how they meet above between the aforesaid nerves, and after being divided again are joined by anastomoses, when they are reunited near the crista galli.

358. VIEUSSENS.[1]—"As soon as the carotids through the carotid foramen have entered the cranial cavity, they are furnished with

[1] "Neurographia Universalis," etc., lib. i. cap. vi.

an additional thicker coating borrowed from the dura mater, and they enter the cavernous sinuses which are placed at the sides of the sella turcica, and there they send out several shoots. But after laying aside this additional coarser coating, and after proceeding beyond the cavernous sinuses, they at once, on both sides, send out an offshoot to the infundibulum, and another to the optic nerves. Immediately afterwards an arterial branch is discovered between the carotids and the superior branches of the vertebral artery, through which, as through a canal, two large seas intercommunicate, and which thus opens into both. If both optic nerves are folded back, and the posterior lobes of the cerebrum are a little drawn apart from the anterior lobes, and if these also are separated a little from one another, it at once becomes apparent that both carotids are divided into two branches, an anterior and posterior [the anterior and middle cerebral arteries], and also that many little branches run out therefrom. On approaching the anterior part of the medulla oblongata, they pass off into innumerable capillary shoots, which are inserted into its cortical substance; innumerable little capillary veins proceed thence in return which tend towards the straight sinus, and terminate in it. The anterior branches of the carotids [the anterior cerebral arteries], which are smaller than the posterior [*i.e.* the middle cerebral], on retreating from the trunks coalesce between the roots of both olfactory nerves in the middle of the basis of the cerebrum; and almost immediately after their conjunction they become again disjointed, and after sending off some smaller shoots which accompany the olfactory nerves, they are again united and form a common canal which is divided into three branches. The two lateral branches provide for the anterior lobes of the cerebrum; and some of their offshoots, which on both sides are bent in an anterior direction, and accompany little veins terminating in the lateral sinuses, by exceedingly small foramina wrought into the ethmoid bone leave the cranial cavity—if you exempt one or two little offshoots which pass into the interior of the frontal bone—and they terminate partly in the papillose flesh underneath the ethmoid bone, and partly in the membrane which lines the internal surface of the nares. The third and middle branch, however, of the common canal mentioned above (after having produced some exceedingly small shoots, which on entering the anterior ventricles of the cerebrum besprinkle their walls and the septum lucidum, and at last terminate in the choroid plexuses) climbs over the corpus callosum, and is cleft into two branches, which making a manifold subdivision are inserted into the back of the corpus callosum, as well as into the falx cerebri, and into those parts of both hemispheres of the cerebrum which touch the sides of the falx. The posterior branches of the carotids [the middle cerebral arteries], retreating from the former, divide the basis of the cerebrum into two lobes, or as it were into two provinces, the posterior of which seems to be much broader than the anterior. The further they retreat from the trunks, the more do they ramify, so as to be broken up into innumerable shoots. These are interwoven with most diminutive little veins terminating in the sinuses of the dura mater, and they pass off into retiform plexuses hanging down from the pia mater; and afterwards they again partly enter the interiors of the medulla oblongata, or irrigate the posterior lobes of the cerebrum, and almost the whole of its convex portion (pp. 31-33). . . . Otherwise scarcely any, or only very few, arteries are seen in those parts of the dura mater which are situated near the sinuses, or which are immediately underneath the cortex. Only a few arteries we are able to observe in the fornix; not many are noticeable in the medullary substance of the posterior edges of the cerebrum, or in the corpus callosum, or finally in that portion of the medullary substance which constitutes the upper portion of the anterior ventricles of the cerebrum. . . . Few arterial shoots are seen in the whole external surface of the medullary substance of the cerebrum and cerebellum which is immediately underneath the cortex. . . . That medullary substance, however, which is farthest removed from the sinuses, is permeated by the greatest abundance of little arteries, especially in the lowest part of the fourth ventricle, where there is a choroid plexus. In the medullary substance which constitutes the walls of the lateral ventricles, and in that which proximately embraces the medulla oblongata, a much larger number and a greater apparatus of arteries is observed. . . . If the carotids are tied near the middle of the neck, and a saffron-coloured spirit of wine is injected into one of the two carotids, and if this experiment is several times repeated; if then the head is opened, it will be found that the cortical substance only is imbued with a saffron colour, and that the natural colour of the medullary substance is not at all changed, although several of the vessels by which it is permeated seem full of the injected saffron colour. . . . Hence it appears that all the vessels which enter the substance of the brain terminate in its cortex, and that the arteries are not continued into the veins" (pp. 39, 40). See on this subject his plates iii., iv., v. In his plate iii. it appears how the carotid bends itself over the corpus callosum, and presently is cleft into two branches, reaching even to the region where the cerebellum enters the medulla oblongata, and which branches almost during the whole of their passage send out shoots in an oblique and even downward direction into the substance of the cerebrum, both towards its exteriors and interiors. In his plate v. are seen the mutual approximations of the carotids above the junction of the optic nerves, and also their separation in a sort of semilunar form, and their repeated conjunction, whence one branch is sent out over the corpus callosum, but two others around a certain small anterior lobe, distinct from the superior lobe, where the substance of the cerebrum in the neighbourhood of the crista galli and of the frontal bone exhibits the appearance of a circle or of a crown, from which as from a centre, or from its proximate circumference, serpentine ridges as it were are determined on both sides. I recollect also having seen this little portion developed in a spiral manner from a centre in the brain of a sheep. In a similar manner is represented the mode in which the carotids are thrown out between the remaining lobes, and thus run in a serpentine manner in the smaller sulci between the convolutions of the whole cerebrum. Concerning the circumflexion and the wonderful ramification of this artery in the cerebrum, see Bidloo's storehouse.[1]

359. RIDLEY.[2]—"The carotid, after a curved passage (which is very well expressed in a figure of Dr. Willis) from the place where it begins to enter the basis of the cranium (which is from the styloid process of the temporal bone) to the place where, on the inside, it passes through the dura mater, and ascends into the brain (which is at the foremost internal process of the sphenoid bone), makes very nearly an inch and a half of distance. After this crooked passage into the brain the carotids are propagated quite through its substance, having first divested themselves of that thick coating borrowed from the dura mater during their stay in the passage aforementioned; but not without the mediation or intervention of the pia mater, which membrane all the branches of the aforesaid, as well as the vertebral artery, more or less first prop themselves upon, before they enter on and disperse themselves through the substance of the brain itself. This is very finely expressed in a cut of Placentius at the end of Spigelius; insomuch that Molinetti (with whom also agrees Marchetti) looks upon it as only a production of those numerous vessels. Nevertheless, all those little ramifications both of the carotid and vertebral arteries—namely, those from the carotid artery, which as soon as it gets through the dura mater, and parts with its borrowed coat, are sent to the infundibulum, the olfactory, and optic nerves, together with those other branches of the vertebral artery which accompany the third, fourth, fifth, sixth, seventh, eighth, ninth, and tenth pairs of nerves, inasmuch as they enter not the brain itself—are altogether exempt from that membrane" (pp. 32-34). In his figure 1 the branches which run out between the trunks of the carotid and vertebral arteries are most excellently represented, and also how from the point of conflux they are bent towards the interiors of the

[1] Swedenborg means here Bidloo's celebrated work entitled "Anatomia Corporis Humani," in 105 plates, Amsterdam, 1685, in largest folio.—EDITOR.
[2] "Anatomy of the Brain," etc., chap. iv.

cerebrum for the purpose of forming the choroid plexuses; for as he describes, "There are two large branches of the vertebral artery, sometimes seeming as though they came from the communicant branch on each side, from the first of which the choroid plexus has its chief origin, and from the last the choroid plexus of the fourth ventricle."

360. WEPFER.[1]—"I followed the carotid artery to the styloid process, and noticed that it is there curved, and that under the petrous portion of the temporal bone it continues its way obliquely towards the front through the carotid canal. . . . On emerging upwards out of the canal it ascends a little towards the posterior process of the sella turcica. Soon it bends again and descends to the sides of the sella turcica and of the pituitary gland; it presently shows itself again, having become immersed into, and affixed to, the deep and conspicuous sinus cavernosus under the anterior process of the sella turcica, with a view of rising thence again, and of perforating the dura mater at the sides of the infundibulum. During the whole of this passage it remains whole and undivided, and I did not notice that it sent out any branch of any consequence to the neighbouring parts. . . . If this artery is cut off near the end of the osseous canal, both below and also above, where it is about to pierce the dura mater; and if it is extracted, it is so winding as to represent a Latin capital letter S, inverted and lying on its back, which letter is also represented by the artery itself. . . . As long as its parts are left near to each other, and as it were crowded together, they present the appearance of a kind of bladder placed at the sides of the sella turcica, and they exceed a nutmeg in size; they fill up the entire space under the dura mater in that place. . . . The anterior bony process of the sella turcica in some subjects has grown fast to its anterior and upper side, either directly or through the mediation of cartilage, so that this portion of the artery has to pass through an oval foramen, or, if you prefer, a bony ring, before reaching that part of the dura mater which

[1] "*Observationes Anatomicæ ex cadaveribus eorum quos sustulit apoplexia,*" Amsterdam, 1681, 8vo.

it has to pierce. I have seen this foramen, or rather this bony semicircle, in some crania; frequently, however, it is absent; perhaps its delicate portion by boiling or some other cause had been removed. . . . The lower part of this artery appears here more bulging and wider than it does in leaving the carotid canal, or on entering the brain (pp. 37-40). . . . Besides, I several times injected water coloured with saffron into the artery before its division into its external and internal branches, and I discovered that the arteries of the dura mater were rapidly coloured, and filled with the liquid, while scarcely any yellow colour at all appeared in the internal carotid on account of the curve which that artery makes near the styloid process on entering the carotid canal (pp. 102, 103). . . . After these arteries on leaving the carotid canal have entirely perforated the dura mater, having done so, they remain yet a little while together, for they are conspicuous for a short distance on the dura mater; but then they are divided into an anterior and posterior, but not into an exterior and interior stem. The anterior stem after crossing the optic nerve, sends out at once an artery of considerable size [the middle cerebral artery,] approaching in thickness the quill of a chicken, into an important and deep fissure of the cerebrum [the fissure of Sylvius] which is there. . . . This artery and its shoots, while pursuing their course in the depth of the anfractuosities and sulci, and while tending upwards towards the superior longitudinal sinus, are for the most part free, and occasionally they appear as conspicuous objects annexed to the pia mater, with which they are interlaced by shoots which are about to depart into the substance of the cerebrum; and when these shoots or certain fibres are broken off, the arteries themselves may be drawn up and pulled out. . . . From this artery, therefore, branches are furnished to all the lateral sulci (for there is scarcely any sulcus at the bottom of which an artery is not creeping upwards) in the anterior part of the cerebrum; these branches for the most part creep through their depth, but sometimes they climb over the ridges, and descend into another neighbouring sulcus.

While with this object they pursue their course among the sulci, they supply minute twigs to the pia mater; for this not only connects the tops of the sulci, but also conjoins and lines them everywhere below. These twigs are partly interwoven into the substance of the pia mater, and are met by other vessels of the same size, and in a similar manner divided into minute filaments, which take their origin in the longitudinal sinus, and with which they are conjoined in an interesting manner; and partly they penetrate this membrane, and dip down into the substance of the brain; and this happens, not at rare intervals, but in very numerous places, as I have often seen. Lately only I saw it in an extraordinary manner in the brain of Victor, an old man of seventy years, who died of phthisis. After having preserved his brain for three days, with a view of examining other things, I was able to detach the pia mater easily from the brain, and on pulling it off, I observed that very many filaments which were continuous with vessels of the pia mater entered into the substance of the cerebrum; and on breaking them off, minute little openings were conspicuous in the surface of the cerebrum, which seemed to have been made with the point of a lancet. The more, however, the arteries which thus freely proceed in the sulci approach the longitudinal sinus, the smaller they become on account of their frequent subdivisions; but I have not yet observed any of them entering immediately into this same sinus. I have only repeatedly seen how the ends of the smaller ascending shoots were joined with the smaller descending shoots. The remaining part of the anterior stem of the carotid [the anterior cerebral artery] advances forward on the basis of the cerebrum, in the direction of the crista galli; and where the cerebrum in that place is divided into two hemispheres the right branch of the carotid is joined with the left. In some subjects I ascertained plainly, by inserting a probe, that they are thoroughly united; at a short distance afterwards they are, however, separated again, and pursue in company their journey to the crista galli, to which they are annexed. In the ox a small branch is transmitted exteriorly through the crista. While thus pursuing their course forwards they repeatedly send out branches into the great longitudinal fissure of the cerebrum, and again into other fissures which open into the front parts of the cerebrum; these branches by subdivision supply all the sulci, the pia mater, and the cerebrum, with twigs in the same manner as stated above. The right and left anterior stems of the carotids after being attached to the crista galli, continue their way in an opposite direction, and turning around, travel between the two hemispheres of the cerebrum backwards over the corpus callosum. During the whole of this road the two stems of the carotid are free, except where by emissary twigs they cohere with neighbouring parts. Not far from the crista galli each stem is divided into a higher and lower branch, which offer very many twigs to all the sulci on either side of the great longitudinal fissure; many of these twigs also in this place enter manifestly into the cerebrum at the sides, and into the corpus callosum on the bottom, so that on pulling at a branch I was able to draw out of the cerebrum distinct little arteries in addition to those little arteries which out of the said twigs are interwoven into the pia mater, and which under the form of an assemblage of capillaries dip into the cerebrum. They send twigs also from both sides into the falx cerebri. What remains of these arterial stems passes off into the straight sinus, into which they are most evidently inserted. . . . The posterior stem of each carotid [the posterior communicating artery] first sends off a branch [the choroid artery] which enters the ventricles of the basis of the cerebrum where they are exposed, and which passes along the sides of the choroid plexuses under the edge of the cerebrum, supplying to it filaments as well as arterial capillaries: what remains of this branch is communicated to the straight sinus, and to the sulci around this sinus. Afterwards another branch [the posterior cerebral artery] departs from the posterior stem, and passing along behind the crura of the fornix it enters those sulci which are there, and it is carried through them in various modes; nay, it transmits also twigs to the straight sinus, and on both sides to the pineal gland. After the posterior stem of the carotid has proceeded about an inch further, it is joined with the vertebral artery which has become bifurcated a second time, and that a continuous duct is the result of this junction, I have proved by passing a probe through it. From this posterior stem innumerable arterial capillaries are disseminated everywhere by means of a little membrane like a cobweb, which clothes here the medulla oblongata; from this same little membrane an immense number of little arterial filaments enter the medulla oblongata here, and also the basis of the optic thalami. This you may freely see by pulling off this thinnest kind of membrane, which is easily done; for when the arterial threads are torn off, you are then able to obsèrve an immense number of little openings made as it were by the edge of a knife, and you will notice the very white medullary substance variegated in a wonderful manner, and set off by deep scarlet spots of blood" (pp. 106-112).

361. WINSLOW.[1]—"The internal carotid on each side enters the cranium by the great carotid canal, the course of which for some reason is angular and winding. The inner surface of this canal is lined by a production common to the dura mater and the inferior pericranium, to which the artery adheres only loosely by a filamentous substance; for there, around the carotid, creep plexiform filaments of the great sympathetic nerve. Having passed through the carotid canal, the artery immediately bends upwards through a notch or little channel in the base of the sphenoid bone; and immediately after its entrance into the cranium it penetrates to the cavernous sinuses at the sides of the sella turcica; where having made a third curvature, it rises upwards in order to emerge out of the sinus, and then bends a fourth time around the anterior clinoid process from before backward. On passing through the cavernous sinuses it is bathed in their blood as it were, together with the third, fourth, fifth, and sixth pairs of nerves. After this fourth and last curvature, the internal carotid having now

[1] "Exposition," etc., section x.

reached the side of the infundibulum, and consequently being very near its companion of the other side, these two arteries communicate in many cases by a short, transverse arterial production [the anterior communicating artery]. At this place each of them divides into two stems, one anterior and the other posterior; and sometimes into three, in which case there is a middle branch between the two former. The anterior stem runs first of all forward under the basis of the cerebrum, a little distance from the same stem of the other carotid. They approach each other again under the interstice between the two olfactory nerves, communicating by a very short anastomosis, and sending small twigs to that pair of nerves. They afterwards separate, being each divided into two or three branches. The first branch of the anterior stem [the middle cerebral artery] goes to the anterior lobe of the brain. The second [the anterior cerebral artery], which is sometimes double, is inverted on the corpus callosum, to which it gives ramifications, as well as to the falx cerebri, and the middle lobe of the cerebrum. The third, which is sometimes a distinct branch, sometimes only an additional branch to the second, goes to the posterior lobe of the cerebrum. This third branch is sometimes so considerable as to deserve to be reckoned the middle of the three principal stems. The posterior stem [the posterior communicating artery] communicates first of all with the vertebral artery of the same side, and then is divided into several branches on the superficial convolutions of the cerebrum, and between these convolutions all the way to their bottom. . . . All these different ramifications run in the duplicature of the pia mater, from which they receive a kind of additional coat; and the capillaries being distributed upon it in a reticular manner, afterwards penetrate the cortical and medullary substance, in which last they terminate insensibly" (nos. 164-170).

362. MORGAGNI.[1]—"I certainly am not able to see how such a figure as represents the curvatures of the carotid artery simply in that manner in which they appear when projected in a per-

[1] "Adversaria Anatomica," vi.; Animadversio, vi.

pendicular line, may be said to express these curvatures best.[1] For this artery while crossing the substance of the cranium is also transversely curved; as has been represented by Lower in another figure which presents the artery to view, not laterally, like Willis's figure, but from behind" (p. 6). In the figure in Lower's work may be seen how the carotid proceeds in the neck by the side of the nervus vagus and the great sympathetic nerve.

363. BOERHAAVE.[2]—"In passing to the cranium both carotids are defended by the trachea and their deep situation, without undergoing any pressure or incurvations, and hardly sending off any branches on the way. Having almost reached the cranium, they each of them send off an external carotid, and then entering through a bony canal, in which they are secured, they are bent therein anteriorly, put off their muscular coating, and give branches to the dura mater. Inside the cranium they are each again defended by the sides of the sella turcica and a process of the dura mater; and then expanding themselves on the surface of the pia mater and nerves, they divide into branches, which by means of the pia mater are inserted into the brain itself" (§ 231).

B. *The Vertebral and Basilar Arteries.*

364. The vertebral artery is the second of those which enter the cranial cavity. Under its patronage the cerebellum, the medulla oblongata, and the spinal cord, so far as it is contained within the cervical vertebræ, chiefly perform their corporeo-vital functions. It is also double, and arises from the subclavian artery, a little beyond the place where the carotids take their origin; it is encompassed by the thymus gland with the aorta. In order to be protected by a bony support both arteries pass through a foramen wrought into the transverse processes of the

[1] Morgagni speaks here of figure 1 in plate on p. 56 in Willis's "Cerebri Anatome," edition of 1664, 8vo.—EDITOR.

[2] "Institutiones Medicæ," etc.

cervical vertebræ, and after having sent out branches thence into the spinal marrow and its coatings, and into the neighbouring muscles, by a slanting ascent they make for the superior condyles. There the vertebral artery repeatedly bends in the form of a knee; first around the second of the highest vertebræ of the neck, called the dentata, and then presently back around the first cervical vertebra, the atlas, and afterwards in a considerable lunar arc outwards, whence, however, immediately it bends back again. During this passage, having sent off branches into the occiput and into its membranes, as well as into those of the neck, it crosses the foramen magnum where the first nerves of the spinal column, or the last of the brain, pass out. It is now furnished with a coating from the dura mater, and by a short circle inside the cranial cavity turns towards the hinder part of the medulla oblongata, and there on each side it forms a little trunk called the *posterior spinal artery.* Other shoots rise thence into the appendage of the medulla oblongata, and into its pyramids and olivary bodies; and likewise into the fourth ventricle and its choroid plexus; while other branches spread thence more widely into the cerebellum and its interior cortex; and the blood which they do not expend, they send into the veins and into the straight sinus. Without mentioning the blood which this artery distributes over the dura mater which is stretched over the occipital and temporal bones.

The second or anterior branch of this artery proceeding first in a horizontal direction and then in one slightly ascending over the basilar process of the occipital bone, meets its associate artery of the other side which passes forth in a similar manner, and approaches towards it. After sending off twigs to the seventh, eighth, ninth, and tenth pairs of nerves, the two arteries coalesce in one trunk which is called the basilar artery; they meet almost at their first approach to the peduncles of the cerebellum. From the angle formed by the two arteries where they coalesce, or from either of the trunks, almost where they are surrounded by the ninth pair of nerves, the *anterior spinal* *artery* departs; to the sides of which several little streams are added below, where anteriorly it descends in a long line in the course of the spinal cord.

The *basilar artery*, or the united trunk of the vertebral arteries, runs in a channel formed by fibres which descend from both sides of the pons Varolii with a view of coalescing, and in human subjects it continues in a longer, and in the brains of sheep and of other animals in a shorter, course towards the roots of the infundibulum which are a little elevated; on the way it supplies some of its blood to the pons Varolii which it crosses, or to its grey substance. Upwards, however, it sends branches into the very central space, and into the infundibulum, and likewise into the beginnings of the third, fourth, fifth, seventh, and eighth pairs of nerves; other branches it sends into the sides of the medulla oblongata; others into the posterior part of the larger ventricles, into the thalami of the optic nerves; and there during its ascent it sends branches into the pineal gland, the corpora quadrigemina, as well as into the internal surface of the aqueduct of Sylvius, and likewise into the surface of the calamus scriptorius.

The two most prominent arches which depart from the common trunk towards the sides, and which thence bend inwards, approach the choroid plexuses which are extended through four ventricles, and there in conjunction with the carotids they give birth to a lymph-like secretion. In a similar manner they insinuate themselves between the cerebrum and cerebellum, into the pia mater belonging to each, and provide for the posterior surface of the former, and the anterior surface of the other.

Finally, by two elbows passing out from the common trunk, or stretching upwards from the two above-mentioned arches, or sent down to them, the vertebrals conjoin themselves with their carotids, and by passing all the way around the area of the infundibulum, like streams or shores they enclose it with their common blood, separating it from the neighbouring parts. The above-mentioned arches of the basilar artery, the progenitors of the choroid plexuses, in the very angle or bosom whence they diverge from each other, embrace the third pair of nerves, about to depart towards the muscles of the eye.

365. WILLIS.[1]—"Near the extreme end of the medulla oblongata, where it is about to pass into the spinal marrow, the vertebral arteries reach its sides. As they are smaller, they enter the cranium with less provision than the carotids; for they are not first diversified into retiform plexuses, nor are they carried in long journeys through roundabout ways; but either artery passing directly over the sphenoid bone embraces the medullary caudex on either side. Although they proceed for a little space divided, yet afterwards they are united, and in a single channel or bed they meet the posterior carotids, inclining mutually towards one another; and so all the branches meeting as it were in a cross-road, mutually embrace one another. The vertebral arteries on emerging first into the cranial cavity, are disposed differently in animals from what they are in man; in the latter they proceed for a while along the sides of the medulla oblongata parallel with one another; afterwards they mutually incline towards each other by a kind of semicircular curve, and presently meet. The branches which at first pursue their way separately, sometimes are two, one on either side; sometimes they are three; and in this case, besides the two former, another branch is produced in the middle. In animals, however, either trunk of the vertebral artery, on its first approach to the medulla oblongata, inclines at once in an acute angle towards the other, and in a short time they are united. The vertebral arteries, just like the carotids, during their progress send out manifold branches, with an innumerable series of twigs, which cover the medulla oblongata, the cerebrum, and all their recesses and cavities, and irrigate them with a copious stream of blood" (p. 25). "But as the carotids carry the share of the blood destined for the cerebrum, so the vertebral arteries serve chiefly for irrigating the cerebellum and the posterior part of the medulla oblongata. . . . The vertebral artery arising from the subclavian,

[1] "Cerebri Anatome," etc., London, 1664, 8vo.

in its whole ascent through the hinder part of the head, passes through foramina wrought into the transverse processes of the vertebræ, till it reaches the basis of the occiput. There each is bent down on either side, and is admitted into the cranial cavity through the foramen magnum; and is then carried along the side of the medulla oblongata. As soon as it is led forth out of the region of the cerebellum, it sends out branches on either side, which cover the surface of the cerebellum, and besides on its back constitute plexuses which are no less important than those commonly called choroid, which are thickly interwoven with large glands. . . . Besides, below the cerebellum both vertebral arteries, inclining mutually towards one another, are united" (pp. 56, 57). In his plate i. you may see both arteries with an intermediate branch passing over the pyramidal and olivary bodies, and near the place of ascent engirded by the ninth pair of nerves; in a like manner you may see them united into a common trunk which is prolonged towards the carotids; its branches also are represented which tend towards the infundibulum. It is different, however, in the brain of sheep, in plate ii.

366. VIEUSSENS.[1]—As the carotid arteries provide the necessary supply for the cerebrum, so the vertebral arteries care for the whole of the cerebellum, and also for some parts of the cerebrum. For after they, during their course under the cranium, have sent out two branches which are distributed over the posterior part of the dura mater, they at once throw out two or three shoots. Some of these during their passage towards the interiors are bent down and incline towards the posterior and lateral parts of the spinal marrow; others, however, have an upward tendency; they climb over the olivary bodies on both sides, and after passing over the posterior edges of the fourth ventricle, they meet at its extremity a great number of little veins which tend towards the fourth ventricle; many little glands also are placed between them, so that one plexus is formed of the many little arteries, veins, and glands,

[1] "Neurographia," etc., lib. i. cap. vi.

which are in this wise woven together. The structure of this plexus is not unlike that of the two choroid plexuses which belong to the lateral ventricles of the cerebrum.

"After the vertebral arteries have emitted those slender shoots which have been described above, two sets of branches are sent out from each of them, from their interior side. The lower of these, which are thicker, describe a kind of semicircle, and ascend to the posterior part of the medulla oblongata, where they give out slender, little shoots. Two of these shoots which are bent downwards on either side, meet about the beginning of the posterior region of the spinal marrow, and at the same time by coalescing form one small canal, which occupies the posterior and middle part of the spinal marrow. On this account it is called the *poste, ior spinal artery.* Other shoots, however, are utilized partly in forming the choroid plexus of the fourth ventricle, and afterwards two branches of this kind of the vertebral arteries passing off into other, and again into other shoots, provide for the posterior, and especially for the convex portion of the cerebellum; they also meet with two veins which in like manner pass through the posterior, convex region of the cerebellum, and terminate in the straight sinus. Besides, certain slender shoots from the above-mentioned veins and arteries pass into the interiors of the cerebellum, and extend as far as its grey substance which below we shall call 'rhomboid.' The two superior branches of the vertebral arteries which take their origin from their interior sides, before coalescing, meet a third branch, which sometimes emerges above their point of coalescence, and sometimes springs out of their junction. These arteries are united about the beginning of the interior region of the spinal marrow, and produce the *anterior spinal artery.* It is to be observed that the spinal artery sometimes takes its origin from one shoot of the vertebral arteries, which occasionally arises above their coalition, and sometimes springs out of their junction. Several little branches are given out of the external sides of the vertebral arteries, and these accompany certain nerves proceeding out of the medulla oblongata. At last the one of the vertebral arteries approaches very closely to the other, and after giving out the above-mentioned shoots, they form one large canal which on account of being composed of the united vertebral or cervical arteries we call the 'cervical artery' [basilar artery]; its length is about two finger-breadths, and being inserted into the middle of the base of the pons Varolii it gives out several small branches on both sides. These branches penetrate the grey substance not only of the above-named pons Varolii, but also of the medulla oblongata, and they are inserted into it by a great number of capillary ends; there also they meet a great number of the same kind of capillary veins, which after emerging out of the same grey substance tend towards the straight sinus and empty their contents into its cavity. After the basilar artery has sent out the above-named little branches, near the upper portion of the pons Varolii, it is divided into two equal branches, which we call the superior, and also the larger [the posterior arteries of the cerebrum]. These branches near the anterior region send out on both sides two sets of shoots; the first and smaller of these, which are divided into several capillary branches and present the likeness of a small plexus, irrigate the depressed space between the infundibulum and the pons Varolii, and after constituting two whitish prominences near the infundibulum, they provide for the infundibulum, and also for the optic thalami. Other shoots, however, approach the carotids and terminate in them. The two superior and larger branches of the basilar artery in a posterior direction give out also on both sides certain small offshoots, which after accompanying little veins terminating in the lateral sinuses, are intertwined with fibrils of the nerves of the fifth, seventh, and eighth pairs, and after crossing at last the nerves of the third and fourth pairs, by insinuating themselves between the posterior part of the cerebrum and the anterior part of the cerebellum, they pass off into very many shoots. Some of these are continued to the posterior lobes of the cerebrum, others to the tentorium, and still others to the anterior part of the cerebellum, being appended to the pia mater, and are disseminated over all these parts. Other shoots, however, of the same branches of the basilar artery, being inserted into the sides of the medulla oblongata, and coupled there with certain little arteries from the carotids, in an ascending direction enter into the posterior part of the cavity of the lateral ventricles of the cerebrum; and in their ascent give out certain most slender little branches to the pineal gland, the corpora quadrigemina, and to the internal surface of the fourth ventricle. At last the farthest, anterior shoots of these arteries, after entering the ventricles of the cerebrum, recline on the thalami optici, and there, together with little veins tending towards the straight sinus and emptying into it, they form a choroid plexus on each side" (pp. 33-35). See also his plates iv., v., and xviii.

367. RIDLEY.[1]—"The vertebral artery enters the brain at the last and largest foramen of the skull, contrary to what Dr. Willis affirms, coming thither on each side out of the hole in the transverse process of the first vertebra of the neck, after a very remarkable curved manner (see plate i., *EE*), and by no means like the drawing and description given by Dr. Lower and Dr. Willis. It also ascends laterally on the medulla oblongata as far as the beginning of the pons Varolii, where they meet together in one single trunk continuing the whole length thereof, by Vieussens called 'cervical artery' [basilar artery]; after which they either send forth two branches to, or receive two from the carotid artery, by means whereof there is a communication between these two large blood-vessels. . . . These communicant branches are very ill drawn in Bidloo's plate ix., but very well in Vieussens' plate iv. . . . It is worth noting that in both these places the main artery from which these branches spring is much more taper or conical, and the succeeding exporting vessels far less both in number and size than those of the carotid artery here, whose foremost and hinder lateral ramifications between the lobes of the brain bear an over-proportion to the trunks from whence they come. . . . Besides, the basilar

[1] "Anatomy of the Brain," etc., chap. iv.

artery here is so far from being conical, that being made up of two vertebral arteries joining together, it is much wider than either of them single" (pp. 35-38). See his plate i., and notice there the remarkable curvature of the vertebral artery as it passes between the first vertebra and the occipital bone, and again where its branches pass over the pyramids and form one trunk, with the anterior spinal artery springing out of the right artery, and with the ramification of the united artery spreading in every direction over the pons Varolii, and a division into two large branches which, as he says, "sometimes seem as though they came from the communicant branch on each side, from the first of which the choroid plexus has its chief origin, and from the last the choroid plexus of the fourth ventricle" (Explanation of Plate I., *g*).

368. WEPFER.[1]—"The vertebral arteries emerge out of the nearest foramen, that large orifice through which the spinal marrow descends. They progress to the sides of the medulla oblongata, to which they give out numerous branches, and which they embrace on all sides; their shoots also penetrate the medulla at this place; for when the medulla is pressed, not only bloody points appear, but I have also seen in it the ramification of vessels; these are likewise met by another kind of little branches which imbibe the superfluous blood, and carry it to the lateral sinuses, on which account they have been falsely supposed by some to be arterial vessels. . . . From these branches of the vertebrals, both before they coalesce into one trunk, and afterwards, numerous little branches are sent off towards the cerebellum, where they are distributed and intercommunicate in the same manner as is the case with the arteries in the sulci of the cerebrum; these little branches terminate in the inmost and posterior region of the cerebellum. A short distance before the common trunk formed by the union of the vertebral arteries is again divided into two stems, a large branch [the superior cerebellar artery] is given out on either

[1] "*Observationes Anatomicæ ex cadaveribus eorum quos sustulit apoplexia*," Amsterdam, 1681, 8vo.

side towards the anterior part of the cerebellum. These branches, after being subdivided into others, spread almost over the whole anterior surface of the cerebellum, and they irrigate its membrane and medulla with their vivifying juice and spirits. After the vertebral arteries for a distance of about two inches have remained united, they are again divided into two stems or trunks. From either stem little branches are given out on each side which tend towards the straight sinus, after this has bifurcated, and towards the choroid plexus. After the vertebral trunk [basilar artery] has again been divided, each stem, running a short distance, is united to a branch of the posterior carotid; and these, after coalescing into one trunk, give out little branches to all the posterior sulci of the cerebrum; in the same manner altogether in which the considerable anterior branch enters into a large sulcus, diffusing itself through all the anterior sulci, and giving out little twigs to the pia mater and the cerebrum" (pp. 108, 109).

369. WINSLOW.[1]—"The vertebral artery goes out from the posterior and upper side of the subclavian, almost opposite to the internal mammary and cervical arteries. It runs up through all the holes in the transverse processes of the vertebræ of the neck, and in its passage sends off little twigs through the lateral notches of these vertebræ, to the spinal marrow and its coverings. It also gives arteries to the vertebral muscles, and to other muscles near them. As it passes through the transverse foramen of the second vertebra, it is generally incurvated, to accommodate itself to the particular obliquity of this foramen. And between this foramen and that in the first vertebra it takes another large turn in a contrary direction to the former. Having passed the transverse foramen of the first vertebra, it is considerably incurvated a third time, from before backwards, as it goes through the superior and posterior notch in this vertebra. At this third curvature it sends off a small branch which is ramified on the exterior and posterior parts of the occiput, and communicates with the cervical and occipital

[1] "An Anatomical Exposition," etc., sections iv. and x.

arteries. Having afterwards reached the foramen magnum of the occipital bone, it enters the cranium and pierces the dura mater, where it may be called the 'posterior occipital artery'" (section iv., nos. 95-97).

"The vertebral arteries enter through the foramen magnum of the occiput, having first pierced on each side the dura mater at the same place where the sub-occipital nerves, or those of the tenth pair, pierce it on taking their departure; the arteries in this place lying above the nerves. At their entry into the cranium they send each several ramifications to the cauda of the medulla oblongata, and to the olivary bodies and pyramids, which ramifications are distributed on the sides of the fourth ventricle, produce the choroid plexus, are spread on the whole surface of the cerebellum, insinuate themselves between the strata, always invested by the duplicature of the pia mater, and are at length lost in both substances of the cerebellum. Afterwards the two vertebral arteries turn toward each other, for the most part immediately under the posterior edge of the great transverse or semi-annular protuberance of the medulla oblongata [pons Varolii], where they unite and form one trunk. This trunk passes directly from behind forward, under the middle of the pons, and partly in the middle groove of the convex surface of the pons, at the anterior edge of which it terminates. In its passage through the groove this trunk sends off several small branches on each side, which surround transversely the lateral portions of the pons, being partly lodged in the small lateral grooves of these portions. These lateral branches are afterwards distributed to the neighbouring parts of the cerebrum, cerebellum, and medulla oblongata. This common or middle trunk of the vertebral arteries having reached the edge of the pons, is divided again into two small branches, each of which communicates with the trunk of the internal carotid on the same side. Instead of this bifurcation, the two last or most anterior lateral branches send sometimes a small branch forward, which forms anastomoses with the internal carotids" (section x., nos. 171-175).

C. *The Ramification of the Arteries and Veins through the Pia Mater.*

370. Willis.[1]—"As the pia mater which envelops the whole brain and its parts, receives the arteries which ascend towards it from a fourfold fountain, so also it abounds throughout with veins which are sent out from four sinuses. These vessels, which intercommunicate, are interwoven with one another, and by shoots thrown out from each and mutually encountering they are in various ways interlaced, and thus almost everywhere constitute retiform plexuses. These plexuses do not only occur on the surface; but whenever, while dissecting, you are trying to separate parts from each other without destroying their unity, this kind of plexuses formed by blood-vessels are found. If, indeed, you take out the mass from the cranium and examine it, this membrane which fastens together the tops of all the sulci and interstices, and lines them with a texture of vessels, causes the whole surface of the brain to appear like a ball covered with a network of embroidery" (p. 8). "Besides, the pia mater, throughout its whole extent, is covered with plexuses of arteries and veins, and to a certain extent is interlaced with them, and thus with innumerable rivulets irrigates all the spaces of the cerebrum and cerebellum" (p. 48). "About these sanguiferous vessels which cover the pia mater, we notice that when the arteries and veins which proceed from opposite sources meet each other, they not only, as is customary in other parts of the body, through individual shoots which are ingrafted upon one another, immediately transfer the burden which they contain; but after being mutually interlaced and interwoven, they also constitute everywhere wonderful plexuses, in which there are most frequently inserted very small and exceedingly numerous glandules" (p. 51). "If you inject the carotid with a darkened liquor, besides tinging everywhere with the same colour the offshoots

[1] "Cerebri Anatome," etc., London, 1664, 16mo.

of he vessels, it will also exhibit here and there in the substance of the cerebrum darkened points. Besides, if the cerebrum of a living animal is dissected, a florid blood issues not only from the cortex, but also from its medullary portion" (p. 52). "We also observe that these arteries and veins, altogether differently from what they do in almost every other part of the body, do not arise near to one another, and attend one another as companions, but proceeding from opposite ends, they meet everywhere mutually; that is, the arteries ascend from the base of the skull, and by creeping through the whole send upwards shoots and branches, which are met by venous vessels arising from the sinuses, and carried downwards. On this account the streams of blood, everywhere in the brain, seem to balance one another; namely, in this way that the smaller shoots of the veins follow or match the greater branches of the arteries, and on the other hand, the smaller branches of the arteries the trunks of the veins. These vessels are also variously and very much ingrafted upon one another, not only arteries upon veins, but what is more rare and singular, arteries upon arteries" (p. 49).

371. VIEUSSENS.[1]—"The dura mater is certainly irrigated by more vessels; but the pia mater is fitted out with a more elegant apparatus of the same; for it supports not only the veins which emerge out of the substance of the brain, but also all the arteries which are inserted into it. These vessels, however, are divided into innumerable and most slender shoots, which may almost be called insensible; these are almost everywhere in a wonderful manner folded together, and form retiform plexuses which are spread out on the pia mater. These plexuses generally escape the eyesight, but they are very conspicuous in persons who have been strangulated, or who have died from madness" (p. 31).

372. How these vessels run out between the sulci and folds, and at the same time in an oblique direction across them, may be seen in Ridley's plate i., in Vieussens' plates ii., iii., v.,

[1] "Neurographia," etc.

and in Willis' plates i. and iii.; likewise in the two plates of Bidloo and Ruysch. There it may be seen that whilst the arteries run almost longitudinally through the very sulci of the cerebrum, and likewise through the diminutive gyres of the cerebellum, the veins do not occupy the furrows or depressions in the surface of the cerebrum, but they hasten in an oblique direction over the very ridges towards their sinuses, and while they associate themselves with others, with their united cavities they insert themselves there in a curved and oblique direction; but drawings speak more eloquently than words.

D. *The Internal Jugular Vein.*

373. The internal jugular vein is larger than the external; from the cavities which are engraven on the temporal and occipital bones it descends like a straight stem with all the blood of the cerebrum, cerebellum, and medulla oblongata, except that which is carried off by the vertebral vein near the foramen magnum of the occiput. While tarrying around the exit, it is increased by one or more little branches from the external ear and the cavity of the tympanum, and sometimes it receives the internal maxillary vein. After leaving the cranium it is soon enriched by another vein, called "guttural," which derives its branches from the larynx, and from the muscles of the thyroid cartilage, and at the same time from the thyroid gland and the muscles which are in its neighbourhood, and from several others, which branches communicate with the external jugular veins. In this manner it extends downwards at the side of the vagus nerve, which transmits to it several nervous fascicles, and enwraps it under the appearance of a ligamentary membrane; and at last it empties either into the subclavian, the axillary, or into the outermost portion of the external jugular vein, yet not in the same manner on both sides; and thus transmits to the heart by the vena cava the copious blood which returns from the brain. Besides, it communicates by branches in various modes with the external jugular.

374. WINSLOW.[1]—"The internal jugular vein is the largest of all those that go to the head, though not so large as it seems to be when it is injected. It runs up behind the sterno-mastoideus and omo-hyoideus, which it crosses; along the sides of the vertebræ of the neck, by the edge of the longus colli, to the fossula in the foramen lacerum of the base of the cranium. The first branches which it sends off are small, and go to the thyroid glands. About two fingers'-breadth higher up it detaches a middle-sized branch, which runs laterally towards the larynx, and may be called the 'guttural' vein. This guttural vein divides chiefly into three branches; the lowest of which goes to the thyroid gland and neighbouring muscles; the middle branch to the larynx, the thyroid muscles, etc.; and the third runs to the great communication between the two jugulars. In this, however, there is some variety, and I have seen the left guttural vein go out from the maxillary vein. About the same distance upward, almost opposite to the os hyoides, the internal jugular gives out another branch which sends twigs to the muscles belonging to that bone, and others which communicate with the foregoing branch. This other branch runs upward towards the parotid gland and angle of the lower jaw, where it sends communicating branches forward and backward to the two external jugulars. It is at this place likewise that the internal jugular sometimes produces the internal maxillary vein and all its ramifications. The internal jugular sends another branch backwards, which is distributed to the occiput, where it communicates with a branch of the vertebral vein; and through the posterior mastoid foramen with the lateral sinus of the dura mater. This communication is sometimes by an anastomosis with a branch of the external jugular, or of the cervical vein which goes thither. At last the internal jugular vein reaches the foramen lacerum of the cranial base; but before this, it bends a little and sends off small twigs to the pharynx and neighbouring muscles" (section v., nos. 102-109). "Sometimes the temporal vein has two origins, one of which is from the internal jugular" (section v., no. 98).

[1] "An Anatomical Exposition," etc., section v.

It is also worth noting that the eighth pair of the cranial nerves or the vagus nerve being tied together in the manner of a bundle passes through the anterior portion of the above-mentioned foramen, where it pierces the dura mater immediately before the extremity of the large lateral sinus; and likewise that the passage of the nerve is made distinct from that of the sinus by a membranous partition of the dura mater, and by very small bony productions of the foramen.

375. The nature of the ramification of the internal jugular vein from its foramen to the neighbourhood of the heart cannot be seen better anywhere than in Eustachius, plate x. fig. 1; namely, that as soon as it leaves the cranium, it receives a considerable venous branch from the muscles of the os hyoides and the tongue, which conjoins itself with the frontal bone; or which from the forehead between the orbits of the eye is carried down by veins over the nose, and likewise by another branch which bends back, and is connected with the temporal vein and that of the external ear. The same branch is continued through several complicated ramifications from the occipital vein. Presently, however, as this jugular vein descends more deeply, it receives another considerable branch from the thyroid cartilage and its muscles. Still further down it receives another branch from the lowest region of the same larynx. Again, on its further journey downwards a shoot from the right jugular vein passes into the left subclavian, into which shoot several veins empty, to all appearance, from the trachea, and at the same time from the jugular vein of the right side, where it extends over the mastoid muscle. From the other side comes another branch from the region of the musculus scalenus. At last the whole of this right trunk on its downward passage, in this subject [*i.e.* in Eustachius' plate x. fig. 1], applies itself to the lowest part of the external jugular vein, or by its mediation to the subclavian vein of the same side, and empties into the superior vena cava more proximately than the above-mentioned two veins; while the left trunk, almost above the place where

the thoracic duct enters the subclavian vein, flows in at a longer distance from the vena cava.

376. Morgagni in one of his plates[1] represents the internal jugular vein descending by the side of the trachea, and pouring its blood immediately into the superior vena cava; and likewise two nerves, the great sympathetic and vagus, proceeding in the middle between the jugular vein and the carotid artery, and reaching out threads to them from the ganglion. He also represents the jugular vein together with those branches which are derived from the veins which are distributed over the face and the tongue. Consult his plate.

E. *The Vertebral Vein.*

377. Among the veins attending the vertebral artery within the cranium is one which passes into the foramen jugulare or foramen lacerum posterius, where the lateral sinuses terminate, and which is different from another vertebral vein of this kind [vena occipitalis] into which the sinus bearing the same name [the vertebral vein proper] empties itself through the foramina of the cervical vertebræ out of the vertebral cavity. The above vertebral vein of the cerebrum [vena petrosa inferior, Henle], which tends towards the same foramen [foramen jugulare], towards which the above-named sinuses and the vagus nerve direct their course, seems to derive its blood from the cerebellum and tentorium, and also from the medulla oblongata. There is still another vein of the cerebrum, likewise called vertebral [emissarium condyloideum, Henle],[2] which passes out sometimes on either side, and sometimes only on one side, through that singular foramen [anterior condylar foramen],

[1] "Adversaria," v., plate ii. fig. 1, p. 123; Leyden, 1742.

[2] Also called *emissarium occipitale*, which according to Henle ("Gefässlehre," p. 328) is connected by a delicate branch with the vena vertebralis. See also on this subject Trolard concerning his "anterior condylar confluent" in no. 328*f.* Luschka states that this emissary canal, which is sometimes wanting altogether, does not always open into the foramen condyloideum, but sometimes diverges into the extremity of the canalis hypoglossi ("Anatomie des Menschen," vol. iii section ii. p. 72).—Editor.

(not far from the foramen magnum), which is sometimes pervious, but very frequently is also found impervious. It is supposed that when it is closed the blood is derived towards the other hole; but as this is a matter of experience, it is left to investigation and ocular demonstration to decide.

378. RIDLEY.[1]—"The third branch of the arteries climbs into the dura mater by the eighth foramen of the cranial cavity [foramen jugulare], together with a small reductory branch of the vertebral vein, where the lateral sinuses enter the internal jugular, and the eighth pair of nerves passes out of the cranium. . . . The internal jugular vein enters the skull at the jugular foramen [foramen lacerum posterius], the vertebral artery at the last and largest foramen of the skull, and the vertebral vein at the ninth foramen (which Vieussens mistakenly calls the eighth), through which it runs into the internal jugular, at that vein's entrance into the foramen rotundum at the bottom of the cranium, under the styliform process where the lateral sinus meets it. There, after having advanced into certain venous productions called sinuses, these jugulars descend from thence in large trunks, growing capillary all along in their passage till they meet the extremities of the arteries, and are indeed nothing else than mere branches of the sinuses, and consequently I look upon the sinuses themselves as nothing else than large veins" (pp. 22, 26).

379. WINSLOW.[2]—"The vertebral vein arises posteriorly from the subclavian or axillary, sometimes by two stems, sometimes by one, which soon afterwards divides into two. The first and principal stem gives out a branch called the 'cervical vein,' which is distributed to the neighbouring muscles, and afterwards runs up through the holes of the transverse processes of the cervical vertebræ. This cervical branch sometimes comes from the axillary vein. The other stem of the vertebral vein runs up on the side of the vertebræ, and having reached the fourth, or sometimes ascending higher, it runs in between the transverse processes of the cervical vertebræ, all the way to the foramen

[1] "Anatomy of the Brain," etc.

[2] "Expositiòn," etc., section v.

magnum of the occiput, communicating with the occipital veins and small occipital sinuses of the dura mater. In its passage it gives off one branch which enters by the posterior condylar foramen of the occipital bone, and communicates with the lateral sinus of the dura mater; but it is not always met with." More will be seen in the chapters on the Spinal Marrow.

380. VIEUSSENS[1] in his plate xviii. fig. 1, under the letters *a* and *c* gives a drawing of the vertebral vein as this flows down outside the bony column, following the course of the vertebral sinuses. He delineates the veins together with a torn-off branch, of which he does not indicate whither it leads; and he also marks two venous canals [*cc*], of which he says that they emerge out of the posterior part of the dura mater, and that the blood over which they have control is emptied into the vertebral veins into which they pass.

381. As far as I can see, however, Vieussens does not yet know the particular source of that other vein [vena petrosa inferior, Henle], which is likewise called vertebral, and which pours its blood into the internal jugular. VERHEYEN in his figure[2] seems to lead it thence [*i.e.* from the foramen jugulare] into the subclavian vein between the jugulars.

F. *The Remaining Arteries and Veins of the interior Head.*

382. The remaining veins and arteries of the interior head have not yet been reduced into order by our anatomical explorers; for a part of these vessels has either escaped observation or has confused the experts. Several, however, which remained unknown to Willis and Vieussens, have been drawn out of their hiding-places by Ridley; yet we must look for them not so much in the descriptive text of the authors, as in their plates, which are equally instructive.

[1] "Neurographia," etc.

[2] "Corporis Humani Anatomia," edit. secunda, Brussels, 1710; plate xxxix. fig. 1, pp. 381, 382. The internal jugulars are lettered there *cc*, and the vertebral veins *ff*.—EDITOR.

In plate vii. of Vieussens are drawn "six venous branches [*f, f, f, f, f, f*] which after emerging out of the interiors of the cerebrum terminate in the straight sinus, and empty into its cavity arterial blood which they have reabsorbed;" they are situated in order between the pineal gland [*H*] and the inferior sinus of the falx. In his plate iii. also there are "two veins torn off [*H, H*] which from the choroid plexus which is found in the fourth ventricle of the cerebrum, and also from the posterior upper part of the cerebellum, tend towards the straight sinus; and which on terminating in the same are bent backward from their anterior position, lest the blood which they convey back into its cavity might obstruct the motion of the blood which flows back from the interiors of the cerebrum." Ridley gives a different version from this in his figure iv., where he delineates two large veins [*l, l*], "one of which," as he says, "enters the straight sinus upon the tentorium, so as to resist the course of the blood in that sinus, in its ascent to the torcular;" the other is likewise upon the tentorium. so as to hinder the descent of the blood to the internal jugular, contrary to a conformation of vessels which Vieussens mentions in his plate iii. under letters *H, H.*

In plates vi., vii., viii., ix., xii., xiii. of Vieussens are exhibited some blood-vessels of considerable size, with their branches, both in the bottom and in the roof of the lateral ventricles, which will be discussed in the Chapter on the Choroid Plexuses. So also in figure v. of Ridley, between the thalami optici and the corpora striata, almost over the whole intervening medullary tract on both sides, yet nearer to the corpora striata, there are similar vessels with their shoots [*R, R*].

In the same plate of Ridley also there are drawn "two large veins[1] [*h, h*] coming from the top of the upper part of the plexus down to the pineal branch of the plexus, all the length of the third ventricle, and then terminating in the straight sinus;" besides other veins over the cerebellum, one of which [*R*] is seen "entering into the lateral sinus on one side." There

[1] The veins of Galen.—EDITOR.

are also observed very small veins on the fornix, and in other places.

In plate ii. of the same author there are "several veins [*m, m*] communicating with the inferior petrosal sinuses;" besides others which communicate with the lateral sinuses. There is one which is connected with the arteries of the dura mater, which is also represented in plate xvii. of Vieussens. In Ridley's figure iv. two veins extending towards the straight sinus are discovered on either side of the longitudinal sinus of the dura mater [*P, P*?].

In Ridley's plate i. there are several radiating veins as it were on the cerebellum, and others bent into angles, where that organ is produced into the pons Varolii.

In his figure iv., and likewise in Vieussens' plate ii., are represented veins which from the falx enter into the superior and the inferior longitudinal sinuses of the dura mater on the side, being inserted there obliquely.

Besides these, Ridley makes mention in his plates of a small vein which had not hitherto been observed, which is attended by its artery, and which passes through the lateral part of the sphenoid bone where this constitutes a portion of the orbit, exactly under the small process of that bone.

383. Most worthy of being mentioned are the larger branches or trunks of arteries which have been exhibited by Ridley, and which are mentioned by Morgagni and others. These creep along and spread themselves in the interior of the brain itself according to the flux of the cortical substance, and convey the blood also towards the interiors; for in the medullary substance both of the cerebrum and the cerebellum we frequently notice small collections of blood, which in dissected brains have the appearance of reddish constellations scattered about. But on this subject I shall treat hereafter. In like manner others, after Ridley and Vieussens, with similar industry have portrayed threads of veins between the sulci of the cerebrum, which stretch their way towards their exits in the sinuses. Those are to be crowned with lasting honours who profess the medical art,

and lend their aid. Meanwhile it must be observed that an altogether different relation prevails between the arteries and veins in the brains and the arteries and veins in the body. Thus in the brain no vein accompanies an artery either on its entrance into, or in its progression through, or finally at its exit out of, the brain.

[MODERN AUTHORS.

383*a*. BURDACH.[1]—"The arteries are dilatory in their approach of the brain; for before ramifying in order to dip into its substance, they move about in numerous curves. The very trunks approach the cranium and its cavity in a serpentine course. After gaining an entrance they give up their fibrous sheath which passes over into the filamentous membrane [dura mater] of the brain; and in correspondence with the sphere to which they henceforth belong, they acquire a peculiar character: for in accordance with the great sensitiveness prevailing everywhere within the cranium, they, together with their annular, muscular fibres, lose every vestige of a proper or independent irritability by becoming thin-coated. Placed under the immediate influence of the brain, they also cease to be attended by their own nerves. Naked and bare, and only loosely fastened to the surrounding parts by a very delicate cellular tissue, they pursue their course. For a greater or less distance they journey on between the arachnoid membrane and the pia mater, and only in the latter membrane do they begin to ramify. Everywhere the cerebral arteries lodge in the spaces left open by the substance of the brain—in cavities, sulci, clefts, gaps, and cross-cuts. They establish themselves there, in order thence to send out their ramifications. And yet they are not too narrowly confined to special sulci, but climbing over some, they dip into one of the succeeding ones; and out of this perhaps they emerge again before they finally arrive at that convolution or gyre where they are finally resolved into twigs and capillaries. Wherever there is a

[1] BURDACH (C. F.), "Vom Baue und Leben des Gehirnes," vol. ii., Leipzig, 1822.

fissure in the brain, and wherever there is a meeting-place of separate formations, the arteries themselves divide into a greater number of branches; as, for instance, between the medulla oblongata and the cerebellum, between the cerebellum and the cerebrum, and between the anterior, upper, and lower lobes of the latter, as well as between its right and left hemispheres" (p. 21, section 94).

"As in the vascular plexuses different branches of one or of several trunks meet together, so also in the external circumference of the cerebrum we see nowhere free, unattached arterial extremities; but everywhere we find manifold anastomoses of the terminal twigs of various arterial branches and trunks, and occasionally also of the larger branches of various trunks; and in the median line we meet with anastomoses of homogeneous collateral branches—so that the arteries after cleaving into various stems, and ramifying in manifold ways, in the end are woven in the circumference into one common net, intertwining the whole brain. Thus while running their course in extensive curves through the pia mater, they resolve themselves into several homogeneous twigs which at first are parallel with one another, and which, while yet of considerable size, anastomose with the twigs of other branches. On leaving the pia mater they mostly continue under it for some distance, creeping along the surface like runners; while at the same time shoots parallel with one another are thrown out from them into the brain-substance, mostly at right angles. The artery therefore, apparently apprehensive of entering the brain, before doing so experiences not only an alteration in its character, but also an inflection in its course, a reticular complication of its branches and twigs, and a resolution of its twigs into the finest possible extremities or into capillaries without any real tree-like arrangement; the more capacious vessels being consigned to the circumference. Openings in the surface receive the vessels on their entrance. Smaller openings are at the sides, larger ones on the bottom of each sulcus. Where the medullary substance lies exposed, these openings are usually scarce and small; but in many places, especially along the lateral columns of the medulla oblongata, also near its anterior depression, between the crura of the cerebrum, near the corpora geniculata, and at the base of the main lobe (Stammlappen), the openings are so crowded that the surface appears cribriform [witness the anterior and posterior perforated spaces]. After their entrance the vessels pass in a parallel direction through the cortex, but by giving off transverse, arching shoots which anastomose with one another, they at the same time construct a pretty compact net. As soon as they pass from the cortex into the medulla, this reticular transverse interlacement ceases, and without giving off any lateral twigs the exceedingly delicate capillaries run on in a straight but slightly undulating course, following on the whole the medullary fibres; so that the interior of the brain, compared with other viscera, receives considerably less blood. As there is an accumulation of vessels everywhere in the interstices between the various formations in the brain, and where they border on one another, so also in the circumference of the cerebrum (Hirnmantel) they run between the closely-fitting strata of two systems. A great quantity of parallel capillaries are accordingly also found between the radiation of the corpus callosum and that of the corona radiata, . . . where they appear stretched across like the threads of a spider-web, when one radiation is stripped from the other. Nay, the presence of these capillaries shows that the boundary line between the two radiations has been hit upon" (p. 21).

383*b*. "It has been impossible thus far to prove with certainty the existence of veins in the interior of the brain-substance. It seems rather as if the capillaries which through the surface have penetrated into the medulla of the brain, pass through the same to some other point of the surface; and as if then only, on returning to the pia mater, they are changed into veins. The brain itself, therefore, is purely arterial, and only in its membranes veins are visibly present. On this account also the venous branches have their places assigned to them rather on the external surface; they are fastened to the dura mater, and approach nearer to the bones of the cranium; while the arteries, on the other hand, draw nearer to the brain, and remain confined to the pia mater. . . . As in the case of the eye and the skin, so also in the brain the veins, from their most delicate beginnings to their trunks, pursue a way which is quite different from that of the arteries; while in the dura mater every artery is attended by two corresponding veins. The arterial trunks also are situated more towards the lower and anterior surface of the brain, while the veins lie more towards its upper and posterior surface. In like manner also the anterior portion of the longitudinal diameter of the cerebrum partakes more of an arterial character, because there the carotid arises, and expatiates into its vascular sphere; while the fluxion of the venous blood has chiefly a posterior direction; a similar direction also is observed in the great cerebral vein [the vein of Galen]; thither also the sinuses concentrate themselves; and there the jugular vein is situated—wherefore the venous character preponderates there" (p. 22).

"The veins of the brain are without any valves. They derive their roots from the peripheral and central surface of the brain; in the pia mater they increase into twigs, and then, while losing their external coating, and acquiring in its place a new covering from the dura mater, they expand into branches and trunks of considerable size; yet these do not preserve the customary round form of vessels, but assume an irregular form, and are called *sinuses*" (p. 23).

383*c*. QUAIN.[1]—"In most parts of the body the arteries are enclosed in a sheath formed of connective tissue, and their outer coat is connected to the sheath by filaments of the same tissue, but so loosely that, when the vessel is cut across, its ends readily shrink some way within the sheath. The sheath may enclose other parts along with the artery, as in the case of that enveloping the carotid artery, which also includes the internal jugular vein and pneumo-gastric nerve. Some arteries want sheaths, as those, for example, which are situated within the cavity of the cranium.

[1] "Elements of Anatomy," eighth edition, vol. ii.

"Independently of this sheath, arteries have been usually described as formed of three coats, named, from their relative position, internal, middle, and exterior. . . . Some arteries have much thinner coats than the rest, in proportion to their calibre. This is strikingly the case with those contained within the cavity of the cranium, and in the vertebral canal; the difference depends on the external and middle coats, which in the vessels referred to are thinner than elsewhere" (pp. 166, 170).

383*d*. Key and Retzius.[1]—"The blood-vessels, before ramifying and losing themselves in the cortex, for some distance run along the exterior surface of the pia. These vessels are fastened most intimately to the pia by fine little membranes. In cross-sections, therefore, it often appears as if the vessels were running in the pia itself, although they are really situated between the pia and another fine little membrane closely attached to it. . . . On examining a piece of pia mater which has been stripped from the surface of the brain, and spread out flat, you will notice how the blood-vessels attached to the pia mater freely send out their shoots, and how these, scattered here and there, protrude like villi from the membrane. For the vascular shoots which at first still preserve their natural position, deflect from the vessels in the pia mater, and at right angles penetrate into the cortex. On entering the cortex they take along a funnel-shaped indentation of pia mater, which by-and-by fits more closely around the coating of the vessel, and in the form of a sheath accompanies every vessel" (pp. 147, 148). "This perivascular sheath, in larger vessels, is slightly different from what it is in capillaries; for in the former vessels it is more or less removed from the parietes of the vessel. . . . In the sheath itself there is scarcely a trace of a structure; it appears almost as clear as glass and homogeneous. . . . We never succeeded under treatment with silver in obtaining in the sheath real outlines of endothelial cellular fields, such as other authors (Eberth, Riedel) seem to have produced; the only result obtained was a diffuse colouring or irregular spurious outlines. . . . Within the perivascular sheath

[1] "Studien," etc., vol. i.

is the middle arterial coat consisting of a fine stratum of muscular fibres. . . . This middle coat, in the arteries as well as in the veins, is usually naked in the direction towards the sheath, without any cellular coating whatever. . . . Interiorly to the middle coat, and usually closely attached to it, is the interior coat, which consists of a single, thin cellular stratum. . . . In the smaller transitional vessels the middle, muscular coat disappears altogether; the perivascular sheath remaining as a clear homogeneous sheath, more or less distant from their inmost coat. Often, however, in the capillaries this sheath is entirely invisible, yet in places where the capillaries branch out, the perivascular sheath becomes plainly visible as it retreats from the interior coat. Everywhere, in fact, even in the finest capillaries, it seems to be present; its presence is indicated by small, beautiful, and singular nuclei," etc. (p. 150.)

383*e*. Lewis.[1]—In a sub-section of his paper entitled "Existence of Pericellular Lymph-sacs in the Brain," this author says, "My attention was first attracted to the significance of these spaces by (*a*) the prevalence, in certain morbid conditions, of numerous nuclei arranged in definite directions around the nerve-cells, (*b*) the presence of undoubted lymph-corpuscles in clear spaces around the cell, and (*c*) the appearance of pericellular spaces in healthy brains occasionally where the cells appeared perfectly normal and certainly not atrophic" (p. 327). He afterwards continues, "The next stage in my observations was arrived at by the discovery that a minute blood-vessel invariably ran in close contact with all the large nerve-cells. In some cases the elongated nuclei of the capillary might not have been sufficiently stained and the outline of the vessel not distinct, yet the line of perivascular endothelial elements would unmistakably indicate its course, except where the vessel had been cut across, when the open lumen surrounded by its perivascular sheath, often with one or more nuclei attached, still

[1] Lewis (Bevan), F.R.M.S., Assistant Medical Officer at the West Riding Asylum, "The Relationship of the Nerve-cells of the Cortex to the Lymphatic System of the Brain," in the "Proceedings of the Royal Society," vol. xxvi., London, 1877.

indicated the close proximity of the vessel to the nerve-cell. In all cases I never failed to recognise, on careful examination, a small capillary either passing immediately across the nerve-cell or running with a gentle curve along the confines of the pericellular space. The invariable occurrence of this arrangement naturally struck my attention as a highly-significant fact, and more extensive observations proved it to be the universal arrangement throughout the cortex cerebri. In many instances a distinct connection between perivascular and pericellular spaces could be clearly observed, although from obvious reasons the majority of specimens exhibited this connection only after the most careful and strict scrutiny, or afforded, on the other hand, no definite indications of its existence" (p. 330). "With regard to the mode of connection it must be remembered that the pericellular sacs are laterally disposed along the sides of the smaller capillaries, and in no case occupy a terminal position; hence the nerve-cell is bathed in a constantly-renewed current of lymph on all sides. Does this distribution in any way indicate the mode of development of the nerve-cell? With the object of answering this query I examined several brains of fœtal and adult animals. . . . These sections [*i.e.* sections from these brains] strongly confirmed the views adopted above, and indicate likewise a development of nerve-cells from within the perivascular sheath, projecting from its walls in egg-shaped ampullæ. The nerve-cells are seen in the specimens [represented in figs. 2 and 3] to follow definitely the course of the blood-vessels, and often surround the latter in crowds, and assume with the direction of the vessel a linear or arched course. In the cortex of the new-born kitten . . . the perivascular sheaths were usually defined and could be traced along the most minute capillaries. The nerve-cells were arranged in one or two series along the course of the capillary, and were clearly separated by a space from the neuroglia in its vicinity. . . . Such appearances would seem to indicate that the nerve-cells of the cerebral cortex are lymphatic outgrowths" (p. 331). In making his researches Mr. Lewis states that he has "struck out independently a series of investigations devoted to the preparation of the brain in the *fresh state*, feeling convinced that the disuse of hardening agents would eliminate many sources of fallacy." For this purpose, he says, he "eventually devised an instrument whereby freezing with ether spray was introduced, and all the conditions for cutting the *finest sections of fresh brain* were obtained" (p. 332).

383*f*. CRUVEILHIER.[1]—"The arteries of the encephalon, *i.e.* of the cerebrum, cerebellum, and medulla, are derived from four principal trunks, two anterior, namely, the internal carotids, which arise from the common carotids, and two posterior, namely, the vertebrals, which are branches of the subclavian arteries. There are several circumstances to be remarked concerning these vessels, namely, their great size, which is dependent on that of the brain; their depth from the surface before entering the cranium; the numerous curves formed by them as they are entering the cranial cavity, the use of which is evidently to retard the course of the blood; the absence of any collateral branches, the only exception being the ophthalmic branch of the internal carotid, by the existence of which the circulation in the eye is connected with that of the brain. Another remarkable point concerning these vessels is their anastomoses at the base of the cranium, namely, the anastomosis, or rather the confluence, of the right and left vertebral, so as to form the basilar artery; the anastomosis of the right and left internal carotids by means of the anterior communicating artery which unites the anterior cerebrals; and the anastomosis of the internal carotids with the vertebrals by the communicating arteries of Willis. By these anastomoses an arterial hexagon (*the circle of Willis*) is formed, the anterior margins of which correspond with the anterior cerebral arteries, the posterior with the posterior cerebrals, and the lateral with the communicating arteries of Willis.[2] From

[1] "Descriptive Anatomy," vol. ii., London, 1842.

[2] "In a person who died of apoplexy, Morgagni found a want of communication between the vertebrals and carotids; and he attributed the apoplexy partly to this circumstance, and partly to the fact that the left vertebral arose directly from the arch of the aorta."—CRUVEILHIER.

this hexagon, as from a centre, proceed all the arteries of the cerebrum, namely, from the anterior angle, the anterior cerebral arteries; from the posterior angle, the basilar artery; from the anterior lateral angle on each side, the middle cerebral; and from the posterior lateral angle on each side, the posterior cerebral artery. Owing to the existence of these large anastomotic communications, any one of the four arterial trunks would be sufficient to carry on the circulation in the brain, if the other three were wanting or obliterated. . . . It should also be observed that the arteries of the cerebellum, pons Varolii, and medulla oblongata are derived from the same sources as those of the cerebrum.

"Lastly, as to the mode of distribution of these vessels it may be remarked that the arteries of the cerebrum pass over the free surface of one or more convolutions, dip into the sulci between the convolutions, are reflected from one side of them to the other, give off a great number of very small branches, emerge from a given sulcus to regain the surface of the adjacent convolutions, and so on until they are exhausted. The principal arteries of the cerebellum run upon its surface, without passing into the sulci between the laminæ, into which they send only very small branches. With some exceptions, the arteries are reduced to capillary dimensions before they enter the nervous substance" (p. 712).

"The cerebral venous system is remarkable for the extreme thinness of the parietes of the veins upon the brain, and for the existence of the sinuses, which take the place of the venous trunks, and differ so much in their distribution from the arteries. The cerebral veins are divided into the *ventricular veins*, which go to form the venæ Galeni, and the *superficial veins of the brain.* All of them run towards the sinuses, in which they terminate in succession like the barbs of a feather upon the common shaft, but do not acquire a great size. From the absence of valves at their orifices into the sinuses, the blood may regurgitate into them. The presence of the spongy areolar tissue at the orifices of these veins, together with their oblique course through the walls of the sinus, must diminish this regurgitation: the communication of the cerebral veins with each other, and the continuity of the several sinuses, explain the varied means contrived for carrying on the cerebral circulation, which can only be interrupted by obliteration of the lateral sinuses. Lastly, the position of the principal sinuses opposite the fissures between the great divisions of the encephalon, and the resisting nature of the walls of the sinuses themselves, prevent the fatal effects which might otherwise ensue from compression produced by obstruction of the venous circulation" (p. 785).

383*g*. Ellis.[1]—"Arteries of the Brain.—The brain is supplied with blood by the vertebral and internal carotid arteries.

"The vertebral artery is a branch of the subclavian trunk, and enters the spinal canal beneath the ligament uniting the atlas and occipital bone. Ascending to the brain, the artery enters the skull through the foramen magnum; and being directed upwards round the medulla oblongata, blends with its fellow in a common trunk (basilar) at the lower border of the pons. As the vessel winds round the upper part of the cord, it lies between the roots of the occipital and hypoglossal nerves; but it is afterwards internal to the last.

"*Branches.*—Between its entrance into the spinal canal and its termination, each artery furnishes offsets to the spinal cord, the dura mater, and the cerebellum.

"The *posterior spinal branch* is of inconsiderable size, and arises opposite the posterior part of the medulla: it descends along the side of the cord, behind the nerves, and anastomoses with its fellow, and with branches that enter by the intervertebral foramina.

"The *anterior spinal branch* is small like the preceding and springs from the artery opposite the front of the spinal cord. It joins the corresponding twig of the other side, and the resulting

[1] Ellis (G. V.), "Demonstrations of Anatomy; being a Guide to the Knowledge of the Human Body by Dissection," seventh edition, London, 1874.

vessel is continued along the middle of the cord on the anterior aspect.

"The *posterior meningeal artery* leaves the vertebral trunk opposite the foramen magnum, and ramifies in the dura mater lining the fossæ of the occipital bone.

"The *inferior cerebellar artery* (posterior) is distributed to the under surface of the cerebellum. Taking origin from the end of the vertebral, or from the basilar artery, this branch winds backwards round the side of the medulla between the pneumogastric and spinal accessory nerves, and enters the median fissure of the cerebellum. Directed onwards along the fissure, the artery reaches the upper surface of the small brain, and there anastomoses with the superior cerebellar artery. An offset of this branch ramifies over the under part of the cerebellum, and ends externally by anastomosing with the artery of the upper surface. As the vessel lies by the side of the aperture of the fourth ventricle it gives a small *choroid* offset to the plexus of that cavity."

383*h*. "The BASILAR ARTERY, formed by the union of the two vertebrals, reaches from the lower to the upper border of the pons; and it ends at the last spot by dividing into two branches (posterior cerebral) for the cerebrum.[1] The vessel touches the basilar process of the occipital bone, from that circumstance receiving its name, and lies in the median groove of the pons. On each side of, and almost parallel to it, is the sixth nerve.

"*Branches.*—Besides the two terminal branches mentioned above, the artery supplies transverse offsets to the pons and the under part of the cerebellum, and a large branch to the upper surface of the cerebellum.

"The *transverse arteries* of the pons are four or six small twigs, which are named from their direction, and are distributed to the substance of the pons. One of them gives an offset to

[1] CRUVEILHIER says concerning the origin of the posterior cerebral artery, "Not unfrequently the carotid gives origin to the posterior cerebral artery, from which, in that case, the posterior communicating artery is then given off, and immediately joins the anterior extremity of the basilar artery."—EDITOR.

the internal ear along the auditory nerve [arteria auditiva, Henle].

"Resembling this set of branches is the following artery, the *inferior cerebellar* (anterior): this arises from the basilar trunk, and is directed outwards to the forepart of the under surface of the cerebellum, on which it is distributed.

"The *superior cerebellar artery* is derived from the basilar so near the termination that it is often described as one of the final branches of that vessel. Its destination is to the upper surface of the cerebellum, to which it is directed backwards over the third nerve and the crus cerebri, but parallel with the fourth nerve. On the upper surface of the cerebellum the artery spreads out in branches, and its ramifications anastomose with the vessel of the opposite side, and with the inferior cerebellar artery. Some twigs of this vessel enter the plicæ of the pia mater (velum interpositum) which projects into the posterior part of the cerebrum.

"The *posterior cerebral artery* takes on each side a backward course, similar to that of the preceding artery, but separated from it by the third nerve. The vessel is then inclined to the inner side of the posterior part of the cerebrum, and divides into many branches. Some of these supply the under part, whilst others turn upwards on both the outer and inner surfaces of the back of the hemisphere, and anastomose with the other cerebral arteries. Near its origin it is joined by the posterior communicating artery of the carotid; and its branches to the brain are the following:—

"Numerous small long branches leave it close to its origin, and enter the base of the brain between the crura cerebri (posterior perforated spot).

"A small *choroid* artery supplies the fold of pia mater that projects into the cerebrum: this small branch is transmitted between the crus and the hemisphere of the cerebrum to the velum interpositum and the choroid plexus.

"From the foregoing examination of the offsets of the vertebral arteries and the basilar trunk, it appears that about half the encephalon—namely, the medulla oblongata, the pons, the cerebellum, and the posterior third of the cerebrum—receives its blood through the branches of the subclavian arteries."

383*i*. "The INTERNAL CAROTID ARTERY terminates in branches for the remaining part of the cerebrum. Having passed through the space of the cavernous sinus, the vessel emerges on the inner side of the anterior clinoid process, and divides at the inner end of the fissure of Sylvius into cerebral and communicating arteries. At the base of the brain the carotid artery lies between the second and third nerves, but nearest the former.

"*Branches.*—In the skull the carotid gives off the ophthalmic offsets before it ceases in the following terminal branches to the cerebrum.

"The *anterior cerebral artery* [the artery of the corpus callosum] supplies the inner part of the cerebral hemisphere. The vessel of each side is directed forwards to the median fissure between the halves of the large brain; and as the two are about to enter it, they are united by a short thick artery, the *anterior communicating*. Each artery then passing into the fissure, bends round the anterior part of the corpus callosum, so as to be placed on the upper aspect in the natural position of the brain, and is continued backwards distributing offsets nearly to the posterior extremity of the hemisphere. The vessel gives off numerous *branches*, and some of them supply the base of the cerebrum, thus:—

"Near the commencement it furnishes small branches to the part of the brain (anterior perforated spot) contiguous to the inner end of the fissure of Sylvius: and it distributes some branches to the under part of the frontal lobe.

"The *middle cerebral artery* [the artery of the fissure of Sylvius] is the largest offset of the internal carotid, and ramifies over the outer side of the hemisphere. Entering the fissure of Sylvius, the artery divides into many large branches, which issue at the outer end of that groove; and spreading over the external of the hemisphere, inosculate with the other two cerebral arteries at the front, the back, and the upper part of the brain. Only a few fine *offsets* require special notice :—

"A set of small branches arise at the inner end of the fissure of Sylvius, and enter the cerebral substance through the part called substantia perforata antica [the anterior perforated space or spot].

"The *posterior communicating artery* is a small twig, which is directed backwards, parallel to, and on the inner side of the third nerve, to join the posterior cerebral artery (of the basilar) near the pons.

"The *choroid artery* (anterior) is small in size, and arises either from the trunk of the carotid or from the middle cerebral artery. It passes backwards on the outer side of the preceding, and finds its way between the hemisphere and the crus cerebri to the choroid plexus of the lateral ventricle. . . ."

383*j*. "The VEINS of the brain enter the sinuses of the dura mater, instead of uniting into trunks, as companions of the arteries. Two sets of veins belong to the *cerebrum*, namely, superficial or external, and deep or internal.

"The external veins of the upper surface are collected into the superior longitudinal sinus; and those of the lateral and under parts enter the sinuses in the base of the skull, especially the lateral sinus.

"The deep veins of the interior of the cerebrum join the veins of Galen, and reach the straight sinus.

"The veins of the *cerebellum* end differently above and below. On the upper surface they are received by the veins of Galen and the straight sinus; and on the lower surface they terminate in the occipital and lateral sinuses" (pp. 204-208).

383*k*. HEUBNER.[1]—"In order to study successfully the effects exerted upon the brain by diseases of the various arteries of the brain, a more minute knowledge of those territories is required where the various ramusculi spread, than is furnished by systematic treatises on Anatomy, by those of Henle and

[1] Heubner (Dr.), "Zur Topographie der Ernährungsgebiete der einzelnen Hirnarterien," in "*Centralblatt für die Medicinischen Wissenschaften*," no. 52, December 7, 1872.

Luschka, for instance. With a view of enlarging our knowledge of this subject, I made upwards of sixty injections in thirty human brains. The method which I followed was always *to inject only limited pieces of an artery together with its offsets,* in order, if possible, to obtain injections of definite sections corresponding to these pieces; and to proceed thus, piece after piece, along the arteries in order to find out the parts of the brain which they supply. This successive injection I was able to accomplish by tying the artery, beyond the opening for the canula, at a point which I could shift *ad libitum,* so that the injecting fluid could penetrate only between the opening of the canula and the ligature into the piece which was left open, as well as into its offsets. In order to preserve the pia mater from injury, the brain was taken out enclosed in the dura mater, which for this purpose had been carefully separated from the skull. The injecting fluid used was Brücke's solution of Prussian blue, which by means of a brass syringe, holding 10 cm., was under a very gentle pressure by the finger driven into the vessels. As soon as the injection had been accomplished, the extent of the injected territory was accurately measured.

"I thereby arrived at the following results:—

"(1) The entire arterial system of the cerebrum, when regarded from the standpoint of its topographical distribution throughout the cerebrum, is distinguished into two provinces, which distinction ought to be carefully observed. One of these I propose to call the *basal* [or central] province, and the other the *cortical* province. The first is formed by the circle of Willis and the chief branches of the cerebral arteries as far as their ramifications. The second begins where the chief branches—the anterior, middle, and posterior cerebral arteries—commence to be resolved into the ramifications of the second order. For the anterior cerebral artery the boundary lies close beyond the ramus communicans anterior; for the middle cerebral artery at a distance of 2-2½ cm. from its origin in the carotid (about the middle of its course across the island of Reil); for the posterior cerebral artery at the distance of 2 cm. from its origin in the basilar artery. From the basal province those arteries start which supply the central ganglia [corpora striata and optic thalami], and the parts belonging thereto. From the cortical province the whole cortex, with the exception of the uncinate or hippocampal convolution, is supplied.

"(2) The nature of the vessels passing from the two provinces into the brain is essentially different. In the *cortical province* the vessels ramify in this fashion, that the smaller shoots proceed from the larger pretty much in the direction of the course of the blood, and, while constantly throwing off additional shoots, for a long distance continue in the pia mater, before the blood enters the surface of the brain vertically from the arterial nets of the pia mater. While still within the pia mater the ramifications of all the three cerebral arteries intercommunicate most intimately and in the most manifold manner, by means of arteries of 0·15 mm. diameter, generally in the bottom of the convolutions. This last result was obtained by the injections of fluids of various colours, made from different places. Every place of the cerebral cortex may thus be supplied from every larger shoot of the cortical substance; provided a sufficient quantity of injecting fluid be pressed into it. In the *basal province* the arteries leave the chief trunks in the form of less numerous, but very small shoots, of the dimension of $\frac{1}{2}$-$1\frac{1}{2}$ mm., which start either at an acute or at a right angle. They dip into the brain-substance after a much shorter course, of about $\frac{1}{2}$-$1\frac{1}{2}$ cm. in length, and ramify in the districts belonging to them. These vessels, however, do not anastomose with one another, but must be regarded as genuine terminal arteries. For, while in the cortical province the injected fluid is seen flowing, according to circumstances, from every branch into the most distant regions; in the basal province, from the same piece of artery or of the circle of Willis, always the same part of the cerebrum, and no more, is saturated with the blue mass. If the quantity of the injecting fluid is increased, no additional districts of the cerebrum are injected, but extravasations arise in the injected part.

"(3) It appears hence that in the basal province, those districts of the cerebrum, especially in and about the central ganglia, may easily be determined, which are supplied from special portions of the arteries" (pp. 815, etc.). Heubner concludes his paper by enumerating the various districts of the cerebrum, and the source whence they derive their supply of blood.

383*l*. DURET[1] in his researches arrived at results similar to those obtained by Heubner and detailed in the preceding number. The results of these two observers are summarized in Quain's Anatomy (eighth edition, vol. i. pp. 378, 379) as follows:—

"The recent researches of Duret and Heubner have thrown some additional light on the circulation in the brain. According to these authors, the three great arteries which go to the cerebrum—the anterior, middle, and posterior cerebral—give origin to two very distinct systems of vessels. The first of these, consisting of branches given off by the arteries immediately after they leave the circle of Willis, is destined to the great central ganglia, and is called the *central* [or basal] *system of arteries;* the other ramifies in the pia mater, and is distributed to the grey matter of the convolutions and the subjacent white matter; it is called the *cortical system of arteries.* Moreover, not only are the two systems thus distinct, but the branches of the several arteries are also limited in their distribution to certain well-defined areas, and their communications are few and small, and occur only at the periphery of their respective areas of distribution, so as to render the areas practically independent territories. This same remark applies, in a less degree, however, to the secondary, and even tertiary division of these arteries.

"The *anterior cerebral* has a very limited central [or basal] distribution, giving only a few small branches (and these liable to much variation as to size and number) to the anterior extremity of the corpus striatum. Its cortical branches are three in number: the first being distributed to the two internal orbital convolutions; the second to the anterior extremity of the

[1] Duret (H.), "Archives de Physiologie," Paris, 1874.

marginal convolution, to the superior, and to the anterior portion of the middle frontal convolutions on the outer surface; the third to the inner surface of the hemisphere as far as the extremity of the calloso-marginal fissure; the fourth to the quadrate lobule; and from this last branch the artery of the corpus callosum is given off.

"The *middle cerebral* immediately after leaving the internal carotid gives off a number of small vessels which pass directly upwards, parallel to each other, into the foramina of the anterior perforated space, and enter the base of the corpus striatum. They are distributed to the two extraventricular nuclei (grey nucleus and lenticular nucleus) of that body, to the posterior part of the nucleus caudatus and the portion which borders upon the optic thalamus. The main trunk of the middle cerebral passes upwards and outwards in the fissure of Sylvius until it reaches the island of Reil, on the surface of which it divides into four branches. The first branch is limited in its distribution to the outer part of the orbital surface and the adjacent inferior frontal convolution; the second branch supplies the posterior part of the middle frontal, and the chief part of the ascending frontal convolution; the third branch passes in the fissure of Rolando to the rest of the ascending frontal and to the ascending parietal convolution and to the anterior part of the superior parietal lobule; and the fourth, lying in the posterior branch of the fissure of Sylvius, supplies the inferior parietal lobule, and the superior temporo-sphenoidal convolution.

"The *posterior cerebral* artery gives off a number of twigs in the posterior perforated spot, and others as it passes round the crus, both of which sets pass into the thalami optici, crura cerebri, and corpora quadrigemina. The cortical branches are three in number: the first is distributed in the anterior part of the uncinate gyrus and its immediate vicinity; the second branch supplies the posterior part of the uncinate gyrus, and the lower part of the temporo-sphenoidal lobe; the third, lying in the calcarine fissure, supplies the occipital lobe on its inner and outer surfaces."]

ANALYSIS.

384. THE animal body is likened to a kingdom or a commonwealth. The empress or queen of this kingdom is the soul; its court is the brain, the viscera of the body are so many provinces, and the boundaries are formed by the membranes. The ministers or servants, however, are the animal spirits and the blood. There are two curiæ or executive chambers, one is the cerebrum and the other the cerebellum. The soul by means of the cerebrum takes cognizance of, understands, discusses, and judges of, the things which are outside of itself, and presently by the will through the muscles it determines its findings into action. By means of the cerebellum, however, it penetrates the inmost things of the nature of its kingdom, and without the cerebrum knowing anything about it, makes its arrangements, lest the will which belongs to the cerebrum should overleap its order and bounds, and upset its kingdom. For this purpose both brains are conjoined in a common medulla which reaches to the lowest parts, and outside and around the same the soul builds up its kingdom, the body. In this wise the form and idea of a kingdom prevails with all parts, in their obeying one empress.

385. The animal body is also compared to the world, wherefore it is called a microcosm. The soul is as it were its deity; the brain its supreme seat, its throne, and in a certain sense its heaven; the lower parts, however, are in the body. From its heaven, or from the brains, the soul contemplates all things in the body as underneath itself; but nevertheless it is present in each part, and cares for each; for it is on account of the soul that they all are, live, and are moved. He who knows the mode in which the soul by its brain or its heaven rules its body or its

world, knows also the hidden commerce of the inmost things of nature with its ultimate things.

386. Here we shall have to explore only the mode in which the brain flows into the body, and the body into the brain, by means of the blood. The brain has committed to the large heart of the body the privilege of propelling the blood around, but to itself it has reserved the jurisdiction over the animal spirit. This it conceives in its cortex, ushers into the fibres, prepares for use in its organs, instils into the blood, and thus provides for the heart, and by the heart for the universal body. This blood it again requires back from the heart; it resolves it into its first principles, and renews and regenerates them; and thus it watches perpetually over the wants and the welfare of its kingdom, which cannot live without the blood carrying out the behests of the soul in the body.

387. The soul, however, takes great precautions lest the heart should extend the sphere of its activity into the brain, and lest it should flood with the torrent of its blood the seat or court of its soul; and thus lest it should subject the rational mind to its own empire; for to live from the heart and from the blood is equivalent to living from the body only. As soon, therefore, as the carotid artery approaches the cranium, it is stripped of its muscular coating[1] or of that of the heart—for the heart cannot act upon any part which lies beyond the continuity of its own muscle—and it is furnished with a meningeal coating, that is, with one derived from the membranes of the brain, and afterwards with a filamentous covering from little branches of the great sympathetic nerve.[2] On its passage

[1] Compare footnote on p. 318.—EDITOR.

[2] In QUAIN we read, "The carotid plexus of the sympathetic nerve, situated on the outer side of the internal carotid artery at its second bend (reckoning from below), or between the second and third bends, gives many filaments to the vessel on which it lies" (vol. i. p. 629). And again he says, "The cavernous plexus, named from its position in the sinus of the same name, is placed below and rather to the inner side of the highest turn of the internal carotid artery to which it gives branches" (*Ibid.*, p. 630). HENLE adds that "from the plexus cavernosus proceed extremely fine *rami vasculares*, which accompany and engird the branches of the internal carotid, viz. the anterior and middle cerebral arteries, according to Bourgery and Arnold" ("Handbuch d. systemat. Anatomie des Menschen," vol. iii., "Nervenlehre," p. 568).—EDITOR.

through the cranium it is bent both sidewards and backwards; again it is deflected a little during its passage through the cranial cavity, where it climbs over the osseous acclivity of the clinoid process. It is further deflected after its descent into the cavernous sinuses of the sella turcica, and again on emerging out of them; and finally, after its passage through the dura mater while climbing up to the cerebrum, it is so twisted that it pursues its course freed from its former master. Then at last it divides into branches, which it distributes at first between the lobes, afterwards between the convolutions and sulci, and finally between the least fissures of the cerebrum; all these branches also it encompasses with pia mater and entwines them with fibres, so as to obey the cerebrum only. Besides, in the cavernous sinuses this artery is itself swollen into a sinus and increases in bulk,[1] quite contrary to what is customary in other arteries, which decrease in bulk as they pursue their course. The vertebral artery also is treated in like fashion; for this too is compelled to lay aside its muscular sheath.[2] Besides, it is repeatedly deflected, and its cavity enlarged, and at last it is committed to the cerebellum and the medulla oblongata, where its little branches are fastened to gyres and fibres, and are tied together with pia mater; so that this artery also puts off the yoke of the heart, and subjects itself to the dominion of a higher master. In this manner the heart, at the boundary of the cranium and of the vertebræ, lays down its mace and sceptre before the feet of the brain; and in this manner a precaution is taken lest the posterior should forcibly intrude itself, or should attempt to act upon, the prior; the grosser upon the purer; the effect upon the cause; the blood upon its spirit, *i.e.* the heart, upon the brain.

388. The brain is thus at liberty to rule, and to demand as much blood from the kingdom of its heart, as it lists—yet not arbitrarily, but according to the state of its own affections and those of the animal mind (*animus*). It is also within the jurisdiction of the brain to send back through the jugular veins

[1] According to WEPFER, on p. 330.—EDITOR.

[2] The remarks quoted from Burdach and Quain, in the footnote on p. 318, apply not only to the internal carotid, but also to the vertebral artery.—EDITOR.

only so much blood, and no more. For at one time the brain requires much blood, at another little; it needs much when it is exasperated and acts forcibly; and it requires little when it breathes tacitly and calmly: it dispenses of its stock according to its state, and according to the motion of its *animus*. On this account also, in a kind of sinuous receptacle near the sella turcica it keeps in reserve arterial blood, so that it may draw thence just as much as its animal mind (*animus*) orders; on this account likewise it stores up venous blood in the receptacles under the occipital and temporal bones, and pushes it into the jugular veins through narrow channels, and indeed against the customary manner of the veins which increase in their course. These very veins also it puts into the trust of the eighth pair of the cranial nerves. All this is done for this purpose, that the two brains may act as the propellers and dispensers of their own blood, and that they may keep in a state of obedience the subject heart, from which they take at their own goodwill the tribute which is due to them, and to which they also send back the tribute which is due from the brain to the heart.[1]

389. As the two brains determine the quantity of their blood, so also they determine its quality; *i.e.* they summon a blood which is better, lighter, softer, and richer in spirit. Should the blood of the body intrude into the brain without any election, the sublime reasonings of the mind would be snatched off by blind ignorance, and the decrees of a free will would be absorbed by a state of base slavery. This is obviated by the brains providing their own quality of blood. That sacred substance of the cortex extracts the spirit from the blood; and as much of it as the fibre of the brain and the fibre of the body need, these demand back from the cortex. Such spirit also as the brain withdraws out of the blood and dispenses to the fibres, the heart and the kingdom of the body purvey to the brain. There is a kind of universal equation of that fluid; for from the common stock is furnished the abundance and nature, the quantity and quality, of what the extreme or outermost parts require and

[1] Compare in this connection Burdach's remarks in no. 383*a*, p. 357.—EDITOR.

consume. On this account the carotid artery arises from the arched trunk of the aorta like a stem without knots, and like a branch; and, besides, the lighter things of their own accord rise upwards, while the heavier sink down.

390. The cerebrum has its own artery and its own blood, and likewise the cerebellum; but the medulla oblongata, which is common to both, draws upon the supply of either. The artery of the cerebrum is called the internal carotid, that of the cerebellum, however, the vertebral, and the medulla oblongata participates of both. The cerebrum and the cerebellum agree, indeed, in the times of their motion, but rarely in the degrees of the same. The cerebrum at one time acts more calmly and more loftily, but at another more tumultuously and on a lower plane, altogether as its animal mind (*animus*) is influenced by the rational mind; the cerebellum, however, preserves constantly its own modes, and its scales are never so much depressed. The reason is that the cerebrum reflects from the understanding respecting that which the man in agreement with the order and the law of nature ought to will, but the cerebellum acts constantly from order and from law; and the two scarcely ever agree in a third except in the wisest of men. This is the reason why each of these organs is enclosed within its own bounds, and why the cerebrum is separated from the cerebellum by a strong and fourfold partition, and why each is furnished with its own artery, and its own vein; lest, if there was one common to both, natural things or those governed by nature should be mixed up with voluntary things.

391. As each of the two brains demands its own artery and its own vein, so also does each convolution and subdivision of the cerebrum. For the cortical substance of the cerebrum is divided into convolutions; these, however, are subdivided into gyres or glomes, and these again into tori or clusters, and each torus into individual spherules. Each separate division, however, appropriates to itself from the general carotid artery its own particular little artery, and thereby a quantity and quality suitable to its uses. For there are some gyres of the

cortical substance which are more active than the rest, especially around its bosses — *umbones* — which require a more copious supply of blood; and there are again others, as around the edges of the posterior lobes, which require little. To each individual part provision is made from the common fountain according to its uses. On this account streams of blood are extended into all the beds—*cubilia*—of the cortex; and there are receptacles and little ponds in the medulla itself, so that the uses of each single and compound part may never be deficient of their particular quantity and quality. While nature thus provides from its general stock for universals, it also provides for the individual parts; for every universal derives its force and nature from singulars, and every general from its parts: this most universal law of nature reigns everywhere.

392. Every little drop of blood which is conveyed by the carotid and vertebral arteries, is common to each of the veriest singular substances and to each part of the cerebrum and cerebellum; each derives from the public store what may be subservient to its own uses. The compound parts, however, or the gyres and convolutions of the cortical and medullary substances, claim as common to themselves whatever is contained in the branches and arteries which are antecedent to themselves. The two brains themselves derive from the common fountain whatever the carotid and vertebral arteries carry within themselves. Thus everything in the universal brain appropriates to itself as its own whatever is in the brain, and what is nearest to it. On this account not only the carotid arteries communicate with the vertebral, but also branches with branches, and least shoots with least shoots.[1] In this manner the individual parts live from the general, and the individuals breathe in the general. Such a form of government prevails in the brain and in universal nature.

393. In this wise we are led in a suitable manner from the general to the parts, and from the universal to the singulars of nature; that is, from the sinuses or the largest veins of the

[1] See on this subject *Heubner's* experiments in nos. 383*k*, p. 370.—EDITOR.

brain to the smallest and least. The arteries and little arteries arrange themselves in order between the convolutions and folds, as the larger sinuses arrange themselves between the two brains and the hemispheres; for the arteries enter every sulcus, cleft, and every least gyre of each brain, just as the sinuses enter the general intervals and the larger fissures. There are accordingly arteries which represent the longitudinal sinuses, by stretching along the anfractuosities; and there are others which represent the straight sinus or the torcular Herophili, by dipping obliquely downwards. Arteries creep along in the folds of the pia mater, just as sinuses creep along in the duplicature of the dura mater. The upper lamina of the pia mater, the arachnoid membrane, covers one part of the arteries, and the pia mater their sides, just as is the case with the dura mater and its sinuses. On this account these arterial branches may not improperly be called arterial sinuses of the pia mater; or, if you prefer, venous sinuses in respect to the purest blood and the activity of the cortex and the fibrils. For the arteries of the brain have not a like character, nor do they convey a like blood, to that of the arteries of the body; since they do not act from the force of their own muscle, but suffer themselves to be acted upon by the brain. We therefore learn the quality of the arteries from the sinuses; for such as nature is at large, so also it is in its least parts, with a difference in respect to extent and perfections. These vessels agree in their general predicates; for as the brains and the hemispheres are in respect to the sinuses, so the little hemispheres or the convolutions of the cerebrum are in respect to their arteries.

394. Every artery and vein, the largest as well as the least, keeps itself strictly in the stream of motion of its brain, and never deviates in the least from its line of direction; for as many vessels and as many fibres as there are, just so many radii and determinations are there which describe the form of the motion; since the parts are essential determinations inaugurated from their first rudiments by the least momenta of the motions. Wherefore we learn from the arteries and veins how the cerebrum,

the cerebellum, and the medulla oblongata expand and constrict their convolutions and congeries. The sinuses themselves of the dura mater are placed exactly in the general direction of the expansions of the cerebrum, the cerebellum, and their hemispheres; but the arteries or the little sinuses of the pia mater are in the determination of the motion of the convolutions and subdivisions. There are therefore as many indices of the form of the motion as there are little vessels and fibres. In the following pages it will be shown how each undergoes its periodic motion and expansion.

395. The carotid artery with its branches shows how the cerebrum acts; but the vertebral artery how the cerebellum acts; the shoots of both conjoined, however, indicate how the medulla oblongata acts. In this wise we learn from the branches and lines where and in what manner the cerebrum communicates with the cerebellum, and how far each extends its activity. Unless, therefore, we look upon the two brains as set into motion, we can see nothing in them but lifeless bodies and corpses.

396. The two brains which act from their own power and from causes inherent in themselves, excite all their arteries, veins, and sinuses, at the same time into their own systaltic and diastaltic motion; but into a motion which alternates with their own: for when the two brains are expanded, the vessels are constricted, and *vice versa.* The vessels, namely, occupy the circumference of the brain, wherefore when the brain swells, they are extended. Again the vessels pass through the fissures and sulci; when therefore the brain is expanded, they are compressed; the vessels are enfolded in the duplicatures of the pia mater, wherefore they are acted upon in the same manner as the sinuses of the dura mater, and perform their systole in a similar manner. The case is altogether different when the two brains subside in themselves. When the cortex, that is, the cerebrum, is expanded, the clefts are filled up, and whatever is contained in the clefts is compressed; hence also the arterial capillary, branch and trunk.

397. The vessels of the brain, different from those of the body, are lengthened out and at the same time compressed during their systaltic motion; but in their diastole they are shortened and enlarged: for they suffer themselves to be acted upon by the brain both in their length and in their breadth, and the blood does not flow in from the heart, as is the case in the body, and expand the coatings of the vessels. If it is allowed to draw an inference from the large sinuses in respect to these small ones, we may assume that there are delicate cords and most minute little muscles which extend from the pia mater, by which their diminutive coatings are stretched apart with a like art. The blood thus with a force similar to that of a syringe, enters successively and at ease from the larger branches into the small channels which are open either way; for nature abhors a vacuum. Posterity will discover this. The interior fabric of the brain, concerning which we shall treat hereafter, indicates this clearly.

398. When the brain is expanded, or what amounts to the same, when the vessels are constricted, every exit from the arteries into the veins, and from the veins into the sinuses, is closed; it is opened, however, on the one hand towards the cortex and the interiors of the brain, and on the other hand into the receptacles of the sinuses and into the jugular veins. But when the brain is constricted, or what amounts to the same, when the vessels are expanded, every passage from the arteries into the cortex, and from the sinuses into the receptacles, is closed up; it is opened, however, from the arteries into the veins, and from the veins into the sinuses. This is sufficiently manifest by the manner in which the little vessels are constructed, and also from the influx of the veins into the sinuses; and in addition from the cause and end for which the blood is introduced into the brain, and again is led away from the brain. There are, however, many little channels between the arteries, and also asylums in both brains, whither that blood betakes itself, which during the systaltic motion is not admitted into the brain, nor into the sinuses, nor is contained in the vessels.

The reason is, lest the arteries and veins when they are too much constricted and lengthened out may break their coatings; and also that when the brain enters again upon its diastaltic motion, it may at once derive thence [*i.e.* from these asylums] some new liquid. These kinds of vessels are very conspicuous in the surface of the brain; for they are not placed in accordance with the direction of the sulci and fissures, nor are they very closely attached to the pia mater, but they freely meander across and athwart this very surface.

399. After premising the above points, a comparison must be instituted between the blood-vessels of the body and those of the brain. The blood-vessels of the body depend upon the one large heart, which is the centre and fountain of the motion of the blood; but the blood-vessels of the brain upon an infinite number of little hearts, of which there are as many as there are parts of the cortex; they consequently depend upon the brain, which exists as a brain essentially in its cortex. The blood-vessels of the body have their systaltic motion, when the heart has its diastaltic motion, and *vice versa;* the same is the case with the blood-vessels of the brain which undergo their systole when the brain has its diastole. When the blood-vessels of the body are expanded, they are also lengthened out; but when the blood-vessels of the brain are expanded, their length is shortened, and *vice versa.* The arterial vessels of the body propel the blood successively from the beginning of the motion to the succeeding parts; the blood-vessels of the brain, however, do not receive the blood successively, but simultaneously, and in a similar manner they pour it out; and in this particular the arteries of the brain resemble the veins of the body. The arteries of the body pulsate, but not the arteries of the brain, except in a manner similar to that of the veins of the body. The blood-vessels of the body are furnished with a muscular coating, with which they react upon the blood; but the blood-vessels of the brain are deprived of a muscular coating,[1] and they retain only the inmost coating of the arteries of the body, having borrowed

[1] See on this subject the footnote on p. 318.—EDITOR.

new surface coatings from the pia mater and its fibres.[1] The blood-vessels of the body by their muscular coating are continued into the heart; but the blood-vessels of the brain by the above-mentioned inmost coating of the arteries are continued into the cortical substances, as into so many little hearts,[2] and thereby into the fibres, which return into the blood-vessels of the body. The arteries and veins of the body, like married partners, constantly press upon one another, and accompany one another; but not so the arteries and veins of the brain; since wherever an artery stops, there a vein begins and continues the course.[3] The veins of the body receive a better blood from their arteries; but the veins of the brain a baser, these being so many receptacles by which obsolete substances are carried off. The arterial vessels of the body have their determination outwards, but the arterial vessels of the brain inwards. The venous vessels of the body are borne inwards, or back again towards the heart; but the venous vessels of the brain are determined outwards or towards the surface. The proper vessels of the heart, the so-called coronary vessels, are veins; but the vessels of the brain are arteries; for in arteries abides that strength and life which is agreeable to the brain. The vessels of the body are arteries and veins, but the vessels which are proper to the brain are fibres. The systaltic and diastaltic motion of the blood-vessels of the body is synchronous with that of the heart, but that of the blood-vessels of the brain with the respiratory motion of the lungs.[4] In this respect the vessels of the two organs disagree; but they finally agree; so that the blood-vessels and fibres of the brain institute the motion of the heart and its blood-vessels; that is to say, the heart and its blood-vessels by such an influx constantly live under the auspices of

[1] Concerning the adscititious coating or the perivascular sheath which the least branches of the cerebral and cerebellar arteries borrow from the pia mater, see *Key and Retzius* in no. 383*d*, p. 361.—EDITOR.

[2] That the least arteries are continued to the very cortical particles or nerve-cells has been shown by *Bevan Lewis*; see no. 383*c*.—EDITOR.

[3] See on this subject *Burdach* in no. 383*b*.—EDITOR.

[4] Compare the results of Messrs. Key and Retzius in measuring the intervals of the motion of the blood in the longitudinal sinus, in no. 328*p*.—EDITOR.

the two brains. In everything else the heart is left to itself, and to its body.

400. From all this it may be seen that the brain derives blood from the heart and the body for this purpose, that it may institute universal, special, and singular circles of the fluids of its kingdom; and that, indeed, it derives thence a better blood, in order that by the spirit which is the inmost essence of the blood, it may provide for the cortex and for the fibres which are continued from it. This spirit after being extracted from the blood, and again being made new, is taken down into the organs of the brain, and prepared there, and at the same time in the blood-vessels of the body, and thus a new blood ever returns, is resolved, and made new again. Both brains continue in this work as long as they are animated and live.[1]

[1] In a note Swedenborg makes the following private suggestions: "Perhaps I shall treat of the mode in which the blood and its vessels penetrate towards the cortex, and how the blood passes further into the medulla of the cerebrum. How they give birth to the cortex, and how they conjoin the lowest universal with the highest."—Editor.

APPENDIX TO CHAPTER VI.

A. *The Common Trunks of the Carotids.*[1]

400*a*. *Experience.*—There are two carotids: the left ascends from the arch of the aorta, and the right mostly from the subclavian artery of the same side. Both keep near the trachea and the internal jugular vein, and continue without branches as far as the larynx. Thus far they are called the common carotid arteries; but here they divide into two large branches, one of which is called the external, and the other the internal, carotid. The former tends more towards the outer parts of the head, and the latter towards the cranium and the cerebrum. The external carotid is more in front, and nearer to the larynx; but the internal more at the back, and at a greater distance from the larynx.

400*b*. *Analysis.*—In order that the blood-vessels in the body may be in the stream of motion, and lest they be disturbed by any diversity in the motions of the body or of the viscera; and again, that they may distinctly perform their functions—they are placed in accordance with the general circles and axes of the whole body, and also in accordance with the proper or particular axes of the viscera. This may be seen everywhere.

400*c*. The carotid trunks, the aorta and the subclavian arteries meet in one common umbilicus, or focus, which is chiefly formed by the subclavian artery. For the centre of the upper body, or the terminus of the vertebral axis, is situated there; on which account also the thoracic duct meets there with the subclavian

[1] From an untranslated work of Swedenborg on the Senses and Sensations, published by Dr. J. F. Immanuel Tafel from the original MS., as part iv. of the "Regnum Animale."—Editor.

vein. The aorta flows down in accordance with the vertebral axis, and it moves through perpetual centres and fulcra, and indeed as far as the receptaculum chyli—reservoir de Pecquet—which it perforates sometimes. For the receptaculum chyli constitutes the other terminus of that axis, and is a kind of focus. This then is the reason why the aorta, the subclavian, and the carotids meet there. The carotid passes thence towards the centre of the cranium to the clinoid processes in the sphenoid bone, and a branch of the external carotid as far as the temples.

400*d*. Whether the blood within its own orb or animal world is borne upwards or downwards, it is the same: thus whether by the heart it is propelled upwards through the carotids, or sidewards through the subclavian arteries, or downwards through the descending aorta; wherever in fact it may be so far as the position of the body is concerned. For each body is a world within the world, and forms to itself its own times, directions, efforts, and centres of gravity, nor does the extraneous world act upon it, except so far as it sustains the whole of this little world, and causes it to exercise correctly its varied powers.

On this account also the centre of gravity of each arterial branch is towards its least ramusculi and their extremities, which are also beginnings. Each organ is such a centre, whither the arterial branches aim, or whither they tend. In the head there are as many centres as there are organs, and little glands; hence also the brain is such a centre, and in the brain itself there are as many centres as there are individual parts. In the body also there are as many centres as there are viscera. These, its centres, the sanguineous stream seeks, and it matters not whether, in respect to our universe, a centre be nearer to or further removed from the centre of our earth. This, however, applies when the centres are in a state of motion; but as soon as ever they are in a state of quiescence, or when the resistance of the vessel overcomes the forces of motion, as is the case sometimes in the head, then the effort or the influence of the universe comes into play.

400*e*. All viscera, and hence also the organs of the head and brain, demand from the heart the quantity and quality of their blood; for the artery itself does not give anything of its own to any viscus. It simply carries and conveys an indiscriminate wave; and does not determine its quantity and quality.

400*f*. That which determines the *quantity* of the blood to be conveyed by the carotids is the whole of that organ which is the recipient of their contents; a number of sources, consequently, attract these streams. In order that all things may flow in accordance with the tenor of nature, there must everywhere be an internal, an intermediate, and an external cause, which conspire in a wonderful manner in the production of an effect. The internal cause is called attraction or invitation; the intermediate is the ministering cause; and the external is called propulsion and incitement. When they conspire, then an effect flows on spontaneously.

The *internal cause* which determines the quantity which is to be supplied by a branch or trunk, is situated in the veriest leasts, that is, in the principles. These, from a cause inherent in themselves, or from an extraneous cause, open themselves, and invite the blood into them as it were from a syringe. For when the least of these glandular follicles are drawn apart, the blood presses in from the arterial branch: as in the brain, where the desired quantity of blood rushes in from the neighbouring parts, as soon as the cortical glandules are expanded. Such also is the case in the remaining glandular follicles, and likewise in the motory fibres. The ultimates in the body are composed simply of glandular congeries, and motory fibres, and also of papillary forms. When these are opened, then from an infinite number of small branchlets there flows in a quantity which is determined by the degree of their expansion. Into the exceedingly great number of least branchlets the blood flows in from larger branches, then from still larger, and finally from the trunks. In order, therefore, that the quantity of the inmost capillaries should always be so great that they may issue a command to the branches which arise from them, there are in the least parts myriads of capillaries which are inserted in one larger vessel, and so on, until at last, near the trunk, their number grows smaller. We may conceive hence how great is the syringic power which exerts an attracting influence from the inmost, by which the blood is invited from the trunk. This also is the reason why the carotid arises almost at a right angle.

It follows hence that no more can be forced in than is invited; for a larger quantity is resisted. Hence also in accordance with the degree of the desire the trunk contracts.

The *external cause,* which determines the quantity through the trunk and the branch, is the undulation which has begun at the heart; for, as has been shown in our work on the "Economy," etc., the blood is urged along by the force of undulation. How great a power is contained in undulation may be seen there; likewise, that this undulation goes upwards, sidewards, and downwards, and towards all the four quarters, with equal facility. This is the propulsion or incitement corresponding to attraction and invitation.

The *intermediate* or *ministering cause* is the reaction of the muscular coat, which is similar in each branch to what it is in the heart; for the force of the heart through a like organism is continued through its branches. See our "Economy," etc. The general rule is, that such as is the force which has arisen in the beginning or the fountain, such is the force which is continued through all the derivations; for there are added to them similar propelling forces. This is called promotion or ministration.

400*g*. In respect to the *quality* of the blood there also exist in a similar way, internal, middle, and external causes. For every member of the body demands its own quality as well as its own quantity. It does not follow, therefore, that a better blood arises to the organs of sense of the head and the brain simply because the carotid rises upwards. This world [that is, the world of the body] has nothing in common with the largest world in which it lives.

The *internal* or *inmost cause* resides in the very glandules and fibres; for the ultimate organic forces are woven of least nervous fibres. These fibres are imbued with a similar animus, or a similar appetence and aversion, as the cerebrum and cerebellum themselves, whence the fibres arise. The largest organs, as the tongue, nares, etc., crave one thing, while they are averse to another; the same, consequently, is the case with the least things. The compound derives what it has from its simples. Whatever, therefore, the brain and its fibres crave, the simples or least parts attract and sip in eagerly with opened lips; but if the least parts are of a different nature, then they are averse to the affluent wave, and reject, and as it were throw it up. Every viscus, member, and organ therefore attracts a blood of such a nature and quality as agrees with itself and its use; and, indeed, it solicits it from the middle of the approaching stream; the rest it either casts out by anastomoses into neighbouring veins, or discharges it elsewhere through excretory ducts. Use determines the connections and each single thing, so that nothing else should interfere. This is the inmost cause, which must be called the invitation, which causes a better blood to be conveyed towards the sensory organs of the head and the brain.

The *external cause* is, that the carotid artery is deflected from the trunk of the aorta towards the left, or backwards; for every wavelet flowing on its own accord, flows in the direction of the vortex of the universe, as may be seen in the water and in other fluids, and in the very atmospheres. On this account the more liquid substances are more easily carried in a direction towards the left than towards the right. This also is the reason why the grosser blood, under the direction of the same force of nature, flows down the aorta descendens to the right, and laterally through the subclavian artery, and why the better essences are carried off by the carotids, wherever they may be: this follows from the same principle. In like manner the branch towards the larynx, as well as the internal carotid, are given off in a direction towards the left.

The *intermediate* or *ministering*, the *promoting cause*, is the tremulousness or the tremulous modification of the organs themselves, which originates in the larynx as well as in the ear, and in the remaining organs of sense, and finally also in the inmost sensories, namely, in those of the brain. The modification is grosser near the larynx ; it is purer in the direction towards the higher organs of sense, and it is purest near the brain ; wherefore the purest substances which undergo this modification are conveyed as far as the brain, where the nature of the substances themselves agrees with the organism. This cause, however, has to be more fully developed in the Doctrine of Modifications.

Among the intermediate causes must also be referred this circumstance, that along the whole way there are placed a number of little glands, which invite into themselves, and thus draw off, the salivæ, and the grosser and more sluggish parts of the blood, as will be more fully shown below; so that only the purer blood remains.

400*h*. In order that these causes may produce their effect properly it is necessary that the carotids should in a long stretch, and without any nodes, that is, without any branches, ascend as far as the larynx near the trachea; namely, for these reasons: 1. That they may form vessels capacious enough to hold all those mixtures, whence each organ may derive its share; which could not be effected by short canals. 2. That according to nature's customary manner all things may be mixed and stirred up as it were into a chaos, whence each part may derive distinctly its own share and endowment. 3. That with the help of the trachea, and afterwards of the larynx, the blood may on the way, and during its first passage, be excited and animated by sonorous vibrations; for the sonorous tremor and the remaining modifications penetrate each individual part; wherefore, as ought to be noticed, the parts are thereby kept distinct from one another, so that each organ is able to draw out distinctly its own essences thence. 4. As the trachea, more than any other viscus, is carried away by extraordinary motions, the above artery does not dare to give off any branches before [leaving it]. See the Chapter on the Trachea[1] (pp. 5-9).

[1] "Regnum Animale," part ii. chap. iii.

B. *The Ophthalmic Artery.*

[400*i*. *Experience.* Quain.[1]—"The *ophthalmic artery,* arising from the internal carotid artery by the side of the anterior clinoid process, enters the orbit by the foramen opticum, below and to the outer side of the optic nerve. It soon changes its direction, passing over the nerve to reach the inner wall of the orbit, along which it runs forwards, and terminates in branches which ramify on the forehead and side of the nose."

Among its branches is "the *central artery of the retina,* which is a very small vessel. It pierces the sheath and substance of the optic nerve about a quarter of an inch behind its junction with the eyeball, and runs embedded within it to the retina, in which it ramifies in minute branches" (p. 375).]

400*j*. *Analysis.*—According to Winslow, there are several branches of the external carotid which enter the eye, partly from the temporal and partly from the maxillary artery. There are also branches of the internal carotid [of the ophthalmic artery], which in company with the optic nerve are continued into the retina. . . . The internal carotid artery agrees perfectly with the motion of the brain, just like the optic nerve; wherefore it flows into the retina, with the circulatory movement of its liquid perfectly adapted to the periods of the animatory motion of the brain. In the internal carotid, therefore, the circulatory movement as well as the external vibratory motion [of its vessels] are in a state of agreement; therefore they harmonize also in the retina. On this account also the veins of the eye form the orbital sinuses, and agree with the sinus of the brain; which is a sign that the eye also enjoys a certain alternate animatory motion, synchronous with that of the brain, to which the nerves and fibres also contribute their share. As the eyes are as it were two succenturiate brains, therefore also the internal carotid flows into that substance of the optic nerve which belongs to the cerebrum. All the changes of state in the organ of sense which take place in accordance with the state of the cerebrum,

[1] "Elements of Anatomy," eighth edition, vol. i., London, 1876.

require that the circulation of the blood in the arteries should agree with the animatory motion of the latter. It is different, however, with the *motion* of the organ; even as the muscular fibres require a different influx of blood, and a different action of the fibre, in order that they may alternate. On this account also the arteries of the external carotid flow into the exterior and interior motory fibres of the eye. There is a meeting of these different arteries near the arterial circle, in order that the external and the internal changes of state may agree together. The wonderful manner in which this takes place is worthy of our admiration (*Ibid.*, p. 124).

CHAPTER VII.

THE PIA MATER.

401. THE pia mater, called choroides by Galen and others, is a thin membrane and meninx of the brain. As a general integument of the whole of its furrowed surface it lets itself down more deeply in duplicatures wherever the brain gapes open; and after forming various processes, and dividing the cortical substance into individual tracts, mansions, and apartments, it again emerges out of the convolutions and sulci of the brain, and continues its course into other similar processes formed by neighbouring sulci. This membrane is spread out under the lowest lamina of the dura mater, which is slippery, polished, shining, resplendent white, and exceedingly sensitive; a thin humour intervenes between the two membranes. When examined without blood in the light, the pia mater on the one side appears transparent, polished, most thin, and deprived of nerves; on the other it is rougher, interwoven with an infinite number of vascular threads, and it communicates with the whole substance of the cortex, from which it can be loosened only with difficulty, except in cases of dropsy, or after it has been macerated for a long time. This membrane thus gathers up all the folds, convolutions, and gyres formed in both brains, and when these folds, as in the cerebellum, are skilfully produced and extended, the pia mater seems continued throughout the whole of its organism in such a manner that the whole organ acquires a kind of laminated appearance. It is also spread widely over the whole extent of the medulla oblongata, over the pons Varolii, the olivary and pyramidal bodies, over its cylindrical caudex, its ventricose enlargement, and its sinuosity at the top; all of which

it covers, invests, penetrates, and distinguishes from one another; and thus it conjoins by a perpetual connection the lowest parts of the medulla oblongata with the highest. When under the dura mater, it is generally more free, and left to its own jurisdiction, and it encloses most intimately viscera which are unconnected with one another. Nevertheless, here and there it makes productions from the convex portion of both brains, as around vessels and membranous ligaments which tend towards the processes, and also into the sinuses of the dura mater, and likewise around the nerves, which it invests from their roots. To explore its spacious extent is equivalent to passing over the whole texture of both brains, and also of both medullæ; nay, to running over the texture of the body itself. Otherwise the pia mater seems to be chiefly concerned in the transmission of arteries into the substances of the two brains and the medullæ, and of veins which return into the sinuses. For in this membrane there is a kind of perpetual interlacement of blood-vessels which in a reticular form cross one another, and at one time climb over, and at another creep under, one another. Of these vessels, as in an ant-heap, each one hastens bent on the prosecution of its own work to the end; and on meeting with another vessel it becomes ingrafted either upon an associate artery or vein. The larger vessels, in accordance with the stream of their universal in the brain, insert themselves obliquely into still larger ones which creep along between the furrows of the gyrated surface; they also keep everywhere in the stream of motion; for they cannot go counter to the brains which revolve and entwist inwards.

402. Willis.[1]—"If you continue to separate from each other the parts of this membrane which are connected together, you will soon learn that the pia mater lines the sulci of all the convolutions of the brain; that it girds the interstices of both hemispheres; that it draws together the posterior part of the cerebrum which would otherwise hang down lax and loose, and that it furnishes the edges of the cerebrum with a certain fringe,

[1] "Cerebri Anatome," etc., London, 1664.

connecting them with the medulla oblongata. In short, this membrane, which is interspersed by most frequent plexuses of blood-vessels, covers the universal cortical substance of the brain. The interior surface of the expanse of the brain, however, which is called the corpus callosum, and which is entirely medullary and white, is by no means clothed by this membrane; but in its stead a number of plexuses of blood-vessels, commonly styled choroid, are suspended in it, and in a certain measure float about freely. . . . Into all the other recesses of the cerebrum, however, and especially into the folds and laminæ of the cerebellum, nay, also into the interstices between the two brains and the medulla oblongata this membrane pushes itself, and entwines itself between the distributions of the vessels. The extent of the membrane seems so much the more wonderful, as it has no particular place whence it originates, and as it not only invests the whole brain or encephalon with a covering, but also lines all its parts with a peculiar envelope, and besides knits together their summits and processes. This meninx appears even to enjoy a manifold and various origin; for wherever sulci or interstices of some parts or processes are produced, portions of this membrane which spring up at once clothe the parts, connect them together, and furnish them with all ramifications of blood-vessels. When the brain is very moist, this membrane can be easily separated, and large and wide patches of it can be pulled off with the fingers; and after they are pulled off, the insertions of the blood-vessels into the substance of the brain and its medulla become plainly visible" (pp. 8, 9).

"The pia mater is much thinner than the dura mater, and consists of a most delicate texture of fibres. . . . In order that the diffusion of this membrane throughout all the convolutions of the brain, and the distribution of the blood-vessels through the most hidden recesses may be better observed, let the head of a man or an animal which has died of dropsy be opened. For in subjects where the brain is filled with moisture, the little stays by which this membrane is fixed to the substance of the brain are loosened, so that the membrane with the plexuses of the vessels can be easily drawn away, and pulled off almost entire; and when it is thus pulled off, the folds of the brain appear naked; the insertions of the blood-vessels into the more interior substance of the brain are also perceived. To a healthy and dry brain, however, the pia mater clings so closely that scarcely anywhere can it be drawn away, or separated with a penknife. . . . The blood-vessels of this membrane are variously platted together and interlaced, forming everywhere wonderful plexuses, between which for the most part very small and very numerous glandules are inserted. This may be seen throughout the whole compass of the cerebrum and cerebellum, and throughout the interior recesses, but chiefly between the clefts of the convolutions. It appears plainly in a moist or dropsical brain, where the glandules, which are otherwise so very small that they can scarcely be perceived, swollen by the moisture become quite conspicuous" (pp. 48, 51, 52).

"I often noticed in heads opened soon after death, the pia mater distended like a bladder, and transparent. It seemed swollen with much water which was enclosed underneath; yet it was found to have been caused by air which distended the membrane; for upon being dissected, the intumescence at once subsided without any effusion of lymph. . . . I sometimes opened the heads of deceased persons who while living had been miserably tortured by headaches; in such heads the pia or interior meninx had grown fast to the dura or exterior membrane for some distance, sometimes to the width of two fingers, near the longitudinal sinus, where the seat of the pain was; and this coalition had caused a rough and unequal swelling. In this swelling the orifices of the blood-vessels had been entirely stopped up, so that no passage into the adjoining sinus was granted to the blood, howsoever it was agitated" (p. 62).

403. PACCHIONI.[1]—"After the cranium has been carefully opened, and not an inconsiderable portion of the dura mater

[1] *Pacchioni Opera, editio quarta*, Rome, 1741.

has been folded back from the front to the occiput, or to either side, so that the principal cohesions of both meninges and of the lymphatics are still remaining; and after the dew which appears has been wiped from the pia mater, you will notice fresh little drops of the same dew, and of the same kind of moisture, even if no pressure is exercised by the fingers. This is a most certain argument not only that the pia mater for some reason is pervious and perforated exteriorly, but also that out of these little foramina or punctures some lymph trickles out. Besides, what shall I say of that oily lymph which is discovered between the pia mater and the tortuous and deep convolutions of the cerebrum? This is by no means supplied by the cortical glands of the cerebrum and the cerebellum; for if you wipe them, you will certainly not perceive any humour oozing out thence" (pp. 116, 117). "But in order to show that this lymph bubbles over with oily particles, you need nothing more than the use of your senses of sight and touch. By using your eyes you will notice that the pia mater in some subjects is besprinkled with innumerable round and whitish particles; sometimes also they are intermixed with glandules of the dura mater. My attention has been called to this by Ruysch; namely, that the pia mater in various places is dilated by fat. Besides, if you touch the cortex of the brain with the fingers, you will observe that it is polished in a high degree, and everywhere bathed with a most subtle oil, as I learned not without surprise from very frequent dissections of bodies. This truth is also placed before our eyes by concretions and hydatids of the lymphatics of the pia mater, where sometimes we have seen oil floating about on the top; that is, we have seen the lymph filled with oily particles of that kind" (pp. 118, 119).

"Lymphatic vessels intimately associated with and enfolded by blood-vessels from the dura mater, are implanted in the pia mater, and adhere to it most firmly, not only by the aid of blood-vessels, but also of many fibres which come forth from the dura mater. . . . I doubt, not without reason, whether all the lymphatic vessels are contained under the plexuses of the blood-vessels; for very often on breaking the connection between the dura and pia mater, there appear very many glandules fastened, and as it were ingrained, upon the latter membrane; wherefore, from a certain dew, and as it were a very white hue which remains spread over the pia mater, by a bold deduction I inferred that besides the above-mentioned insertions and ligaments, there are also implanted in it very small lymphatic vessels. By investigating therefore more attentively the complication of the vessels which are exposed, and by slowly pulling off one membrane from the other, I noticed that both were in addition connected by a sort of thin filaments, which emerge from the glandules of the dura mater. When these are stretched out to a certain point, and then broken, the tip of the finger on touching them becomes moistened by a clear liquid. The progression of these lymphatics, at least within the pia mater, is not very difficult to trace, since by adhering to the sides of the blood-vessels they follow their course even into their smallest windings; thus they appear both on the surface of the pia mater and in its separate portions which clothe the convolutions of the cerebrum, and which they do not moisten very much. And when these are exposed to the light they exhibit most slender, whitish vessels, not unlike the substance of the pia mater, and for the most part interlaced with blood-vessels. . . . I remember in certain persons who had died of apoplexy, and whose brain abounded with lymph, that their pia mater was three times as thick as in the natural state; and, indeed, I observed this more than once; almost all connection of the vessels had ceased there, and nearly transparent hydatids were here and there interspersed, which had the appearance of so many varicose lymphatic vessels. Although the pia mater invests the brain everywhere, and pervades its cortical gyres, its interstices, and the walls which are contiguous to the falx, down to the corpus callosum, nevertheless it is always associated with lymphatic vessels; yet I have not yet been able to tell whether they penetrate the medullary substance, although I applied all necessary diligence to the problem. . . . Heertodt relates that in a boy who had died of hydrocephalus he saw the lymphatics of the brain partly turgid and partly broken. . . . It is, nevertheless, a settled fact that the interior surface of the dura mater is moistened by some liquid, which, as I remember to have seen in dissections of bodies, especially of old men, had even become gelatinous by disease, to which, among others, the celebrated Malpighi bears witness. And that this liquid becomes stagnant in the ventricles of the brain, I have learned not only in a case of hydrocephalus, and in some who had died of apoplexy, but also in a number of epileptic persons, and in such as had died of convulsions in the head. . . . In a cardinal, sixty years old, who had become epileptic during an attack of gout, on the right cortical portion of the head, towards the occiput, there was found a large hydatid, which equalled the size of a pigeon's egg; this seemed to have been formed by the pia mater itself, and its lymphatics, which had been very greatly extended; it came under the notice of the eye on account of the liquid which was contained in it. It was partly a lymph thin and yellow, and partly turned into a sort of thick gelatinous mass. In this case, as seemed remarkable, it was an undoubted fact that the base of this bladder, namely, the cortex of the brain, had acquired a consistency, offering such a resistance as to seem scirrhous" (pp. 128, 130, 131, 133).

"If the liquid of the blood and of the lymphatic vessels of the body is tried by the fire, one species more than others is more or less coagulated, and then vanishes in smoke; but the lymph of the brain when exposed to the fire does not blister, nor does it leave any coagulated mass, but the whole of it vanishes and evaporates. In the ventricles of the brain and the cavities of the spinal marrow also there is a fluid which does not coagulate, but which evaporates totally" (p. 89).

404. The celebrated FANTONI and others sometimes saw hydatids in the pia mater;[1] more frequently there was a coagulable serum adhering to the membrane; but never, says he

[1] See his letter to Pacchioni in his "Opera Omnia," etc., p. 111.

and others, have any lymphatic vessels shown themselves over the convolutions of the brain.

405. VIEUSSENS.[1]—"The pia mater is a very thin and transparent membrane, which covers immediately the whole mass of the brain. It furnishes a covering to all the nerves proceeding from the brain, and upon entering the vertebral cavity it is divided into two membranes; the exterior membrane of these embraces the spinal marrow, and all the nervous fibres proceeding from it; the inner membrane, however, covers immediately the same medulla, and invests separately the aforesaid fibrils proceeding from it, and passing off into spinal nerves. This membrane, which consists of a most delicate tissue of fibres, is connected here and there with the dura mater, partly by blood-vessels, partly by nerves or membranous ligaments which are thrown in between; and this connection at one time is more lax and at another more strict. And in addition it is so firmly attached to the external surface of the brain that it can scarcely be separated from it uninjured. Finally, this membrane, by binding together the tops of all the convolutions and sulci of the cerebrum, renders its surface smooth and oblong-round, and makes its shape in a certain measure similar to our world. After it has thus proximately engirded the cerebrum, cerebellum, and medulla oblongata, it insinuates itself between the cerebrum and cerebellum; it makes its way deeply into their internal sulci, and covers up all the clefts; it enters also the interstices between their folds, and distinguishes one from the other. In a certain measure also it distinguishes the cerebrum from the cerebellum, and both from the medulla oblongata. Never, in dissecting human brains, was I able to discover glands, not even with the aid of the microscope; and for this reason, because I think that when they are discovered they are either the extreme blunt ends of vessels, and are swollen with water, or else are always preternatural productions. . . . Besides, the pia mater has a most polished external surface; its internal surface, however, is rendered somewhat rough on account of the vessels

[1] "Neurographia Universalis," cap. v.

which adhere to it. This adherence of the vessels is externally never prominent; and the external surface appears equally transparent whether the vessels which are internally appended to it are separated or emptied of blood. . . . This thin membrane, besides, covers all the nerves proceeding from the brain; and with some of them, which around their origin consist of distinct fibrils, it separately invests each of these fibrils. Hence it is that very often when this membrane is severely injured, the roots of the nerves which proceed from the brain suffer likewise. . . . The pia mater is also occasionally thick, and interwoven with very many nervous fibres" (pp. 29, 30).

406. Ridley.[1]—"The pia mater is a very thin and pellucid membrane, co-extensive with the brain itself, not only in its external, but also in its internal structure; and likewise through all its plicatures, interstices, and cavities, even over the corpus callosum itself, although loosely. . . . This membrane, cut by chance while I was paring the top part of the brain down to the lateral ventricles with a razor, in a body I lately had, gave me an opportunity of showing it as plainly in those ventricles as the largest membrane of the body to several who stood by. . . . But this is to be sought for either in recent bodies, or in such as before death, through such diseases as dropsy, strangury, some sort of apoplexies, and the like, have been filled with extravasated serum. . . . This is the proper membrane of the brain, and insinuates itself through all the close plicatures of the brain, and that not in a continuous, but rather retiform contexture, and so it may be called by the same name as the membrane investing the crystalline humour of the eye, namely, the arachnoid. . . . As regards glands, I could never see them, but I have noticed the external surface of the cortical part of the brain, in strangled bodies, appear glandulous very plainly through this transparent integument. . . . The blood-vessels belonging to the brain itself it conducts as it were through its duplicature; in their passage allowing them the opportunity of growing extremely fine, after many serpentine windings towards their capillary extremities,

[1] "Anatomy of the Brain," etc., chap. ii.

before they are extended into the brain. . . . There are also blood-vessels belonging to the nutrition of the brain itself; these I found upon diligent inspection spread plentifully upon the inside of the exterior lamina, and they are very well delineated by Bidloo. This duplicature is also very plainly communicated to all the nerves, both within and without the cranium, making by its exterior lamina a second integument under the first from the dura mater to the whole fascicle of nerves; and a third by its interior lamina, which yields an involucrum or covering to all the single fibrils, which collectively make up the whole nervous body itself. Through the admirable fineness of this membrane investing those medullary fibres, altogether insensible of themselves, it happens that there is such a prompt consent between part and part, and between all and the brain itself" (pp. 10-19).

407. HEISTER.[1]—"The pia mater enters all the convolutions, and invests also the spinal marrow and nerves. In a healthy brain it is tight and firm; with dropsical persons lax. With the dura mater it is connected only by the veins, which pass off into the sinuses. No nerves have been found entering into this substance, nor any lymphatic vessels" (no. 269).

408. WINSLOW.[2]—"The pia mater surrounds the whole mass of the brain more particularly than the dura mater. It adheres very closely to the brain, and is connected with the dura mater only by the veins which open into the sinuses. It is made up of two very fine laminæ, the outermost of which covers pretty uniformly all the convex surface of the brain, and lines in the same manner all the concave or inner surface of the dura mater. The internal lamina forms a great number of folds, duplicatures, and septa, which insinuate themselves into all the convolutions and sulci, and between the different strata of the cerebrum and cerebellum. . . . In each of these laminæ we discover another kind of fine duplicature which contains vessels; but these small vessels are hardly perceivable without the help of an injection" (nos. 49, 50, 52).

1 "Compendium Anatomicum," Amsterdam, 1723.

2 "Anatomical Exposition," etc., section x.

409. RUYSCH.[1]—"It must not be thought that the insinuation of the pia mater into the brain takes place in the same way in which the omentum is let down among the circumvolutions of the intestines, or like linen, which we may push into various little depressions, the length and breadth of which is thereby much diminished. That this, however, can never be the case with the pia mater will appear manifestly to every close observer. It appears most clearly from this consideration, that after it has been very carefully separated from the cerebrum and cerebellum, its size is thereby not increased, no matter how much it may have insinuated itself into the sulci, unless, indeed, from every part and everywhere the connections established with the help of the fibres and blood-vessels are loosened by raising it with the hand. The pia mater, therefore, seems to me to sink down into all the sulci, and into certain processes of the convolutions, pretty much in the same way in which the falciform process which is subject to the longitudinal sinus, emerges out of the duplicature of the dura mater; so that the pia mater produces as many processes as there are convolutions; the form of these, however, is not falciform, but it is creeping in a serpentine manner. Into the interstices of the cerebellum, however, the pia mater emerges by as many falciform processes as there are sulci or convolutions; when this is removed and withdrawn it presents the pleasant appearance of the compartments of a white poppy head" (p. 7). From the figures of this author (p. 8) you may see how the arteries are wonderfully diffused over the membranes, until their ramifications escape the sight. You can see there also the serpentine processes of this membrane in the cerebrum, and its falciform processes in the cerebellum. In another figure again, after the cortical substance has been taken out, there are the empty compartments and cellules, similar to the honeycomb of bees, exposed to the sight in an irregular manner, just as they are formed by the various convolutions.

[1] "Ruyschii Opera Omnia," Amsterdam, 1737. Epistola anatomica, problematica septima de Pia Matre, Amsterdam, 1744.

[Modern Authors.

409*a*. Todd.[1]—"In tracing the pia mater of the spinal cord upwards, it will be found gradually to become much thinner and more delicate as it passes from the medulla oblongata to the hemispheres of the cerebellum and cerebrum. In connection with these latter parts it becomes of extreme tenuity, and owes its physical tenacity chiefly to the intimate connection of the arachnoid membrane with it. The cerebral pia mater is almost exclusively composed of numerous ramifications of minute vessels which are accompanied by white fibrous tissue in small quantity. These vessels divide and subdivide to the last degree of minuteness, and are admirable objects for examining the structure of capillary vessels. The pia mater adheres closely to the whole surface of the cerebrum, cerebellum, and connecting parts, and numberless vessels pass from it into the nervous substance in contact with it. On the surface of the cerebrum it adheres to the superficial grey matter and sinks down into sulci or furrows between the convolutions. Wherever there is a depression or fissure of the brain, the pia mater is found dipping into it. It likewise sinks into the fissures between the laminæ of the cerebellum. We shall obtain, however, a very inadequate notion of the extent of the pia mater, if we confine our examination of it to the exterior of the cerebrum and cerebellum. At certain situations this membrane is continued into the cavities or ventricles of these organs, where it doubtless fulfils some office connected with the support and nutrition of certain parts of them" (p. 25). "The pia mater adheres very closely to the surface of the brain, coming for the most part into contact with the grey or vesicular matter. When a portion of it is carefully raised in a fresh brain, numberless extremely minute blood-vessels are seen passing from it into the cerebral substance. These are the principal

[1] Todd (R. B.), M.D., F.R.S., "The Descriptive and Physiological Anatomy of the Brain, Spinal Cord, and Ganglions, and their Coverings," London, 1845.

nutrient vessels of the brain. On its outside the pia mater adheres partially to the arachnoid membrane. At those points which correspond to the convex portions of the convolutions the adhesion of the arachnoid to the pia mater is close; but at other places the latter membrane separates completely from the former. The pia mater of the brain differs from that of the spinal cord in its great delicacy and tenuity; it wants the strength and density of the latter membrane. This is owing to its being composed almost entirely of extremely minute and delicate blood-vessels, whilst the spinal membrane consists chiefly of white fibrous tissue. The blood-vessels of the former are infinitely more numerous than those of the latter, and the reason of this probably is that the cerebral membrane is chiefly in contact with grey matter, which requires a great quantity of blood, but the spinal membrane immediately embraces white matter, which is much less vascular" (p. 30).

409*b*. QUAIN.[1]—"The pia mater is a delicate, fibrous, and highly vascular membrane, which immediately invests the brain and spinal cord. Upon the hemispheres of the brain it is applied to the entire cortical surface of the convolutions, and dips into all the sulci, which thus contain a double layer. From its internal surface numerous small vessels enter the substance of the brain, and hence this inner surface is very flocculent, and is named *tomentum cerebri.* On the cerebellum a similar arrangement exists, but the membrane is finer, and the double fold only distinct in the larger sulci. The pia mater is also prolonged through the transverse fissure into the lateral ventricles, and there forms the velum interpositum and choroid plexus. It is also prolonged into the fourth ventricle, where it forms the choroid plexus of the fourth ventricle. On the spinal cord the pia mater has a very different character from that which it presents on the encephalon, so that it has even been described by some as a different membrane under the name *neurilemma of the cord.* It is thicker, firmer, less vascular, and more adherent to the subjacent nervous matter: its greater

[1] "Elements of Anatomy," eighth edition, vol. ii., London, 1876.

strength is owing to its containing fibrous tissue, which is arranged in longitudinal shining bundles. . . .

"*Structure.*—The pia mater consists of interlaced bundles of connective tissue, having a more regular arrangement in the outer and inner layers, while in the middle is a network of fine elastic fibres. . . . The pia mater contains great numbers of blood-vessels, which subdivide in it before they enter the nervous substance. Each vessel lies in a canal, the walls of which are composed of a more dense arrangement of the fibres of the membrane (perivascular canal). The diameter of the canal may be two or three times that of the contained vessel. A similar sheath, derived from the pia mater, accompanies the vessel into the substance of the brain. At its commencement it is loose and funnel-shaped and can be injected from the sub-arachnoidal cavity. On the cerebrum the inner layer of the pia mater is adherent to the cortical substance of the convolutions, but on the cerebellum a space exists between the two, traversed by fibres which pass from the cerebellum to the pia mater. This space is continuous with the intervals between the perivascular sheaths and the brain substance" (pp. 571, 572).

409*c*. KEY AND RETZIUS.[1]—"In the brain the pia proper consists of a very fine membrane, the interior boundary layer of the entire soft meninx [*i.e.* of the arachnoid and pia mater combined]. The pia proper corresponds essentially only to the inmost lamina of the pia in the spinal cord, and consists of a simple membranula, invested with endothelium, and containing stiff, shining, decussating fibres of varied number, similar to those in the inmost lamina of the pia in the cord. The little membranes bounding the sub-arachnoidal passages everywhere pass over into the pia mater. The blood-vessels, before ramifying and losing themselves in the cortex, for some distance run along the exterior surface of the pia. These vessels are fastened most intimately to the pia by fine little membranes.

[1] "Studien in der Anatomie des Nervensystems," etc., vol. i., Stockholm 1875.

In cross-sections, therefore, it often appears as if the vessels were running in the pia itself, although they are really situated between the pia and another fine little membrane closely attached to it. The pia mater always follows the surface of the brain very accurately in all its anfractuosities and depressions; it presses closely against it, but is very easily pulled off from it. Special methods, therefore, are required, in order to succeed in representing the pia mater in cross-sections in its natural position in respect to the surface of the brain. Frozen preparations are best for this purpose; although in this case we must always take into consideration the fanciful images which are caused thereby in the brain substance. Sometimes also you may succeed in obtaining the pia in its natural position along the surface of the brain, in preparations hardened in hyperosmic acid or chromate of potash and afterwards in alcohol; or also in preparations which have been somewhat dried. But never in such preparations does there appear between these formations a space, an actual epicerebral space [as maintained by *His* and his followers]. This circumstance is of special importance in frozen brains; since, especially by the act of freezing, either pre-existing spaces are enlarged, or new artificial spaces are obtained by bursting. On the other hand, however, there cannot be discovered any parts whose office it is to establish a connection, no fibres which from the pia mater penetrate into the brain, no peculiar cementing substance of any kind. The neuroglia [nerve-cement] of the surface of the brain, which in some places contains fine plexuses of nervous fibres running in a horizontal direction, is intimately and closely attached to the pia mater. Smaller portions of neuroglia are often found clinging to patches of pia mater which have been pulled off; which is an evidence of the close adhesion of these substances. In the surface of the brain we were unable to discover any layer of cellular endothelium, a stratum of such cells as have been described by Golgi and Boll. Everywhere the neuroglia encountered freely the pia mater. Still, in all the regions of the cerebrum, as well as of the spinal cord, there is one formation to which is assigned the office of attaching the pia mater; namely, the blood-vessels which from the pia mater enter into the cortex of the brain. On examining a piece of pia mater which has been separated from the surface of the brain and spread out flat, you will notice how the blood-vessels attached to the pia mater freely send out their shoots, and how these, scattered here and there, protrude like villi from the membrane. For the vascular shoots, which at first still preserve their natural position, deflect from the vessels in the pia mater, and at right angles penetrate into the cortex. On entering the cortex they run along a funnel-shaped indentation of pia mater, which by-and-by fits more closely around the coating of the vessel, and which in the form of a sheath accompanies every vessel" (p. 148). "This perivascular sheath, in larger vessels, is slightly different from what it is in capillaries; thus in the former vessels it is more or less removed from the parietes of the vessel. . . . In the sheath itself there is scarcely a trace of structure; it appears almost as clear as glass and homogeneous. . . . We never succeeded, under treatment with silver, in obtaining in the sheath real outlines of endothelial cellular fields, such as other authors (Eberth, Riedel) seem to have produced; the only result obtained was a diffuse colouring, or irregular spurious outlines. . . . In the smaller transitional blood-vessel the middle, muscular coat disappears altogether, the perivascular sheath remaining as a clear homogeneous sheath, more or less distant from the interior coat. Often, however, in the capillaries this sheath is entirely invisible; yet in places where the capillaries branch out, the perivascular sheath becomes plainly visible as it retreats from the interior coat. Everywhere, in fact, its presence is indicated by small, beautiful, and singular nuclei" (p. 150). "The spaces which are contained within the perivascular sheaths are serous canals which are in open communication with all the sub-arachnoidal spaces. A communication between these spaces and the epicerebral space of His, the existence of which, however, is doubtful, does not exist" (p. 142).

"In the *cerebellum* the relations are a little different; namely, in respect to the fastening of the pia mater to the cortical substance. For some sort of formations are there, serviceable to the more intimate attachment of the pia mater. These are the fibres described by Bergmann, Hess, Schulze, Deiters, Henle-Merkel. In the free, open surface of the cerebellum we looked for these fibres in vain; but we found them, and indeed very copiously, in the furrows of the cerebellum. Sometimes we thought we succeeded in discovering these formations also in the surface itself, but only in the neighbourhood of the sulci, and exceptionally. Their proper territory, therefore, lies in the furrows or sulci; and we think ourselves authorized in maintaining that the attaching fibres belong to the sulci. We have examined them in man, in the dog, and in the rabbit. Their relations are almost the same in these various creatures. They always exist in great numbers. . . . On pulling off the pia mater from the surface of the cortex, it will be found that a greater or smaller number of these fibres is pulled off at the same time, and that many of them remain attached to the pia mater. A great number of these fibres, however, are usually torn from the pia mater, and with their trumpet-like enlargements they stick out of the cortical substance like a diminutive forest; or else they have the appearance of a narrow border, or of an indented little membrane. . . . As a general thing these fibres appear homogeneous, transparent like glass, and they are not very stiff, but pliable. . . . Not unfrequently they ramify in the direction of the cortex; they divide dichotomously, and sometimes this division is repeated. The ramifications in this case form an acute angle with one another, and dip into the cortical substance. . . . It seemed singular to us that this kind of fibres should occur only in the cerebellum, and we therefore repeatedly strove to discover analogous formations in other parts of the central organs. Yet we never succeeded in our endeavours; certainly not in the sulci of the cerebrum. Whenever we thought that we had met with single fibres of this sort, on instituting a more precise examination, it always turned out that we had mistaken fine filaments drawn out of the neuroglia [nerve-cement] for the genuine attaching fibres" (pp. 154 155).

409*d*. Bevan Lewis describes certain "pericellular lymph-sacs in the brain," around the individual cortical substances or the nerve-cells. These pericellular spaces, according to him, are connected with the perivascular sheaths of the capillaries which are derived from the pia mater. He says on this subject, "In many instances a distinct connection between the perivascular and pericellular spaces could be clearly observed, although for obvious reasons the majority of specimens exhibited this connection only after the most careful and strict scrutiny." (See his paper on "The Relationship of the Nerve-cells of the Brain to the Lymphatic System of the Brain," from which we have quoted largely in no. 383*e*.) From this it would seem that the pia mater through the perivascular sheaths of the capillaries is continued into the immediate neighbourhood of the individual cortical particles or nerve-cells.—Editor.]

ANALYSIS.

410. Nothing in universal nature is arranged in a more perfect order than the brain, especially the human; but before the evidence of the senses nothing appears less in a state of order, because nothing is more occult, or filled with arcana. Still the senses are not the judges. For man is the last fabric of the universe, and in man his brain is pre-eminent, because it is the court of his kingdom, and the heaven of his world, inhabited by his soul which from below looks up to God, and from above looks down upon the body.

411. From this court of the kingdom, from the brain, we learn what order nature follows, and what laws it observes, in proceeding from the inmost to the outermost, from prior to posterior things, from principles to effects, or from heavenly things as it were to earthly ones, and *vice versa.* Nature has placed this noble seat apart from the body, and besides has enwrapped it with doors and bands, that is, with the cranium, the dura mater, and the pia mater which covers the brain immediately. The cranium is hard and earthy, the dura mater softer, but the pia mater is the thinnest of all; this is taken up by a still purer, nay, by a *mater piissima,* which invests the individual substances of the cortex, and which at last escapes the sight, and betakes itself to the mind, at a distance from the senses. We may thence reflect on the quality of this membrane, on the quality of its woof, and of the liquid which thrills through it, since these qualities are shadows, ideals, and analogies of those things which we acknowledge by the senses, and express with the articulate voice. This, however, belongs to our Introduction to Rational Psychology. Let us return to the pia mater.

412. This thin membrane is proper to the brain, and nearest to it; the dura mater and the cranium, however, are not teguments proper to the brain in the same degree, because they are exterior and more remote. According to the laws of order, that which is interior is also prior, superior, purer, more universal, and more perfect. Hence the pia mater, because it is nearest to the brain among its three coverings, is the first, highest, purest, most universal, and most perfect; and the same difference which is observed between the bony covering and the dura mater exists also between the dura and the pia mater; and again between the pia mater and the piissima which encircles the individual substances of the cortex. The difference or distinction, therefore, seems to be a rational and an analogical one, of priority, superiority, purity, universality, and perfection. Thus by a geometrical method we learn from the one the quality of the other, or the quality of the pia from the dura mater.

413. In respect to *priority* the pia mater is prior to the dura mater in time, place, and quality. In respect to *superiority* it is nearer to the brain, to the court of the kingdom or the heaven of this world; it is thus nearer to the soul, and consequently, speaking in accordance with the doctrine of order, it is superior or higher. In respect to *purity* it is thinner, more yielding, more liquid, lighter, and more simple. In respect to *universality* it is more extensive; for it covers and veils eminences, acclivities, and valleys; it enters also into convolutions, sulci, little clefts, and miniature gyres, and collects into one congeries the agglomerations, aggregations of parts, and strata of the cerebrum and cerebellum. In respect to *perfection* it is more potent; it excels in strength and power, is more elastic, more distinct, more unbounded, freer, more sensitive, more constant; also in respect to form, essence, attributes, accidents, modes, and qualities it is more perfect.

414. As the dura mater invests the two brains and the hemispheres in a more general way, so the pia mater clothes integral parts, aggregations, convolutions, and ridges, which are so many tortuous, and often subdivided, little hemispheres, and analogue

brains, and which taken together bear the same relation to the larger hemispheres and brains which the parts bear to their whole. Such a membrane is drawn over all these parts, and makes its way between them, in order that the determinations of the form and of the substances, as well as of the motions of the two brains and the medulla oblongata, may be most distinct; and that as long as they have their animatory motion they may be entire and perennial.

415. The cortical substances are so many forms and forces of the acting brain, which are so disposed that they have respect to their fellows as to themselves, and in the common cause each lays claim to its own part. In order that they may act in congruity under the bond and form of society, small numbers associate themselves in an orderly way as it were into grapes and clusters; these again into bunches; and these into long congeries, whence arise the convolutions which build up the cerebrum and the cerebellum. Each part, however, has limits assigned to it, since they are encompassed by a membrane which reduces the scattered forces into one, and enlists them in the common and public cause. Such is the purpose of the pia mater which is spread over all, and insinuates itself between them, and thus compounds the individual parts by the necessary laws of inmost nature. In this wise the individual substances, forms, and forces of the brain, by means of this membrane, are like so many little members of one commonwealth, and live for the common good.

416. Each particle of the cortex is besides a substance by itself, and enjoys its own power and force, and has its own sphere of activity; in like manner each congeries and agglomeration; and also the whole, namely, the cerebrum and cerebellum. Each, within its own sphere and within its own boundaries, has the freedom of acting for itself while acting for the others or for the public good. This power, however, is limited by membranes, septa, and bonds, and finally the power of all is limited by the pia mater which connects the individual parts, and at the same time grants a full measure of acting to each individual; for it is pure, light, elastic, yielding, obedient, and in respect to the

inmost forces of the brain it is passive. If, therefore, this membrane is obstructed by any viscidity, ichor, or serum; if it swells, stiffens, or is torn, then at once the kingdom labours, the senses are blunted, the memory becomes infirm, the animal mind wanders, the understanding is obscured, and the will is stopped. Thus the order of things perishes, and with it analysis and the reason of laws. Hence it appears over what uses the pia mater presides. There are besides members and organs of the brain which are mutually distinct from one another: such are the fornix, the pineal gland, the corpora quadrigemina, the septum lucidum, the ventricles, the aqueduct, the infundibulum, the pituitary gland, and several more. Unless these were distinguished from one another by a membrane, there would be no distinction, no ratio, no respect, no dependence and harmony, but an absurd confusion of functions. While the pia mater, therefore, couples together the individual parts, it also distinguishes them, and obliges the brain to obey the soul,—the end, nature, and principles,—and it compels the body to obey the brain.

417. From the two brains the pia mater is also continued around the spinal marrow; and in like manner outside of the cranium and the vertebral cavity it is continued around the roots of the nerves, and it collects, unites, and distinguishes the fibres precisely according to the same law which it follows in respect to the substances of the brain. In the universal kingdom there is nothing continuous except the fibre and the membrane; congregation and form only vary the modes; consequently there is nothing but the cerebrum, the cerebellum, the medulla oblongata, and spinal cord, or more strictly speaking, there is nothing but the continuation of the cortex and of both the meninges, which is the all in all, and which as it rules the universe in the highest, rules it also in the last and middle things.

418. This same membrane is a containing plane which leads the blood-vessels and the blood into the cerebrum and cerebellum, from the outermost as it were to the innermost, or from the circumference towards the centres. The body is in outermost

things and in the circumferences; its life is the blood. The two brains, however, are the inmost places and the centres; their life is the purer blood or the animal spirit; but the life of all is the soul, which grants to each the ability of living. In proportion, therefore, as the blood of the body penetrates into the brain, it is borne towards the inmost parts; while in proportion as it is projected into the sinuses, it returns to the outermost. All this is being transacted by means of the pia mater, which receives the blood-vessels, weaves them into its septa, enwraps them with its duplicatures, and in a certain definite direction continues them into the brains, or insinuates them into centres, of which there are as many as there are cortical substances. It also arranges and disposes properly for influx the plexuses of the blood-vessels, which have their sport on the surface of the brain, and which rejoice as it were at their return to the soul, and into new life. It provides also, lest the least capillary vessels should stray from the normal course.

419. There seem to be as many origins of the pia mater as there are cortical parts of the brain. That purest little membrane which encompasses these little particles, is the first and piissima mater of all; and when the soul aspires towards the general from the singulars, it produces most delicate little fibres, and covers these with a web, which collects into one the animal forces, and directs them towards certain ends. For the part exists before the whole; the whole derives from the parts all its property; thus the brain from the substances of the cortex, which are so many first and purest brains. The effect flows altogether from the efficient cause. But in order that there may be a continuous connection or a perpetual circle of things, little blood-vessels return from the body, and these again insert their simple fibres into the membranes of the cortices. The pia mater seems therefore to derive its origin and nature from the individual parts in the brain, and again from the individual parts in the body. We must therefore look for its origin in the end of all, and the end we must seek in the origin of all, just as the origin of the circumference must be looked for within the circle; yet it is by no means discovered there.

APPENDIX TO CHAPTER VII.

A. *The Texture of the Pia Mater.*[1]

419*a*. *The pia mater is not a single, but a double membrane, and if we add the arachnoid, it is of a triple order.* . . . That the pia mater is double, the most keen-sighted explorers maintain on the strength of their observations. At all events an infinite number of little shoots,[2] having the appearance of fibrillæ, are taken from its interior surface, while the exterior surface remains whole. On this account its interior surface appears rough and covered by a certain mucus,[3] while its external surface is polished and even. This shows that there is some double texture. The same may be concluded from the arterial vessels which press against its outermost surface.[4] Besides, there is no doubt of the arachnoid mater extending over the whole pia mater.

B. *The Blood-vessels in the Pia Mater.*

419*b*.[5] Nowhere seems there to be a more copious wave of

[1] From part ii. no. 375.

[2] That is, the perivascular sheaths encompassing the capillaries which from the pia mater enter into the brain substance. See *Key and Retzius* in no. 409*c*, p. 408.—Editor.

[3] By this mucus Swedenborg evidently means the liquid portion of the neuroglia or nerve-cement which is intermediate between the pia mater and the cortical substance of the brain. See no. 409*c*.—Editor.

[4] On this subject Key and Retzius say, "The blood-vessels are fastened most intimately to the pia by fine little membranes. In cross-sections, therefore, it often appears as if the vessels were running in the pia itself, although they are really situated between the pia and another fine little membrane closely attached to it." See no. 409*c*.—Editor.

[5] From Codex 65 of the Swedenborg MSS. in vol. iv. of the Photolithographed edition, p. 4, etc.

arteries than in the pia mater, which is spread out in the closest proximity to the cortical substance. Wherever the surface of the pia mater is furrowed or ploughed through, a little artery is present, which reclines on the sulcus, and sends out an infinite number of little shoots. These, on dipping down more deeply, are broken up into numberless purer shoots, which insert their capillaries everywhere into all interstices where any part of the cortical substance seems to be present. This also is confirmed by the experience of all, especially by the singular experience of Ruysch, according to which a new compages or plexus is appended to the ends of the little vessels in their finely-split ramifications.

419*c*.[1] The pia mater has vessels attached to it in an infinite number of places; for the transmission of which vessels it serves as a kind of little bridge: and the more so, since it not only overlies the cortex, but is continually interposed between it and its different masses, producing itself into septa in a serpentine manner between the windings of the cerebrum, and in a falciform manner between the folds of the cerebellum. Nay, it everywhere sends down offsets into the furrows and little spaces between not only the combined, but also the simple substances, to which indeed it is affixed. This is in order that there may be a unanimous concordance of all the parts with the general: just as in the body, its nerves, muscles, glands, and in the members constructed of them, where the outermost and common membrane always detaches from the inside a finer membrane, and then a finest, which connects the simple fibres as the common membrane connects the fascicles. How this takes place is very evident in the cerebellum; and indeed in the cerebrum too, although here its continuity is such that it forms a plexiform web.

419*d*.[2] The quantity of blood in the pia mater is so great that it deserves to be called a vascular net rather than a

[1] From the "Economy," etc., ii. no. 142; see also Part ii. of our present work, no. 72.

[2] From Codex 65 of the Swedenborg MSS. in vol. iv. of the Photolithographed edition, p. 48.

membrane. The principal vessels which arise from the carotids keep in the sulci and furrows of the anfractuosities. They are in a certain sense so many *little sinuses of the pia mater*, not unlike the large sinuses of the dura mater; for they creep in the duplicature of their pia mater, as the latter do in that of their dura mater. The former press upon the processes of the pia mater, just as the latter are incumbent upon the processes of the dura mater, namely, upon the falx cerebri, and the tentorium. Through the process [or duplicature] stretching out below, the former, that is, the sinuli of the pia mater, send out an infinite number of shoots, and even beyond the pia mater into the cortex; and these shoots return thence again into their little sinuses. In the falx cerebri, the tentorium, and the other processes of the dura mater, there are also an infinite number of shoots which insert themselves into their sinuses, and at the same time dip into the neighbouring substance. Below or underneath the serpentine processes of the pia mater there are also perchance lesser sinuli; just as there are inferior longitudinal, and occasionally also inferior lateral sinuses in the falx cerebri and the tentorium of the dura mater. The shoots in the processes of the pia mater also meet sometimes in a certain more general shoot or branch, which descending in an oblique or straight direction strikes root in the cortical and medullary substance, exactly like the large straight sinus, which extends in a similar manner towards the interiors of the whole brain, even as far as the pineal gland. The former sinuses, or those of the pia mater, derive their blood into diverticles or asylums which are here and there hollowed out in the medullary substance; exactly as is the case with the large sinuses which terminate in the lateral sinuses, and these in the diverticles or receptacles outside of, and at the same time within, the jugular fossæ. The former, on account of reclining on the serpentine processes of the cerebrum which are continued to a large extent into its gyres and anfractuosities, surpass in number the venous sinuses, which simply divide the cerebrum into hemispheres, and separate that organ from the cerebellum, between which organs also the straight sinus pursues its way. Every little sinus of the pia mater, however, making its way towards a particular glome or cluster of the cortical substance, seems to preside over it; for every convolution is subdivided into several such clusters.

Whether these little so-called sinuses of the pia mater contain venous or arterial blood, is justly a matter of doubt, and also whether they partake of the nature of each. That they do carry both venous and arterial blood, appears from this consideration, that the arterial blood, after its volatile nature has been extracted and expended upon the cortex, returns again through the same little vessels; or that it leaves the sinus of the pia mater as arterial blood, and returns into it with blood more of a venous character. Nor does all the blood then pass into the veins which lead into the dura mater and thence into the sinuses, where they terminate; but again and again the same blood flows into the cortex and back again; according as the cortex acts more strongly or more feebly, more quickly or more slowly; or according as the cerebrum holds its breath, while it revolves ideas, and ponders over reasons. At all events the remaining part of the blood which returns from the substance of the cortex into its little sinuses, is not of the same character as that which it had first on leaving the little sinuses for the cortex. Nor does the fact that, so far as the character of the blood and serum of the little sinuses is concerned, it partakes of a venous nature, conflict with that other fact that there are in the cerebrum separate veins which receive the blood afterwards, and which in various obtuse, sharp, and right angles meet the rest of the veins. By these last veins also the above blood seems to be received for no other purpose than that it shall no longer return from them; for when it has once reached them, it must needs be derived thence into the sinuses. From these considerations, therefore, it may be inferred somewhat, that these little sinuses are not simply diverticles of blood. It is different, however, in the cerebellum, and also in embryos, and likewise in some brutes, where the blood is not dispensed according to the wants of a state similar to that which prevails in the adult human cerebrum.

419*e*.[1] The pia mater does not seem to enter immediately into the particles of the grey substance, but mediately through the coatings of the little arteries, which pass between the termini of each. For the pia mater often leaves the little arteries to themselves, which then in deeper and narrower places pass off into a reticular form, without any meninx connecting them, as is the case on the surface; on which account also they can be separated by a mere immersion in water; according to the art exercised by the celebrated Ruysch.

Which coat, however, is chiefly derived into the spherules of this cortical substance through the medium of the arteries, cannot be explored with the aid of the senses. But from various signs it seems that we are authorized to conclude that it is the *inmost coat of the arteries.* These vessels always leave behind their external, nay, their muscular coat on entering the brain; while the interior coat is continued even beyond the meninges.[2] This last coat conveys the purest blood into the very cortical substance, and thence into the little fibrillæ; as will be confirmed in the Chapter on the Arteries of the Brain and of the Body.

C. *Relation of the Pia Mater to the Arachnoid Membrane.*

419*f*.[3] The arachnoid membrane, which has borrowed its

[1] From Codex 65 of the Swedenborg MSS. in vol. iv. of the Photolithographed edition, p. 5.—Editor.

[2] This statement is confirmed by the researches of Key and Retzius and Bevan Lewis. The former say, "In the smaller transitional blood-vessels the middle, muscular coat disappears altogether, the perivascular sheath derived from the pia remaining as a clear homogeneous sheath, more or less distant from their inmost coat" (see above, no. 383*d*). The latter declares, "In all cases I never failed to recognise, on careful examination, a small capillary either passing immediately across the nerve-cell, or running with a gentle curve along the pericellular space" (see above, no. 383*c*).—Editor.

[3] From Codex 65 of the Swedenborg MSS. in vol. iv. of the Photolithographed edition, p. 204, etc. See also the Chapter on the "Arachnoid Membrane" in part ii. no. 486.—Editor.

name from the arachne (spider), the delicacy of whose web it emulates, is superadded to the pia mater; and like a second lamina of this membrane, it sinks down into the individual tracts and external gaps of the brain, whether they be low or high, or spread out in a plane; yet it does not enter the sulci and clefts. When the arachnoid, therefore, is removed, the quality of the cerebrum appears, and especially it becomes manifest how the cerebellum is distinguished into little gyres. This membrane is attached to the underlying pia mater more closely on top of the cerebrum, and more loosely at its base and over the cerebellum. Again it adheres to it more closely in the eminences of the medulla oblongata than in its depressions; and it is conjoined more strictly with it in front of the spinal cord, while it floats about more freely in its posterior part, where it is suspended from the ligamentum denticulatum.

419*g*.[1] The arachnoid membrane is a perennial and continuous covering over the whole encephalon; different in this respect from the dura and pia maters, which are, indeed, continued over it, yet with interruption, through plicatures and insinuations; for the pia mater conjoins the individual parts in a particular manner, but the arachnoid membrane connects them in a general manner. This latter membrane, indeed, does not insinuate itself with the pia mater into the very anfractuosities and sulci, but it is spread over the whole; so that it does not enter into the cerebrum or cerebellum, but is altogether limited to the surface; for when the membrane is taken off, the cerebrum and cerebellum appear bare with all their anfractuosities and sulci. The pia mater is thus a superior universal membrane, the arachnoid an inferior universal membrane, and the dura mater a general membrane; for this does not sink down into the individual parts, but around the sinuses it simply forms those larger processes which are those of the dura mater.

[1] From the Chapter on the "Arachnoid Membrane" in Part ii. nos. 498, 499.

D. *The Sub-arachnoid Liquid.*

419*h*.[1] *The pia mater constantly exudes a certain dew, . . .* and therefore it is a perpetual source of some humour. (See above, Pacchioni, in no. 403.) *The little arteries also which creep between the two membranes exude a similar moisture.* The arterial shoots which creep in the duplicature are most numerous. If now the pia mater itself sustains such a large number of little arteries, which adhere to it in various places, and perforate it, . . . and if in addition we attribute to the arteries of the brain the power of secretion, as we do to those of the body, it follows that a perennial stream of moisture collects and flows between the two membranes, or under the arachnoid membrane.[2] Whenever the cerebrum and cerebellum, and at the same time the medulla oblongata and the spinal cord, swell during the alternate periods of their animation, the juice is expressed, and received by the spaces between the two membranes; altogether in the same way as it is received in the membranes of the body during each systole and diastole of the heart. . . . The pia mater is purely vascular, or compacted of the extreme capillaries of arterial vascula, and not of the genuine fibres of the brain; for no fibre is reflected into the pia mater from the brain. If, however, it is vascular, it must necessarily distil a noble moisture, and, indeed, under the arachnoid membrane, or from its own exterior surface. From its interior surface, however, exudes a subtle fatness which is intermixed with the above moisture.[3]

[1] From the Chapter on the "Arachnoid Membrane" in Part ii. nos. 501, 502.

[2] See on this subject the note on "The Cerebro-spinal Liquid" in Vol. ii.—Editor.

[3] This, it would seem, is the liquid portion of the *neuroglia* (nerve-cement) which exists between the internal surface of the pia mater and the surface of the cortex.—Editor.

CHAPTER VIII.

THE CORPUS CALLOSUM.

420. WHEN the hemispheres are drawn apart, from the crista galli along the whole length of the falx cerebri, there comes into sight a medullary body, white and hard, loosely covered with pia mater, which by Veslingius is called corpus callosum, and by Vieussens the true fornix, because being placed underneath the two edges of the cerebrum, it proximately sustains the hemispheres. Between it and the falx cerebri a fibrous substance is sometimes noticed. The corpus callosum runs out also laterally over the ventricles, and touches the "isthmus,"[1] and thus covers the organs that are concealed within, so indeed that each of them maintains properly the place appointed to it by nature. This body is bordered all around by the white medullary substance, which like a ceiling spreads thence sinuously over the roofs of the lateral ventricles; and below this upper surface it pursues its way towards the medullary border of the corpora striata, where it meets that medullary substance which penetrates more deeply, and is called the middle part of the centrum ovale [corona radiata], and by Willis the anterior border of the corpus striatum. Not far below the fornix are extended two mammillary elbows [posterior crura or pillars of the fornix], according to Willis's figure, which are the edges or borders (*margo*) of the corpus callosum embracing the medullary caudex near the cerebellum; these elbows are thus continuous with the medullary vault. Through the medium of the body of the fornix the corpus callosum is

[1] "The space between the cerebrum and cerebellum, upon the corpora quadrigemina." See Ridley, "The Anatomy of the Brain," p. 13.—EDITOR.

also in a certain sense introduced into the bottom of the lateral ventricles; and with that medullary tract [tænia semicircularis] which by Vieussens is described as "a tract transverse and a little oblique," and which when opened out below forms the "geminum semicirculare centrum," it expands itself in such a manner that while distinguishing the individual parts, it associates them together. When, however, the corpus callosum itself is quite cut through, in all directions, its interior courts appear, formed of a beautiful order and apparatus of fibres. A medullary border or expanse passes everywhere around; thence fibres emanate and run out on both sides, like streaks on a roof with hollow tiles; these fibres run across almost parallel with one another, though a little obliquely. In some subjects, however, they tend obscurely towards a certain middle medullary tract, which is called the medullary seam or raphë dividing the streaks in the middle. This raphë, which runs along the whole length between the longitudinal striæ, divides the corpus callosum into two halves, and distinguishes the medullary substances of the cerebrum into a right and a left region in the same plane altogether in which the falx cerebri makes this division above, and the third ventricle with the remaining clefts intersects and separates them underneath. It appoints therefore to each living organ its place on the side and in the circumference; and with their places thus allotted they know how to go through their alternate motions in general and in particular with their associates in the same hemisphere, and with those in the other hemisphere. The corpus callosum is hence a narrow beam and promontory of the cerebrum through which there is access into its interiors, comparatively as into the shady kingdoms of Proserpine; for unless this corpus with its hinges is removed, there is no entrance open to the inner sanctum, where amid valleys and greyish white shrubs, as it were, little rivulets of blood stray about, which merge into daylight where the "isthmus" cleaves the soil, and leads the veins into the straight sinus. Here the corpus callosum lies athwart, like a doorkeeper, and opposes its back and shoulders, lest a transit should be open from the higher into the lower, and from the lower into the higher parts; such is the decree of the inexorable judge. It is placed under the edges of the hemispheres, into which it runs out on the right and on the left, and soon immerses itself into the medullary ocean and centrum ovale [corona radiata]; and of the medullary substance which extends around it, it composes the doors and septa of the ventricles, through which it returns again to its own callosity.

421. WILLIS.[1]—"In both hemispheres of the cerebrum, near their anterior portions, is the corpus callosum, or the medullary substance, which is here much thicker and more compact than in any other place. Here also it is affixed to the upper parts of the medulla oblongata on both sides. From these upper parts, as from its origin, this substance, which covers and vaults the cerebrum, gradually decreases in thickness. At last the outer edge of this expanse is more closely drawn in, and is conjoined below with the caudex of the medulla oblongata by a connection established by membranes and blood-vessels. . . . The interior recesses of the cerebrum come into sight still more clearly, if the border of that organ from its cohesion with the medulla oblongata, as far as it can be done, is separated and raised on all sides, and if at the sides of the same medulla with which it is united near the corpora striata, it is cut through its substance a little further on; and if at the same time the fornix is dissected near its roots, and together with the roots is folded back. For then the whole structure of the cerebrum can be raised together; it can be folded back anteriorly, and can be studied in a plane; so, indeed, that the whole interior surface of the corpus callosum spread out into a broad plane may be seen and handled. There, in addition to its medullary and very shining surface, we can distinguish a number of white parallel lines, which intersect at right angles the falx cerebri" (pp. 10, 11).

422. VIEUSSENS.[2]—"When the two hemispheres of the cerebrum are drawn apart, the medullary substance comes into

[1] "Cerebri Anatome," cap. i.

[2] "Neurographia," etc., cap. xi.

sight, which lies between them, and which is called the corpus callosum, but which we in the following pages designate as the 'true fornix.' This corpus callosum, which is produced from the expanded medullary substance of both hemispheres of the cerebrum, inclines downwards from the anterior towards the posterior portion of the cerebrum, and near the corpora quadrigemina is divided into two parts [the posterior crura of the fornix], which lie under the cortex of the posterior edges of the above viscus, and together with their medullary substance (in conjunction with which they constitute the posterior region of the centrum ovale) closely embrace the peduncles of the medulla oblongata. These same parts are continued on both sides in a somewhat winding course to the posterior part of the crura of that organ [*i.e.* the optic thalami], and are so closely applied to that part as to coalesce with it. It is to be noted here that no medullary tracts extend from the anterior part of the corpus callosum, *i.e.* from that which is intermediate between the anterior processes of the medulla oblongata, or between the upper, anterior corpora striata. . . . The fabric of the above corpus callosum cannot be properly examined unless the whole convex part of the cerebrum is first removed piecemeal; whereby, when its parts and its situation are examined, the medulla of the cerebrum is plainly exposed to the sight. This medulla throughout the whole of its extent appears distinguished into tracts, and is promiscuously inserted into the cortex, with which it is everywhere covered on the outside. After the convex part of the cerebrum has been piecemeal cut off and taken out as far as the back of the corpus callosum; if then its medullary substance near the sides of the same corpus callosum is cut with a scalpel [from the front backwards], the anterior ventricles which are underneath are discovered, and their size, and their figure which is oval, become visible. Almost the whole vault or ceiling of these ventricles is formed by the corpus callosum. The walls, however, are constructed of medullary fibrils which emerge out of the grey substance of both hemispheres of the cerebrum.

The upper sets of these fibrils, that is, those which occupy the convex part of the hemispheres, incline on both sides first outwards, and afterwards, together with some other lower medullary fibrils with which they coalesce, they are inflected inwards, and embrace proximately throughout their extent the anterior processes of the medulla oblongata [the corpora striata], and its crura [the optic thalami]; so, indeed, that by the coalition of these medullary fibrils, and by their being inflected as it were upon themselves, in the middle region of the cerebrum, two caverns as it were are formed, which are separated from one another by the intervention of the septum lucidum and the fornix. These caverns are usually termed the anterior or lateral ventricles. It is sufficiently plain that all the medullary fibres of the corpus callosum (with the exception of those which terminate in the tænia semicircularis), on emerging out of the cortex from these ventricles, run around the corpora striata and the optic thalami, and as it were become one with them (where indeed they pass off into the above ventricles); so that they terminate there in a kind of spongy body, which occupies the oval outside of the aforesaid ventricles. On this account we have called it the "centrum ovale" [corona radiata]; although behind it is bent inwards, so as to touch the posterior part of the corpus callosum, and to be united to it, and hence does not quite present an oval shape" (pp. 57, 58). "After the septum lucidum [by the dissection] has been folded back anteriorly, if then the posterior parts of both hemispheres to which the corpus callosum is attached from above, are separated from the crura of the fornix which are underneath and there hidden away, and if they are folded back in a posterior direction, it appears manifestly in the dissection of the cerebrum that the corpus callosum is bifidous as it were behind, and that its medullary substance which on both sides is woven into the posterior edges of the medulla of the cerebrum, terminates in those bodies which are usually called the crura of the fornix; and further that it is continued towards the posterior portion of the tænia semicircularis or stria terminalis, and that there it coalesces with the optic thalami" (p. 60). "It is seen manifestly from the above that the true fornix is that medullary part which is usually called corpus callosum, which is thrown in between both hemispheres of the cerebrum, and serves for forming the vault or ceiling of the lateral ventricles; further, that by a certain fourfold column, namely, by the two roots of the so-called fornix, and its two crura, it sustains the convex part of the cerebrum itself, and prevents this from breaking in by its own weight, and from being thus destroyed" (p. 61).

423. Ridley.[1]—"The foremost division of the cerebrum is only as deep as the corpus callosum; the hindermost, however, goes to the very medulla oblongata itself. . . . The middle and uppermost part of the medullary substance, by the ancients always called corpus callosum, was thought to escape the covering of the pia mater, and in it are not visible any bloody specks, as in most parts of the medulla cerebri. The corpus callosum is the medium uniting the medullary part of each hemisphere or division of the cerebrum, and famous for the transverse striæ running through it from each side of the aforesaid hemispheres, the septum lucidum only coming between. . . . From the extreme limits of the two lateral ventricles, from before backwards, arises that medullary space called by Vieussens 'centrum ovale' [corona radiata], the forepart of which Willis calls 'limbus anterior corporis striati'" (pp. 114-117).

"The medullary tracts in the interior or concave surface of the corpus callosum are seen running transversely through the septum lucidum to the fornix, and from thence longitudinally into its posterior crura or columns, over which they run in a wreathed manner, terminating in the back part of the lateral ventricles which are enclosed in the hinder members of the brain; and these ventricles at length terminate in, and are continuous with, the subjacent anterior part of the crura of the medulla oblongata [the optic thalami]" (p. 192).

[1] "Anatomy of the Brain," chaps. xiii. and xvii.

424. WINSLOW.[1]—"Having cut off the falx from the crista galli and turned it backward, if we separate gently the two lateral parts or hemispheres of the cerebrum, we see a longitudinal portion of a white convex body which is named corpus callosum. It is the middle portion of the medullary substance which under the inferior longitudinal sinus of the falx, and also a little towards each side, is parted as it were from the mass of the cerebrum, to which it is simply contiguous from one end of that sinus to the other, so that at this place the edge of the inside of each hemisphere only lies on the corpus callosum, much in the same manner as the anterior and posterior lobes lie on the dura mater. Both extremities of this medullary body terminate by a small edge bent transversely downward. The surface of the corpus callosum is covered by the pia mater, which runs in between the lateral portions of this body and the lower edge of each hemisphere. Along the middle of its surface, from one end to the other, there is a kind of raphë formed by a particular intertexture of fibres which cross each other; for though these fibres appear to be transverse, yet they are really a little oblique, and those that come from the right side slightly as it were intersect those that come from the left. This raphë is made more perceivable by two small medullary cords which accompany it on each side, and adhere closely to the transverse fibres. The corpus callosum becomes afterwards continuous on each side with the medullary substance, which through all the remaining part of its extent is entirely united with the cortical substance, and together with the centrum ovale forms a medullary arch or vault of an oblong or oval figure. To perceive this, the whole cortical substance, together with the medullary laminæ mixed with it, must be cautiously and dexterously cut off in the same direction with the convexity of the cerebrum. After which there will be observed a medullary convexity much smaller than that which is common to the whole cerebrum, but of the same form; so that it appears like a medullary nucleus of the cerebrum, especially when we con-

[1] "Anatomical Exposition," etc., section x.

sider it together with the medullary substance of the inferior part or basis of the cerebrum. And from thence Vieussens took occasion to name this nucleus the centrum ovale" (section x. nos. 62-64).

425. LANCISI.[1]—" That part which holds the middle place in the cerebrum, and which, like the pineal gland, has not a twin nature, is the corpus callosum with the fornix and the septum lucidum. It is of a medullary quality, and occupies a seat, and indeed not a narrow one, between the right and the left hemispheres of the cerebrum, and it is diffused and continued into the [medulla oblongata, or that part of the] spinal marrow, which is enclosed within the cranium. . . . Although the corpus callosum, the fornix, and the septum lucidum have been furnished by the ancients with distinct names, they are still one and the same medullary substance which occupies the middle between the hemispheres of the cerebrum, and which by the place it holds, and by its figure, is discriminated from the rest. By the corpus callosum, however, is understood a medullary plane, like a white belt, a finger and a half in width, which as to its upper part is carried along almost horizontally under the sagittal suture. Its anterior portion is indeed a little narrower, and the posterior a little wider, and under the name of the fornix and its crura it declines into an elliptical figure, but for the same reason it unites and connects the larger hemispheres of the cerebrum. . . . Again, to its production those medullary fibres principally conspire which proceed from two sections of the cortex of the upper and anterior parts of the hemispheres of the cerebrum; for these being so placed as to touch the falx cerebri, descend, and are inflected inwards over the corpus callosum, and with the eye as a judge, they do not seem to be made for any other purpose than to secrete a liquid out of their cortical glands, and with their secretory ducts furnish a woof for constructing the mass of the corpus callosum, and for bathing and filling it with spirit. . . . By a retiform

[1] *Jo. Mariæ Lancisii Opera, quæ hactenus prodierunt omnia*, Geneva, 1718, vol. ii., Dissertatio vii., de Sede cogitantis Animæ; ad D. Joannem Fantonum.

contexture of blood-vessels this medullary mass is most intimately supported and cherished by the pia mater. . . . In horses the medulla alluded to above passes as it were between two walls of the cortical substance of the cerebrum, until it hastens into the corpus callosum, where there is a termination and a meeting-place of other medullary fibres from the nearer fornices of the lateral ventricles, which are also called thalami optici and corpora striata. This is seen in a most conspicuous manner if a lamina is removed horizontally on both sides from the corpus callosum with a very thin knife; for then at once innumerable fibres present themselves under the appearance of white threads, which are agglutinated to one another, and carried in a parallel direction to the vaults of the ventricles. Whence it is evident, that by the transverse fibres of the corpus callosum the two hemispheres of the cerebrum are mutually connected, and rendered continuous; and what is of greatest interest to us, that by means of the corpus callosum the roots of the spinal marrow, which make their way from the cerebrum, are united, and preserved in a perpetual state of intercourse. . . . By dissection and a removal of the external parts we learn that this body is rendered compact by medullary nerves which are carried across it transversely, and which are likewise parallel to one another; and which are certainly very conspicuous in some subjects, so that they present the appearance of the thicker threads of a silken web. . . . Malpighi describes them as so conspicuous in the brain of fishes, that when they are examined while held against the light they have the appearance of an ivory comb; but even with the greatest care we have not seen this clearly in human bodies. And although this kind of fibres—so far as they are parallel with one another, and continuous with the same termini on both sides—can be seen each and all from one beginning terminating at one end, it is nevertheless more probable that alternately the one set reaches from the left hemisphere into the right vault of the ventricle, and the other from the right hemisphere into the left vault. . . . We have learned also that these transverse, medullary fibres of the corpus callosum, which act the part of a woof, receive no mean strength from a stratum of medullary fibres underneath, which run along from the anterior crus of the fornix, which is called its body, to the posterior parts; *i.e.* which by a contrary journey spread in such a manner under the corpus callosum, that the fibres seem to vary their bent in that place. . . . One circumstance, however, which hitherto has either been altogether neglected, or not sufficiently observed, we have noticed in the upper plane of this same corpus callosum or on its surface; namely, that all medullary fibres which are carried across transversely are bisected at right angles by two unequally round nerves, which are likewise medullary, and which, without dura mater, and with an apparently merely borrowed arachnoidal coating, run through the middle of the same corpus callosum, from its anterior to its posterior portion. . . . By repeated dissections, it appeared that they were no real nerves, but simply edges raised a little over the medullary plane of the corpus callosum. . . . These nerves which, as we said, run along through the middle of the corpus callosum, after proceeding in a straight direction over the universal, horizontal plane, almost so as to be mutually contiguous, soon recede from one another a little, and afterwards are inflected posteriorly over the crura of the fornix; nay, although a little later on they seem to evanesce, they make their appearance again; and, indeed, they pass manifestly on top of the same crura, where they meet one another, stimulating the third ventricle, and at last they penetrate interiorly and are lost among the optic thalami, where they have relation to the lateral ventricles. But in order that the excursion of these medullary nerves through the crura may be freely seen, it is necessary to cut off those processes of the cerebrum which are continued into the corpora quadrigemina. The same nerves pursue a similar course in the anterior part of the corpus callosum; for they are bent backwards over its external surface which is called the anterior crus of the fornix [genu], and under the chiasma of the optic nerves they are curved outwardly near the foramen of the infundibulum, and they seem to evanesce, where the medullary substance of the cerebrum constitutes the basis of the thalami, which are the beginnings of the spinal marrow" (pp. 304-308).

In addition see Willis's plates iii., iv., and especially plate vii., in his "Anatome Cerebri," and plate v. in his "Anima Brutorum;" likewise Vieussens' plates iii., vi., vii., and Ridley's figure v.

[MODERN AUTHORS.

425*a*. REIL.[1]—"A threefold band engirds the corpus callosum on its two surfaces. Two of these bands are exactly in the middle; one on its outer, and the other on its inner surface; they are called seams or 'raphēs.'

"The *raphē externa* [external longitudinal stria] comes from the back of the *rostrum* of the corpus callosum; it follows the course of that organ upwards bending around its knee or *genu*, continues its course through its middle, increases in bulk, and spreads out more as it approaches the posterior edge, around which it bends; and it disappears on the superadded thickened border (*bourrelet*) in the neighbourhood of the lyra. On the interior surface of the corpus callosum directly opposite to the former band a similar stria, *raphē interna* [internal longitudinal stria], pursues its course over the septum lucidum and the fornix. This stria also is reflected downwards with the corpus callosum, and girds together lengthways, on its interior side, the singular *genu* of that body. It has dug out for itself on its surface a shallow furrow, to the edges of which is fastened the septum lucidum. In a posterior direction it passes over the fornix, entering far into the posterior pencil-like extremity of the ventricle of the septum. There it mixes with the fibres of the fornix which are stretched over the interior area of the lyra; and from the interior angle of the trigon it goes backwards directly to the thickened border, between which and the corpus callosum

[1] Reil (Dr. J. C.), *Das Balkensystem oder die Balkenorganisation des Gehirnes.* (The System or Organization of the Corpus Callosum in the Cerebrum), in the "Archiv der Physiologie," edited by Professors Reil and Autenrieth, vol. ix., Halle, 1809.

it is lost. In a number of places it looks as if the fibres of the longitudinal striæ passed into the corpus callosum, and, on the other hand, as if fibres of the corpus callosum entered the striæ. The transverse bars of the corpus callosum, indeed, pass uninterruptedly between the two raphës, the external and the internal, yet in the middle they are drawn together more closely by them, and more intimately interwoven."

425*b*. "On the upper surface of the corpus callosum, where the hemispheres recline upon it, on either side of the raphë externa, and parallel with it, there run *two firm, long and permanent strands of longitudinal medullary fibres*, which, just like the raphë externa, are stretched out immediately on the corpus callosum. I call them *the covered bands*, because from above, and on either side, they are covered by that convolution [gyrus fornicatus] of the median surface of the hemisphere which rests immediately on the corpus callosum. This convolution on its interior edge is unattached to the corpus callosum for several lines, and appears rolled up. . . . In front it bends around the *genu*, and accompanies the same in its posterior direction as far as the *anterior perforated space* (locus perforatus anticus), and then passes over into the convolution which forms the inner side of the sulcus containing the olfactory nerves. In the rear this same convolution is likewise reflected backwards around the corpus callosum; it fastens itself to the superadded thickened border (splenium or bourrelet), and then passes over into the oblong lateral convolution which follows the interior wall of the descending cornu, to which the posterior crura of the fornix remain attached, until they terminate in the hippocampus major.

"Where the convolutions bend over the corpus callosum, they are met by the posterior crura of the fornix, with which they enter into a close union. The crura, which hitherto had been medullary, become inflected in the form of a trough; they receive some grey substance from the convolutions in their interior, retaining it to the end, and forming therewith the hippocampus major in the descending cornu.

"Outside of this amalgamation of the crura of the fornix with the convolution, the thickened border of the corpus callosum (*bourrelet*) is much thinner; it therefore appears to have parted with some of its substance.

"If the convolutions in all these places are raised up, *the covered bands* are discovered there immediately, in the form of flattened worms which can easily be peeled out. Under these bands the texture of the corpus callosum becomes altered; the distinction into parallel striæ or bars is lost on its exterior side, the stamina of which these bars consist become more delicate, and they are more closely pressed together" (vol. ix. pp. 173, 174).

425*c*. In a supplement to his paper Reil makes the following additions:—

"Both *covered bands* make a visible depression or furrow upon each side of the corpus callosum. They curve around that body in front, draw near to one another on the *rostrum*, grow narrower and more delicate, at last become like threads, and thus are held together, and finally they terminate in the angle which the end of the rostrum makes with the peduncles of the corpus callosum. In the same angle also terminate the longitudinal convolutions [gyri fornicati] which accompany the corpus callosum, and wind around the rostrum. At the posterior end of the corpus callosum the covered bands also bend around that body together with the longitudinal convolutions, on removing which a deep impression is noticed. They are also reflected around the forceps-like productions, but immediately afterwards they give out rays, which form a delicate radiation underneath that which issues from the thickened border. . . . The remaining more powerful bundles coalesce with the medullary substance of those convolutions which are continued into the descending cornua" (vol. xi. p. 352).

425*d*. "On the interior or lower surface of the corpus callosum there is, moreover, the *fornix*, which pursues the same course as the covered bands, and which, on the interior surface, seems to be analogous to the covered bands on the exterior surface. . . .

All these parts seem to answer the same purpose; they are subservient to the circulation in the longitudinal axis of the cerebrum, or in an antero-posterior direction."

425*e*. "The corpus callosum has a similar structure to that of the cerebral peduncles. Like them it consists purely of medullary bars running transversely. . . . Each little bar consists of many delicate medullary filaments. In the middle, between the *raphë interna* and *externa*, the transverse bars are more interwoven with one another, and more closely drawn together. . . . None of these little transverse bars is absolutely bounded or limited, but filaments are seen to pass from one bar to the other, when the corpus callosum is pulled apart. . . ."

425*f*. "It seems as if there was a force urging the corpus callosum from all sides back towards the middle, especially in its antero-posterior diameter. Hence its forceps-like projections or horns in front and in the rear, and hence the open space between the hemispheres of the cerebrum [before and behind the corpus callosum]. In front, the middle portion of the corpus callosum bends downwards, but it does not double up and fasten itself to the upper part; on the contrary, an open space is left between the two parts of this body, and the reflected part runs backwards in the direction of the chiasma of the optic nerves. In the rear the part which bends downwards doubles up completely, and fastens itself to the lower surface of the corpus callosum. Hence the thickened border (splenium or bourrelet) on its lower side, which has the appearance of being superimposed. . . ."

425*g*. "The anterior curvature of the corpus callosum I term its *genu* or knee. The lower portion of the *genu* tapers off into a beak or *rostrum*, which on either side terminates in a medullary band [the peduncles of the corpus callosum] which is continued backwards between the optic nerves and the anterior perforated space" (vol. ix. pp. 175-177). In the supplement to his paper Reil says that "the bands or peduncles of the corpus callosum on coming from the posterior edge of the anterior perforated space ascend upwards along the posterior, inner edge of the anterior lobe in the direction towards the anterior commissure;" and further, "they consist of a bundle of medullary fibres which are connected with the *substantia innominata*" (*ibid.*, vol. xi. p. 347, etc.). Reil's *substantia innominata* (ungenannte Marksubstanz) according to Hugenin[1] consists (1) of the fillet (lemniscus) of the lenticular nucleus of the corpora striata (Linsenkernschlinge); (2) of the posterior longitudinal bundle of the tegmentum of the crus cerebri (hinteres Längsbündel); and (3) of the inferior pedicle of the optic thalamus. "From these peduncles," Reil says further, "occasionally bright white filaments start off, which passing over the *rostrum* of the corpus callosum, and inclining around the front part of that same body, on its upper surface coincide with the longitudinal striæ of Lancisi" (*ibid.*).

"Laterally the *rostrum* terminates in the thin, medullary membrane, on which rest the convolutions of the interior and lower surface of the anterior lobe, and which in conjunction with the anterior perforated space constitutes the inferior wall of the *capsula* [claustrum or nucleus tæniæformis]."

425*h*. "Exactly in the curvature the *genu* is thickest; towards the *rostrum* it tapers off more and more. In its interior surface all its constituent little bars are concentrated in one point, which is situated exactly in the bend of the *genu*, and from which issues on both sides [the upper and the lower] a beautiful, crescent-like radiation, which like a couple of open fans is continued through the curvature from the upper into the lower end of the corpus callosum. In the centre line of the *genu* the septum lucidum is stretched out laterally, which seems to be a duplicature of the epithelium, and to bear an analogy to the mediastinum in the thorax; but which in its middle leaves open a cavity, the ventriculum septi. In front this ventricle has two short horns, which to the right and the left are produced in the *genu* of the corpus callosum; but in a posterior direction the ventricle terminates in a long pencil-like point,

[1] Hugenin (G.), "Anatomie des Centres Nerveux," etc., traduit de l'allemand, Paris, 1879.

which goes backwards over the body of the fornix as far as the *lyra*. . . ."

425*i*. "The posterior and broader end of the corpus callosum is much more urged back towards the middle than the anterior extremity, and all its fibres, which spread out laterally into the posterior lobes of the cerebrum, are gathered into one bundle. Hence the greater bulk of the corpus callosum in that place. The fibres which accumulate there are reflected backwards or downwards, and fasten themselves on the lower or interior surface of the corpus callosum, where they give rise to a superadded thickened border (splenium or bourrelet) which forms the posterior end of the part called *lyra*. . . . From that hinder part of the corpus callosum extend two thick bundles of medulla in the shape of a forceps, which outside of, and beyond, the posterior crura of the fornix make their appearance in the posterior cornu of the lateral ventricles forming there the hippocampus minor (or calcar avis), and which are continued almost in a horizontal direction over the posterior cornu to its extremity; and farther still to the extremity of the posterior lobe of the cerebrum. . . . These bundles of medulla are partly continuations of the upper surface of the corpus callosum, and partly of the superadded thickened border—splenium—underneath. . . . The interior layer of the posterior part of the corpus callosum is continued to the outer wall of the posterior cornu. This I call *tapetum*. . . . Another part of the *tapetum* inclines downwards through the mouth of the middle or descending cornu, and invests the lowest part of its outer wall down to the obtuse end of this cornu. . . . In both horns the *tapetum* goes down to the bottom of the same, where their outer and inner walls meet. In the posterior horn it decussates almost at right angles with the peduncular stratum of fibres which lies outside of it. The stratum of fibres coming from the corpus callosum does not strike here upon the peduncular stratum; but falls over it, without mixing with it. Like two detached medullary layers these strata are in mere juxtaposition, and can be separated from one another quite smoothly" (vol. ix. pp. 179-182).

425*j*. ARNOLD.[1]—"The middle portion or body of the corona radiata with its fibrous fascicles decussates with the fibres of the corpus callosum; the former, which come from below and within, in their course outwards [*i.e.* towards the cortex], break through the latter, and radiate towards various points of the circumference of the cerebrum. This passage of the fibres of the corona radiata between those of the corpus callosum becomes clearly visible on removing from below and from within the grey substance of the nuclei of the corpora striata, and at the same time by laying bare distinctly the lower surface of the corpus callosum with its fibrous fascicles. A considerable portion of the fibres of the corona radiata makes its appearance outside, above the nucleus lenticularis, presenting the form of an ear. In a similar manner, only much more manifestly, the anterior commissure passes through the foot of the corona radiata. The relation of the corona radiata and of the corpus callosum, however, is not constantly such that their fibres everywhere mutually intersect one another; for the fibres which emanate from the posterior edge of the corona radiata are merely covered in part by the fibres proceeding from the thickened portion of the corpus callosum, and as separate layers in mere juxtaposition with one another, and without mutual decussation, they pursue their way into the posterior lobes of the cerebrum. This mutual relation of the corona radiata and of the corpus callosum seems to me unmistakable, if *first*, in one of the hemispheres the basis of the corona radiata is from within carefully freed of the grey substance of the corpus striatum, and the epithelium is pulled off from the lower surface of the corpus callosum; after which the place where the fibres of the corpus callosum in the circumference of the lateral ventricles meet those of the corona radiata in an acute angle, and where the fibres of the one pass between those of the other, becomes exposed to the sight. It is also impossible

[1] Arnold (F.), "Bemerkungen über den Bau des Hirns und Rückenmarks" (Observations on the Structure of the Brain and the Spinal Marrow), Zürich, 1838.

to observe there with any degree of confidence an inflection of the fibres of the corona radiata towards the corpus callosum. *Secondly,* the relation between the corona radiata and the corpus callosum in the posterior lobe of the cerebrum, as stated above, is unmistakable; for there the fibres which come from the corpus callosum on the one hand, and from the corona radiata on the other, remain in layers near one another, and it is impossible to prove the inflection of one set of fibres into those of the other. *Thirdly,* this relation is made very plainly visible by the passage through the corona radiata of the anterior commissure, which agrees in general with the great commissure of the cerebrum, *i.e.* the corpus callosum; for this passage can be traced without any difficulty. *Fourthly,* another circumstance in favour of this relation is, that in the cerebellum also it cannot be proved that the fibres of its peduncle are inflected into those of the pons Varolii, which is the commissure of the hemispheres in this part of the brain."

425*k*. "My investigations induce me to embrace the views propounded by Gall, Ackermann, Reil, and Burdach in respect to the decussation and juxtaposition of the fibres of the corona radiata and those of the corpus callosum, and to reject the opinion expressed by older and more modern anatomists, Varoli, de la Rue, Willis, Ridley, Malacarne, Mayer, Cuvier, Autenrieth, Döllinger, Tiedemann, according to which the radiation of the crura cerebri is inflected into the corpus callosum" (p. 73).

425*l*. SOLLY.[1]—"The fibres of the front, sides, and superior part of the anterior lobe pass backwards and inwards to the distance of an inch and a half from the anterior extremity of the cerebrum, where they cross the fissure which divides the two hemispheres. The anterior edge of the commissure [*i.e.* of the corpus callosum] consequently forms the posterior boundary of the anterior part of the fissure. In this situation the fibres are folded one upon another; so that on a

[1] Solly (S.), F.R.S., "The Human Brain: its Structure, Physiology, and Diseases," second edition, London, 1847.

transverse section of the 'corpus callosum' the anterior edge appears thicker than the centre, though it is not so thick as the posterior edge.

"The fibres from the convolutions of the upper part and sides of the middle lobes run downwards and inwards, being joined by those from the convolutions at the base of the brain." In a drawing accompanying this description of the fibres of the corpus callosum, Solly shows that these fibres proceed from the interior portion of the upper lobes, and not from that which is nearest to the central fissure, and hence to the falx cerebri; and in the description of his drawing calling attention to this fact, he says, "It will be seen that these fibres ascend to the convolutions above the mesial line," *i.e.* above the mesial or middle line of the hemispheres themselves.

In respect to the formation of the posterior end of the corpus callosum, Solly says, "Then, again, from the upper, under, and posterior surface of the posterior lobe [the fibres] run forwards and inwards to cross the fissure at the distance of nearly three inches from the posterior extremity of the cerebrum. The fibres from such extensive surfaces are necessarily numerous, and give a considerable thickness to the posterior edge of the 'corpus callosum'" (pp. 251, 252).

425*m.* In a footnote on p. 252 he adds, "M. Foville[1] gives a very different account of the nature of the corpus callosum and the origin of its component fibres. He considers that they commence from the corpus striatum and thalamus, and says they have nothing to do with the hemispheres, but in reality form a commissure between the two crura cerebri of a vaulted form. Mayo, in his 'Outlines of Physiology,' has very clearly proved the manner in which that mistake has occurred, and shown that Foville in producing the appearance which induced him to adopt the opinion stated above, breaks through the point where the fibres from the columns [*i.e.* from the medulla oblongata] intersect the commissural fibres [*i.e.* those of the

[1] Foville, "Traité complet de l'Anatomie, de la Physiologie et de la Pathologie du Système Nerveux Cerebro-spinal," Paris, 1844.

corpus callosum], and then follows the columnar [peduncular] fibres in their course to the corpora striata. Rolando advances the same opinion regarding the composition of this commissure as Foville, quoting the opinions of Tiedemann in support of his own. Notwithstanding such weighty testimony, I am convinced from repeated dissections that they have been deceived, most probably as explained by Mayo in his Physiology."

425*n*. Hirschfeld.[1]—"The corpus callosum is a transverse commissure uniting together the two cerebral hemispheres. It is chiefly composed of a fibrous expanse of the cerebral lobes, and of a small portion of the cerebral peduncles. . . . Two surfaces are distinguished in it, the upper and the lower. . . .

"*The upper surface of the corpus callosum.*— . . . In the middle of this surface there is a median furrow running from the front backwards, which on either side is bounded by longitudinal striæ called *the longitudinal nerves of Lancisi* (chordæ longitudinales). . . . The striæ cut perpendicularly some transverse fibres underneath (chordæ transversales).

"*The lower surface of the corpus callosum.*— . . . On the median line of this surface there is a raphë (*raphë inferior*) which is cut perpendicularly by transverse fibres. The fibres of one side are not a continuation of those on the other side, because they are isolated from one another by the median raphë. Besides, they are less pronounced than those of the upper surface."

425*o*. "The transverse fibres of this surface are prolonged towards the horns [of the lateral ventricles] of each side, becoming oblique. The fascicles of oblique and reflected fibres which penetrate into the posterior horns where they surround the hippocampus minor (or calcar avis) have been called *forceps major Reilii.* The fibrous fascicles which are continued into the descending horn of the lateral ventricle, and which surround the hippocampus major, have been designated under the name of *tapetum Reilii.* On each side the transverse fibres of the lower surface do not anastomose with the radiating fibres of the

[1] Hirschfeld (L.), "Névrologie et Esthésiologie. Traité et Iconographie du Système Nerveux et des Organes des Sens de l'Homme," 2de édition, Paris, 1866.

cerebral peduncles, and consequently are not a continuation of the same; and, indeed, for the following reasons:—

"(1) The fibres of the corpus callosum are more diminutive than those of the peduncular expanse. (2) Their direction is not the same, and does not allow them to become united. (3) There is between these fibres a raphë which isolates them from one another; which raphë may be considered as a second tænia semicircularis.

"This surface in its median line and in its front part is identified with the upper border of the septum lucidum; in the rear with the body of the fornix. On each side it is free, constituting the upper wall of the anterior cornu of the lateral ventricles, and contributing to the formation of the descending and posterior cornua. Besides, it is lined with the ependyma, *i.e.* the coating of the ventricular cavities."

425*p.* "*The lateral wings.*—Their terminus is still in dispute among the anatomists. The majority among them admit that the corpus callosum is lost laterally in the thick portion of the hemispheres. Foville expresses an entirely different opinion. According to him this organ has no intimate connection with the hemispheres. The corpus callosum in his opinion is bounded on the sides by a longitudinal thickened border, corresponding to the level of the external boundary of the optic thalami and the corpora striata, and constituted simply by an incurvation from above downwards of the fibres of the corpus callosum which are continuous with the radiations of the cerebral peduncles. Besides, Foville regards the corpus callosum as a commissure formed by the peduncular expanse. . . .

"This organ is formed by a plane of layers of fibres which are placed one above the other, which are horizontal, curvilinear, and which embrace one another; their number being undetermined. This plane of fibres, in its circumference, and on the level of the optic thalami and the corpora striata, becomes the point of departure for fibres radiating in all directions. The one, ascending, direct their course towards the convexity of the cerebrum; the other, descending, direct themselves towards the base. In fine, the horizontal fibres, forming the intermediate body of the corpus callosum, spread and radiate in an anterior, posterior, and also in a lateral direction. . . .

"From all that precedes, I conclude:—

"(1) The corpus callosum is constituted by fibres which terminate in the convolutions, or which emanate thence.

"(2) The fibres of the lower surface of the corpus callosum on either side seem to be continuous with the radiating fibres of the cerebral peduncles; but this continuity is not direct; especially not in the posterior parts, on account of a raphë existing in the place where the two orders of fibres meet.

"(3) There is a decussation of fibres on the level of the thickened longitudinal borders of the corpus callosum; but this decussation exists between the peduncular fibres and the corresponding fibres of the corpus callosum.

"(4) The cerebral peduncles and the corpus callosum send fibrous expansions into the convolutions, so as to form their nuclei.

"(5) The corpus callosum is a real commissure of the two hemispheres, and not, as Foville holds, a commissure of the cerebral peduncles" (pp. 122-127).

425*q*. MEYNERT.[1]—"As regards *the system of the corpus callosum* (trabecular system), microscopic examination of cross-sections from small mammal brains, among which that of the Bat has been made the subject of careful investigation by Oellacher, confirms the opinion expressed by Arnold, that the corpus callosum is made up solely of commissural fibres, connecting symmetrical territories of the cortices of the two hemispheres, and not, as Foville wished to prove, of fibres of the projection system, crossing the middle line to enter the ganglia of the opposite side. It appears also that its fibres are not distributed, as Burdach thought, exclusively to certain groups of convolutions, but, in common with the fibres of the projection system, to all parts of the cortex. In this way the fibres of the

[1] Meynert (T.), "The Brain of Mammals." Translated by James J. Putnam, in Stricker's "Manual of Histology," American edition, New York, 1872.

projection system become intimately interwoven with those of the trabecular system (Arnold, Reichert). The splenium corporis callosi [*i.e.* its thickened border] is not a solid mass, but consists of two laminæ, to form which it folds longitudinally upon itself, and these two laminæ, separating somewhat from each other in their course towards the temporal lobe, leave between them the clefts called respectively the posterior and inferior horn of the lateral ventricle. The upper lamina of the splenium comes to form also the outer ventricle wall, the tapetum (Reil). The foreign bundles of fibres, which form an intricate and delicate network with those of the corpus callosum proper, may be traced microscopically without the least danger of their being confounded with connective-tissue fibres, or with vessels. Among them (as Arnold has already stated) are bundles which run from the posterior part of the gyrus fornicatus to the fornix, spreading themselves out over the lower half of the surface of the septum lucidum" (p. 676).]

ANALYSIS.

426. The corpus callosum is a narrow beam, by which there is an access to the interior organs of the cerebrum, and as it were to the shadow-kingdoms of Proserpine; for unless that body and its hinges are moved and turned, the entrance is not open. Or, again, this body is like a doorkeeper lying athwart, who opposes his back and shoulders, lest the inner sanctum be approached by an unbidden guest. It lies there bound on both sides by the edge of the hemispheres, the pia mater dipping down inwardly towards the sides. It thus distinguishes more immediately the lower region of the cerebrum from the highest; for otherwise the cortical cerebrum, by sheer necessity fastened down here in its extremities, could not freely, as is demanded by the case, act upon the sinuses, and upon the falx cerebri which is suspended from the sinuses.

427. This body unites and distinguishes in a general way all the members and organs which lie scattered as it were throughout the large palace of the cerebrum, although wedded to distinct functions; all the protuberances, cavities, ridges, and interstices; a part of which are hidden in its interior organism, and others are exposed on its surface. To some of these it is subjected, upon others it is superimposed, and between others it is inserted. It is *subjected* to the great interstice which separates the two hemispheres, and consequently to the falx cerebri, and to both its sinuses; and likewise to the margins or shores of the convoluted cerebrum raised as it were into waves; of this the corpus callosum is as it were the mainland furnishing to it a safe port. It is *superimposed* upon the third ventricle, viz. upon the middle cavity of the longitudinal axis, and likewise

upon the ceilings of the lateral ventricles. It is, however, *inserted* or thrown in between all the parts, separating those on the left side from those on the right, and likewise by outspread wings distinguishing the higher parts from the lower. It is as it were a general lever, stretching its arms obliquely upwards and downwards, and it rests upon the body of the fornix where its fulcrum is. In this wise it poises weights, sustains motions, and unites the forces of the active cerebrum cut up into so many cavities, sulci, and clefts. Otherwise all the individual parts would lapse into chaos, which being indistinct and undetermined is equivalent to nothing.

428. The question, however, arises, Whence does the corpus callosum derive its fibres and roots? It is generally admitted that each fibre originates from its cortical or grey glandule; it is also admitted that no fibre lapses into the middle of this belt (*fascia*), where the striæ are parallel; but that they all pursue their course from their origins through the spread wings. The fibres which are thus led forth and pursue their course are continued into the belt, and from its borders are carried transversely towards the raphë in the middle, and again reciprocally from the raphë towards the borders. These spread wings are inrooted in the posterior extremities (*limbis posterioribus*), or in the substances of the lowest lobe of the cerebrum, that is, in those which rest upon the tentorium and cerebellum; into which there is even a good deal of cineritious substance inserted. These spread wings are also inrooted, although more sparingly, in the upper lobes of the cerebrum. In this wise the corpus callosum derives its fibres from the upper part of the anterior, and from the lower part of the posterior cerebrum; but it does not derive them from the cortex which occupies the upper surface of the cerebrum near the division of the hemispheres, nor from that which occupies its fore-part—prora. On this account also the corpus callosum connects the upper parts with the lower, and those of one side with those of the other; and it thus forms a knot not unlike the Gordian, which cannot be solved except by the dissection of its body. By its means also

the hemispheres, and the parts contained within the hemispheres, intercommunicate with one another.

429. The corpus callosum, or rather its fibres derive their juice and spirit from their little fountains, that is, from [the cortical particles of] both hemispheres and their extremities; and they conduct it towards the body of the fornix. From this place they pour it out and distil it into the ventricles, and by a continued course lead it through the infundibulum into the pituitary gland. But of this I shall treat hereafter. It is thus manifest whence the cerebrum brings forth its essences, and its refined spirits, which are the first-fruits of the blood, and which in the organs belonging to its laboratory are prepared and then carried away, namely, from the posterior parts, and at the same time from the lobes of the anterior cerebrum. The corpus callosum is the first storekeeper, and also the road leading to the chymical laboratory of the brain, over which it is spread, and the organs of which, being under its care, it covers in a general way.

430. Besides, it serves for the propagation of sensation, namely, of the impressions of the senses of touch, smell, taste, hearing, and especially of sight; but of this I shall treat hereafter. It contributes therefore its share to every function of the cerebrum, which is the common organ of acting, of sensating, and of preparing the hidden qualities of the blood. The entities of nature are more beautiful, and have allotted to them a better place, in proportion as they attend to several functions, and at the same time perform distinctly various things.

APPENDIX TO CHAPTER VIII.

An Earlier Analysis of the Corpus Callosum.[1]

430*a*. Argument: (1) *The corpus callosum concentrates in itself all the medulla of the whole cerebrum, with the exception of that part which, above and below, is despatched towards the medulla oblongata.* (2) *The concentrated medulla it derives into the lateral ventricles partly through the body of the fornix, and partly through its posterior crura which are on the optic thalami.* (3) *It consequently derives into itself all the animal spirit which it despatches afterwards through the body of the fornix, or pours into its crura; as well as the nervous juice which courses between the fibres, and is sent towards the optic thalami.* (4) *This it does through the animatory motion of the corpora striata, and the above optic thalami.* (5) *Which motion, by the mediation of the ventricles, is determined into, and ends in, this body.* (6) *On this account the corpus callosum is in the place of a support, so that the machine which on either side, and below as well as above, is in a state of motion, shall remain in its nexus;* (7) *and likewise through the connection of its fibres with those of the lower extremities of the cerebrum.*

430*b*. *The corpus callosum concentrates in itself all the medulla of the whole cerebrum.* This is made very conspicuous from the description of the authors; as well as from the very fluxion and connection of the fibres of the medullary substance. For they terminate in the surface nearest to it, or in the very ceiling of the lateral ventricles, into which they are reflected, and whither other fibres are derived for the purpose of entering into a con-

[1] From Codex 65, as reproduced in vol. iv. of the Photolithographed MSS. of Swedenborg, pp. 260-269. From the year 1735-38.

junction with them, according to Vieussens. All the medulla of the corona radiata in the middle of the cerebrum, with the upper limit of the corpora striata, rests upon this ceiling in a certain measure; as well as the tænia semicircularis with the "geminum centrum semicirculare," . . . which, if it does not enter the corpus callosum itself, at least touches the base of the fornix. Whatever flows into the ceiling of the above ventricles, by continuous connection enters the corpus callosum and its exterior border; for the whole of the vaulted surface of the ventricles is constituted by that border. On this account it receives into itself the whole medullary substance of the cerebrum. *Except that part which above and below is despatched towards the medulla oblongata.* Above, indeed, the medulla of the cerebrum is despatched from the lower portion or the lower borders of the cerebrum, or from the posterior region of the corona radiata, where the last or ultimate fibres of the corpus callosum are said to be united to those of the last or hindermost borders of the cerebrum. This medulla of the cerebrum passes into the medulla oblongata over the region of the corpora quadrigemina, and under the fibres of the processus cerebelli ad testes, and thence into the posterior region of the spinal cord. Below, the medulla of the cerebrum passes into the medulla oblongata through the pons Varolii under the crura cerebelli ad medullam, and hence into the anterior part of the spinal cord. These fibres by common consent and also by ocular experience seem to be produced from the middle of the corona radiata, and at the same time from the corpora striata.

430*c*. *The corpus callosum derives the whole of that medullary substance which is concentrated in itself, into the lateral ventricles, partly through the body of the fornix.* The body of the fornix is the peduncle of the corpus callosum, as shall be shown in the following article; for the medullary substance which through the ceiling of the lateral ventricles is derived into the corpus callosum, is carried for the most part by parallel fibres which are confasciculated towards the medullary raphë in its middle; and thence towards the body of the fornix. *Partly also it is* *carried into the lateral ventricles, through the posterior crura of the fornix which are on the optic thalami.* For the corpus callosum [or rather the fornix] is divided below into these crura, which, as is shown by experience, apply themselves to the optic thalami, with which they coalesce. But whether any portion of that medullary substance which has entered the corpus callosum, betakes itself into the medulla oblongata from above, or from the region of the corpora quadrigemina, remains doubtful from this consideration, because according to Willis and his drawing, this medullary substance is there attenuated, and is adjoined to the medulla oblongata through a kind of membranous expansion and by means of vessels. Granted that the fibres of the corpus callosum are united to those of the posterior extremities of the cerebrum, still I believe that these fibres preserve their direction towards the optic thalami; especially also as the posterior commissure is seen making its way in the very same place. Therefore these fibres remain quite distinct from those which pass on farther.

430*d*. *The corpus callosum, consequently, derives into itself all the animal spirit which it despatches through the body of the fornix, or pours into its crura.* The animal spirit necessarily follows its fibres, because it is enclosed therein; for whither the fibres tend as containers, thither also the fluids are carried as contents. The genuine spirituous essence does not seem to be transferred in its least fibres to the corpus callosum, but its composite or the animal spirit, which we have declared to be identical with the white blood. The spirituous essence, indeed, is conveyed to the cortex from the blood, but from many indications it may be inferred that both that and the newly-formed essence are discharged into fibres of the second degree or order. Meanwhile the animal spirit following the continuous course of the fibres, at last seems to be determined from the corpus callosum towards the body of the fornix. Thither, namely, the nexus tends, in accordance with which we have spun the thread of our induction; for we are not allowed to explore the ways by injections, as in the case of the blood-vessels; since the fibres do not become enlarged by degrees like the vessels, nor is there any liquid analogue to the animal spirits, with which they might be injected.

430*e*. *The nervous juice, however, or that which courses between the fibres, is sent towards the optic thalami.* For thither tend both the crura of the fornix, which are continuous with the ceiling of the lateral ventricles. They are, indeed [in animals], similar to mammillary expansions, or to additional peduncles, which cast themselves on the optic thalami, and coalesce with them. The fact of this nervous juice which courses between the fibres being derived into the ceiling of the ventricles, appears from the fibres of the medullary substance of the cerebrum, which on arriving there [*i.e.* in the corpus callosum] are reflected, and in consequence of this, open themselves and become divided; for that substance which is nearest to the ventricles, and extends over their surface, appears spongy and retiform in a different manner, as is shown sufficiently from the fibres which are unravelled there, and afterwards are differently connected. When the fibres of the cerebrum are thus divided, it seems as if the liquid contained between the fibres must necessarily escape thence, and consequently pursue its way whither a similar compages of fibres tends, that is, towards the so-called optic thalami, into which they insert themselves. And this must be the case so much the more, because the texture of the fibres seems to be such that at each alternate time when the ventricles are expanded, they are drawn apart like a net either in width or in length.

That such a juice as is called nervous, and which together with an oily lymph contains some spirituous quality, is carried towards the optic thalami, is confirmed also from the longitudinal striæ of which Winslow and Lancisi speak, and which like two nerves, or two protruding borders, cross at right angles the parallel fibres of the corpus callosum, and then at last are lost in the optic thalami. These medullary striæ are said to pass under the arachnoid membrane, which is a general vessel or duct for that juice or lymph, or which carries all that superfluous juice where exigency requires it. But whether this juice is distilled immediately into the ventricles, or whether it is partly employed in preparing and in restoring the humours of the eye, belongs to another chapter.

430*f*. *This the corpus callosum does through the animatory motion of the corpora striata, and the optic thalami.* In order to understand this better, however, it is necessary to discuss it under various heads: 1. The animatory motion is the only one which urges and propels the spirituous juices in the fibres and between the fibres. 2. The corpora striata chiefly act upon the corpus callosum. 3. The optic thalami have less effect, unless they exert it upon the crura of the fornix which are stretched out over them. 4. But least of all does the cerebrum act upon it. 5. So that even when the cerebrum rests, the corpus callosum may nevertheless undergo its alternate periods of expansion and constriction.

1. *The animatory motion is the only one which urges and propels the spirituous juices in the fibres, and between the fibres.* This has been shown above, therefore I proceed at once to the second point. 2. *The corpora striata chiefly act upon the corpus callosum.* With these bodies the corpus callosum has a certain continuous connection; and this connection is so much closer, since the corpora striata seem to transmit into the ceilings of the lateral ventricles, and thence into the corpus callosum, their own fibres, which being united to the fibres of the cerebrum in this expanse, cause an immediate action. When therefore the corpora striata are expanded and constricted in alternate periods, an effect results thence upon all that is continuous with them, or upon the whole surface of the ventricles, which in accordance with that motion are either relaxed or constricted; and as the corpus callosum is depending upon this expanse, there must necessarily result thence an action of that body. 3. *The optic thalami have less effect, unless they exert it upon the crura of the fornix, which are stretched out over them.* For this reason, because they do not act upon that higher or anterior portion of the ventricles which passes off into the corpus callosum; but only upon their

extremities which are indeed acted upon by the optic thalami, but not with that same force as is most manifestly exerted by the corpora striata. 4. *But least of all does the cerebrum act upon that body.* This may be concluded—though indeed it is worthy of a more minute investigation—from this consideration, that the fibres of the cerebrum enter into the ceiling of the ventricles only in a reflected form; therefore they do not act directly upon the ceiling and the corpus callosum. On this account the whole of this machine is moved even when the cerebrum is almost quiescent. For when the ventricle is constricted, the fibres of the cerebrum—because they then discharge their contents—are unstrung rather than tightened; which also seems to be the reason why the sense of smell cannot act except when the cerebrum is constricted, as has been remarked above. This is evident also from this consideration, that the corpus callosum is situated under the cerebrum, and only contiguous to it; so that it does not seem to be a part of it, except by a more distant continuity. Nevertheless there are fibres which, according to Vieussens' description, enter more directly, and unite themselves with those fibres which are bent back; but whether they are fibres proper to the corpora striata, or whether they, coming chiefly from the middle of the corona radiata, are connected with them so as to be obliged to make common cause with the corpora striata, he has not explained. It results thence that when the cerebrum acts, a greater quantity of animal spirit and nervous juice enters, but this becomes less according to the degree and quality of its action.

430*g*. *This animatory motion, by the mediation of the ventricles, is determined into, and ends in, the corpus callosum;* that is, the whole of the motion of the corpora striata, which together with the optic thalami alone expand and constrict the lateral ventricles; and which action is separate from that of the cerebrum. That the expansion and constriction of the corpus callosum depends proximately upon the ventricles is shown by the mere connection of the parts. Wherefore that body acts in accordance with them, that is, it is lengthened out and contracted, it swells and subsides; but in accordance with what principle cannot be explained clearly without a previous description of the ventricles. Meanwhile it may appear from the carotid (which at last becomes bifid) with its branches, which is reflected upon the corpus callosum; namely, that each time the ventricles are expanded, or, what amounts to the same thing, each time the corpora striata are constricted, the corpus callosum is spread in width, and shortened or contracted as to its length, and indeed more conspicuously towards its posterior part where the carotid becomes bipartite. The particular modes, however, of the motion appear from the branches of the same artery, and from the obliquity of the transverse fibres of the body. Whenever, therefore, the corpus callosum is lengthened out, which takes place when the ventricles are constricted, the lowest part of the falx also, to which it is attached by vessels, and sometimes by a fibrous substance, is drawn down; consequently the sinus of the falx also is constricted.

The corpus callosum, therefore, in respect to its function of gathering up into itself fibres from the whole medullary field, and at the same time animal spirit, and in distilling that into the ventricles, acts solely in accordance with the periods in which the ventricles are expanded and constricted; wherefore the two must conspire in the production of the same effect, so that the one depends upon the other in an unbroken connection. By such an animatory motion, therefore, the animal spirit is derived towards the corpus callosum, and consequently through the parallel fibres, which in alternate times are expanded and constricted, it is directed into the raphë in the middle which ties the fibres together. These fibres, therefore, are carried across transversely, because each ventricle acts from its own side; whence it follows that all force is concentrated into the middle axis, and into the centre of the axis or the body of the fornix, and thence into the posterior crura of the fornix and into the optic thalami. For the continuous nexus of the fibres is the stream of the animal spirit, and the nexus of that is the stream of its animation, according to which the fibres are directed.

430*h*. *On which account the corpus callosum is in the place of a support, so that the machine which on either side, and below as well as above, is in a state of motion, shall remain in its nexus.* For on its sides are the lateral ventricles, below is the third ventricle, above is the great fissure of the hemispheres, which being drawn apart each alternate time, require such a pedestal and support in the middle: not so, however, the cerebrum. The corpus callosum, however, is subject to the modes of the corpora striata, by which the ventricles are moved, as was stated above. . . .

430*i*. *This nexus is also preserved by the connection of the fibres of the corpus callosum with those of the lower extremities of the cerebrum.* The object of this connection is that thus the fibres of the corpus callosum may be inrooted in the fibres of those bodies, the animatory motion of which seems to be more constant than that of the higher cerebrum; for these lowest extremities of the cerebrum recline upon and rest against the cerebellum with which they are connected by the tentorium, as well as by a number of branches of the vertebral artery in their interior structure; which branches pass through this portion of the cerebrum in company with branches of the carotid artery on their way into the lateral ventricles and their choroid plexuses, and also into the roof by which these cavities are vaulted. Those fibres of the posterior cerebrum, or of the posterior centrum ovale [corona radiata], which are despatched into the medulla oblongata, seem to decussate in such a manner that those which belong to the right side incline obliquely towards the left side, and *vice versa;* so that there may result thence a firm structure, which is exhibited to the sight in the brains of fishes; at the same time also they are massed together with the last fibres of the corpus callosum, so that through the mediation of the corpus callosum they are also connected with the fibres of the whole cerebrum. The cerebrum is thus always firmly held together, when a stronger force presses in;

and by a similar massing together, and a mutual friction against each other, the fibres always keep themselves in a whole, natural, and free condition. This also rather promotes than impedes the flux of the animal spirit.

As such delicate fibrils interwoven with one another in the medullary substance, cannot by any anatomical art be plucked apart and unravelled, there is no hope of our ever getting by that way to see the naked and pure truth; wherefore we are compelled to remain in a rational consideration of the connections and the phenomena flowing thence. For there is not a single fibre in this whole medullary ocean but flows in accordance with the direction of the motions themselves; and there is no substance which accommodates itself more easily than that of the brain. Yet in the mere exploration of these things much time and subtle thought is required, so that out of the darkness we may get into twilight, and thence at last into some light.

[Swedenborg's theory of the corpus callosum will be found fully discussed in the light of modern science in Note iii., Sub-section C, entitled "The Functions of the Corpus Callosum, the Fornix, and the Choroid Plexuses."—EDITOR.]

CHAPTER IX.

THE FORNIX AND ITS CONNECTIONS.

431. THE fornix of the ancients is that part of the medullary substance which lies underneath the corpus callosum, and divides the lateral ventricles higher up and more immediately. It is chiefly known by the striæ which in the corpus callosum run transversely towards the raphë in its middle, while in the fornix they flow in accordance with the direction of the ventricles. If, however, the medullary tract or zone by which the corpus callosum spreads over the lateral ventricles, is referred to the fornix, a similar extension around the ventricles is given to the fornix, as is attributed above to the corpus callosum. But if this medullary expanse is assigned to the corpus callosum, the fornix is circumscribed into narrower limits. The fornix descends into a process, and forms a small medullary body not unlike a stationary axis, which is placed before the third ventricle as a post or bolt; there the corpora striata and the optic thalami meet. This axis Vieussens calls fornix, as well as the middle of the fornix, and also the fimbriated appendage of the corpus callosum or of the true fornix. By Winslow it is called the base of the fornix. Below flows in and out the tænia semicircularis, or that medullary tract which in the bottom of the ventricles runs between the corpora striata and the thalami optici, and which by Vieussens was described as "a tract transverse and a little oblique." Below this tract is his "geminum semicirculare centrum." From the body of the fornix, both in an upward and downward direction, are sent out medullary roots; the superior ones, which are called the anterior, incline a little towards the heads of the corpora striata, and embrace

particularly the septum lucidum; but the posterior roots, which are also called the crura and pillars of the fornix, immediately beyond the body of the fornix are divided into elbows; and thus bipartite they climb upon the thalami optici, which they follow until they bend into their nerves. To the thalami they cling very closely, and almost fasten themselves to them; but the farther they remove from the body of the fornix along these thalami, the more lightly at last they become attached to them. Their exterior surface is white and roundish; but their interior, according to Vieussens, is whitish grey, and a little hollowed. On account of their inflection with the thalami towards the optic nerves the ancients called them cornua Ammonis or cornua arietis; while Aurantius styled their beginnings hippocampi and also bombyces. Their upper portion near the body of the fornix they called lyra and also psalloides, on account of the striæ running there transversely, and also on account of their being stretched across from one crus to the other. That portion also, on account of the ribbon-like edge passing around it, Vieussens called the posterior fimbriated part; while the body of the fornix itself he styled the fimbriated part of the true fornix or of the corpus callosum. Between the above-named anterior roots and pillars there also runs out from the very base of the fornix a straight medullary tract [the stria pinealis or the peduncles of the pineal gland], which by Vieussens is called "the medullary tract interposed between the optic thalami." It is continued over the third ventricle as far as the corpora quadrigemina; and during its course it sends out fibres to the little foramen which opens from the lateral ventricles [anus], which fibres pass around its orifice; it forms also an expansion between the thalami.[1] This medullary tract gives birth also to still another transverse tract [the posterior commissure] which is placed exactly before the corpora quadrigemina; and this same tract again with fibres sent out from some other source forms

[1] See Key and Retzius in no. 508*i*, where they say that "in the fully-developed brain, tissues shoot out of the stria pinealis, forming more or less a diminutive vault over the third ventricle."—Editor.

one which is short and diminutive, called "frænulum," which enters into the medullary substance lining the valve of Vieussens on this side. In this wise this medullary umbilicus or the body of the fornix, by fascicles of fibres sent out from it, cares for parts neighbouring and distant. In connection with this medullary tract [the stria pinealis or the peduncles of the pineal gland], which is between the thalami optici, we must also mention the ceiling of the third ventricle, which when it comes into sight—for it is easily torn—for the most part appears double. Laterally near the edges of the ventricle it is bent towards the thalami optici. This so-called ceiling has spread under it some grey substance.

432. Willis.[1]—"The two halves of the cerebrum meet, and are founded as it were upon a most white substance, similar to that which lines interiorly the whole mass of the cerebrum, and vaults it in a certain sense. This substance is harder than it is in any other portion of the brain; and as it is altogether medullary, it receives in itself the medullæ of all the convolutions, and it serves to them in the place of a common basis" (p. 10). "The medullary process itself, called commonly fornix, below its origin or beginning has two white, medullary roots, both proceeding in a like manner from the corpus callosum; these roots meet near those upper bodies [corpora striata] where the cerebrum is attached, and they pass into the fornix itself, as into that broad process, which like a beam is stretched out under the chamber of the cerebrum. Under this double root of the fornix a medullary tract, of the same size, is planted transversely [the anterior commissure], by which, as by a bridge, there is a certain passage and communication between the two lentiform processes [the upper corpora striata] and the [lower] corpora striata, which have their roots in them. Again, from the middle surface of this fornix is erected a thin and transparent septum [septum lucidum], which almost throughout the whole of its extent is affixed to the ceiling of the corpus callosum; and for this reason, that while the triangular fornix

[1] "Cerebri Anatome," etc., cap. i. and x.

is stretched over the excavation which has been prepared by a folding together of the cerebrum, the septum distinguishes its apparent cavity as it were into three compartments, and thus causes three ventricles to be formed in it" (p. 11). "The heads of the corpora striata are wider and more obtuse, incline towards one another, and are almost contiguous to one another. From this angle of inclination arises the twin root of the fornix. Under these roots is a certain transverse medullary tract [anterior commissure] which seems to connect the corpora striata. The extremities of these bodies, however, having become more pointed are bent outwards, and constitute as it were two sides of an acute triangle; with the anterior portion of their surface the corpus callosum coheres for a long stretch in the middle" (p. 15). "The fornix seems to serve a double use: *first*, it takes care lest the interior sides of the cerebrum, hanging down loosely and unconnectedly, should fall in, or be moved outside their proper limits; for they cohere with the medulla oblongata and the cerebellum not only by the intervention of the pia mater, and fastenings taken from it; but the fornix also, which like a ligament is produced from one extremity of the cerebrum to another, forces together and contains its fabric within its proper shape and position. For it is a purely medullary part, and of the same substance as the corpus callosum, of which it merely seems to be a process, which originating anteriorly between the corpora striata, and progressing over the two crura of the medulla oblongata [thalami optici], first distinguishes them. Afterwards it removes from them, and is carried across the middle ventricle, and near the posterior part of the cerebrum is divided into two arms as it were. These, after being deflected on both sides, cohere again with the edge of the corpus callosum, and embrace closely the medulla oblongata [*i.e.* the optic thalami]; they also connect with their extremity and firmly tie together the posterior mass of the cerebrum, lest it should be diffused or fall to pieces. The *second* and more important use of the fornix, however, seems to be that the animal spirits through its body should pass immediately from one extremity of the cerebrum to the other, and as it were through the bill of a pelican, be circulated into its own intorted belly" (pp. 68, 69). "In order that the medullary ducts might be seen better, I recently instituted a more accurate anatomy of the brain; namely, by lightly shaving off its parts with a pointed knife, I removed everywhere the softer and brownish substance nearest to the cortex of the brain, thus leaving a whiter and harder substance. By this process, which I repeated in various places of the cerebrum and the medulla oblongata, several medullary cords, like distinct nerves, which communicated in a wonderful manner with one another and with other white or medullary bodies, came into sight."[1]

433. VIEUSSENS.[2]—"What is commonly called the fornix is a white body, which is thrown in between the lateral ventricles and separates them from the third ventricle, and the more it is extended towards the posterior parts of the cerebrum, the more its lateral parts are spread apart. It is produced from certain white tracts of the medulla of the cerebrum, which near the anterior parts of the cerebrum first pass by the 'geminum semicirculare centrum,' and after being united in the anterior part of the third ventricle, pass off into two bodies, which have the appearance of a thick nerve; these when united compose that body which is usually called fornix. Near its anterior portion only it is immediately united with the septum lucidum, and elsewhere with the corpus callosum.

"Where it is produced towards the posterior portions of the lateral ventricles of the cerebrum, it passes off into two parts which are called crura; these embrace the thalami optici, and by an inflected course terminate in their posterior part. The exterior surface of these crura of the fornix is white, and they are of a roundish shape. . . . The fornix has lateral parts, which are thin, very soft, and a little extended; these reach to the anterior parts of its crura, and are usually called the fimbriæ of the fornix. Some portion of the choroid plexuses is under-

[1] This last quotation I am unable to verify.—EDITOR.

[2] Neurographia," etc., cap. xi.

neath them on both sides, and adheres to them. Here the fornix is immediately above the crura of the medulla oblongata [optic thalami]; and where it rests upon the third ventricle in relation to its position it is long, straight, and scarcely arched. And here I cannot help wondering why all anatomists should have deigned to apply the term *fornix* (vault) to this part of the cerebrum; since there is no empty space between it and the roof of the third ventricle, and it does not retain the position or the form of a vault, nor is it able to afford this use; for it is indeed sustained by the parts which are underneath it, but the upper mass of the cerebrum is by no means supported by it. But, inasmuch as that part of the medulla of the cerebrum, which is usually called corpus callosum, is somewhat in the shape of a vault; nay, and as it also manifestly performs the use of a vault, it seems to me that the term fornix ought to be applied rather to the corpus callosum than to that part which is usually signified by fornix. As this latter part, however, is immediately united with the corpus callosum, we therefore call its roots the anterior, and its crura the posterior pillars of the corpus callosum, or of the true fornix; for upon these four distinct pillars the corpus callosum rests in a certain measure: but the part which is intermediate between the roots and the crura I call the 'fimbriated appendage of the true fornix'" (pp. 60, 61).

"From what has been said above it appears manifestly that the true fornix is that medullary part which is usually called corpus callosum; which is interjected between both hemispheres of the cerebrum, and serves in forming the vault of the lateral ventricles; further, that supported by a certain fourfold column, namely, by the two roots of the so-called fornix, and its two crura, it sustains the convex part of the cerebrum itself, and prevents this from breaking in by its own weight, and thus from being destroyed" (p. 61).

"The medullary tract which is intermediate between the thalami optici [the peduncles of the pineal gland or stria pinealis] is a white and straight body, placed under the ceiling of the third ventricle, which seems to be composed of some white fibrils derived from the roots of the fornix, and from the anterior portion of the 'centrum semicirculare' on either side. Certain fibrils, however, of this medullary tract towards the back part of the cerebrum line the exterior margin of the 'anus,'[1] and afterwards inclining towards one another from both sides, they pass off into the transverse, medullary tract [the posterior commissure] which is between the pineal gland and the 'anus.' It is to be observed here that somewhere near the 'anus,' out of either side of the medullary tract which is interposed between the optic thalami [stria pinealis], certain white fibrils are brought forth which meet together, and pass off into a small medullary tract which is a little arched, and which has the appearance of a small nerve. . . . An ash-coloured and soft substance [soft or middle commissure] covers the upper part of the third ventricle like a ceiling, wherefore I call it 'lacunar' or ceiling. Upon this ash-coloured substance the above-mentioned medullary tract [the peduncles of the pineal gland or stria pinealis] rests, and is united with it, where the optic thalami, which by its intervention are united, are separated from one another. On account of its uncommon softness it is very easily torn, and its torn particles on both sides of the third ventricle shrink up to such a degree that they scarcely appear. After the ceiling of the third ventricle has been examined and torn, so that its lateral parts are a little drawn apart from each other, nothing solid remains interposed between the 'vulva'[2] and the 'anus.' It appears manifestly that this ventricle is excavated within the medulla oblongata, and is situated between its two crura [optic thalami]; at the same time also is seen the orifice of the infundibulum, which is

[1] "It is a foramen hollowed out near the posterior region of the lateral ventricles, in the neighbourhood of the corpora quadrigemina, by which the lateral ventricles likewise communicate with the third ventricle."—VIEUSSENS, p. 64.

[2] "The 'vulva' is nothing else than a foramen near the anterior region of the lateral ventricles, which is hidden under the fornix, and hollowed out near its roots; by its intervention the lateral ventricles communicate with the third." —VIEUSSENS, p. 64. This seems to be the "foramen of Monro," or the "foramen commune anterius."—EDITOR.

appended to the middle of its body, and also the opening of its wide-mouthed cavity. Nay, the two roots of the fornix are also discovered, before which is placed the medullary body which has the appearance of a thick nerve, and which is situated transversely before it, and is united with it [the anterior commissure]; this commissure also in front enters most intimately into the 'centrum semicirculare' on either side, and thereby joins the two together; on this account we style it a commissure [anterior commissure], which has the appearance of a thick nerve (*commissura crassioris nervi æmula*). This commissure, however, is formed by the coalition of certain white tracts, which are the first which are brought forth in the anterior region of the cerebrum from the medulla of both hemispheres" (pp. 64, 65).

"All the medullary tracts of which the anterior processes of the medulla oblongata [the corpora striata] consist, are derived from the upper region of the centrum ovale [corona radiata], and they pass off into the white medullary substance [the 'centrum semicirculare,' and the tænia semicircularis] which is interposed between the aforesaid corpora striata and the optic thalami, so that that medullary substance which encircles the exterior compass of both optic thalami in the form of a semicircle, is as it were a twin centre of all white tracts which are derived from the upper region of the centrum ovale [corona radiata]; on this account also I call it the 'centrum semicirculare' [with the tænia semicircularis], which is double; namely, one on either side. . . . The white membrane with which the crura of the medulla oblongata [optic thalami] are covered is a white, thin, and very soft substance, which is composed of white fibrils which are derived either from the tract which extends over the medullary ceiling of the third ventricle, or from the 'centrum semicirculare' on each side, and which parts are placed very closely to one another. But where this membrane, which is not unlike a thin skin, produces itself towards the posterior region of the optic thalami, its fibrils gradually incline towards one another, until at last they coalesce from both sides, and together with certain white tracts which emerge out of the posterior part of the above-mentioned optic thalami, they pass off into the optic nerves" (p. 67).

"A small and short medullary tract [the frænulum] appears interposed on the external surface of the corpora quadrigemina in the rear; this is drawn out from the transverse medullary tract which occupies the anterior part of the 'valvula major cerebri' [valve of Vieussens], and which ascending in a straight line is united with the posterior part of the pons Varolii. This small and short medullary tract resembles in a certain measure the membranous band by which the gland and the preputium are connected, wherefore I term it 'frænulum'" (p. 73).

434. Ridley.[1]—"The cerebrum may be considered in its inward appearance, which is concave and medullary, as taking its origin from the extremities or apices of the medulla oblongata, or rather more anteriorly from the foremost part of Vieussens' centrum ovale, commonly called the 'lentiform processes,' or according to Dr. Willis, the corpora striata. Thence it is presently bent back on each side in the form of a fornix or vault; very nearly as far as the corpora quadrigemina, a little below which on each side it is joined with the crura of the medulla oblongata [the optic thalami] on their under side, being continuous there to those parts commonly called the crura fornicis" (p. 115). "From the extreme limits of the lateral ventricles, in an antero-posterior direction, there arises that medullary space called by Vieussens the 'centrum ovale' [the corona radiata], the anterior part of which Willis calls the 'anterior edge of the corpus striatum.' The fornix is a medullary part arising from two roots in the anterior part of the basis of the cerebrum, which are placed between and upon the top parts of the thalami optici, which roots come out of the anterior part of the 'geminum semicirculare centrum,' so called by Vieussens, like two large nerves, and afterwards are joined together, constituting a broadish medullary body, which after having first projected

[1] "Anatomy of the Brain," chap. xiii.

itself for some space in an anterior direction between the corpora striata, runs next the length of the third ventricle, growing all the way broader and broader, and thinner towards its edges (which by Vieussens are called 'fimbriæ'). It is reflected backward, however, towards the hinder part of the lateral ventricles, like two arms, commonly called 'crura fornicis,' the extremities whereof on each side are by Aurantius called hippocampi and bombyces; whence I know that he had chiefly observed this part in animals, in which by virtue of the hinder part of the fornix in that place growing somewhat thicker, and running over the hinder and upper parts of the thalami optici, which are more prominent in them, that is, in sheep, calves, etc., than in men, it is made to appear on either side like the bending crest of the sea-horse, and in colour is much like the silkworm, certain minute striæ, which Malpighi calls 'fimbriæ,' crossing them like rings obliquely. This, however, is contrary to the same author's account of them. He says that these fibres or striæ run upon them otherwise, that is, longitudinally, as they do on the septum lucidum, embracing the thalami optici on their upper part on both sides, but adhering closely to them, as one continued substance, on their under part, where they are called by Vieussens the anterior pillars of the true fornix or corpus callosum. Thus they become continuous there with the posterior part of the corpus callosum, where it winds down upon the sides of the crura of the medulla oblongata [the optic thalami], and makes up those undermost spaces or cavities of the two lateral ventricles, which by Aurantius are called 'ventriculi hippocampi' or 'bombycini' [the middle or descending, and the posterior cornua of the lateral ventricles]; but by Vieussens the posterior part of the centrum ovale, and which by that kind of curved passage loses something of its oval figure" (pp. 117-119).

"Between the corpora striata and the optic thalami there is a medullary space [the tænia semicircularis] on each side, which in a sinuous manner encompasses the thalami themselves, and receives the extremities of the striæ in the corpora striata, as they descend from the before-mentioned centrum ovale. This is therefore called by Vieussens the 'geminum centrum semicirculare' [the supposed lower part of the tænia semicircularis], but by Willis the posterior edges of the corpora striata. . . . On the outside of the thalami optici I have always found and often showed a very fair medullary tract, here described, running all along between the corpora striata, and from the very hindermost extent of the corpora striata forwards, down to the roots of the fornix, to which they seem to be continuous" (pp. 122, 123). "Before the corpora quadrigemina, under the pineal gland, runs a transverse process [the posterior commissure], by Vieussens called 'processus natibus antepositus,' and described as 'nervuli æmulus,' which upon further inquiry, by drawing the thalami optici still wider, appears rather to be 'nervi' than 'nervuli æmulus,' being as thick as that behind the roots of the fornix, to which in situation it is just opposite; and it seems to join the thalami optici together, as that does the corpora striata" (pp. 125, 126). "There is a certain medullary cord or process which joins the corpora striata together, according to Dr. Willis, and which by Vieussens is called 'commissura crassioris nervi æmula;' and according to him it is the medium or commissure by which his 'geminum centrum semicirculare' intervening between the two 'corpora striata superiora anteriora' and 'posteriora,' and his 'tractus medullaris transversus et obliquus' intervening between his two 'corpora striata inferiora anteriora' and 'posteriora,' have a communication with each other. Dr. Willis places this cord or commissure under the roots of the fornix, but it is always behind it, though contiguous to it" (p. 128).

435. WINSLOW.[1]—"The septum lucidum is united by its lower part to the anterior portion of that particular medullary body, called improperly the fornix with three pillars [because of some resemblance it is thought to bear to the arches of ancient vaults]. It is in reality nothing but the corpus callosum, the lower side of which is like a hollow triangular

[1] "Anatomical Exposition," etc., section x.

plane, one side of which is anterior, and two posterior; and three edges, two lateral and one posterior. The lateral edges are terminated like two arches, which uniting at the anterior angle, form by their union what is called the anterior pillar of the fornix; and as they run backward separately towards the two posterior angles, they have then the name of the posterior pillars. The anterior pillar being double is larger than either of the posterior; and the marks of this composition always remain. Immediately below the basis or end of this pillar we observe a large, white, short, medullary cord stretched transversely between the two hemispheres, and commonly called the anterior commissure of the cerebrum. It is to this pillar that the septum lucidum adheres; but underneath it is not attached to the base, and therefore the two lateral ventricles communicate with each other. The posterior pillars are bent downward, and continued through the lower portions of the ventricles all the way to their extremities, resembling a ram's horn, which is a name that has been given to them. They diminish gradually in thickness during this course, and at their outsides they have each a small, thin, flat, collateral border, to which the name of 'corpora fimbriata' has been given. The inferior surface of the triangular ceiling which lies between these arches is full of transverse, prominent, medullary lines; for which reason the ancients called it psalloides and lyra" (section x. nos. 69-71).

"It is to be noted that the sides of the fornix, of the eminences, ventricles, canals, and infundibulum, are all covered by a very fine membrane, in which by injections or inflammations we discover a great number of very fine vessels. This membrane is in a manner a continuation of the vascular plexus of the septum lucidum, and that seems to be a detachment of the pia mater" (*ibid.*, no. 90).

436. Morgagni.[1]—"That ceiling of which Vieussens writes that it 'constitutes the upper part of the third ventricle,' I have frequently seen, from the top of the sides of the thalami optici which it conjoins, bending downwards a little; nay, sometimes I

[1] "Adversaria Anatomica," vi., Lugduni Batavorum, 1740; Animadversio, x. p. 11.

have seen two, of which one was below the other, the higher one of which, you would say, was lying upon, and was united to, the ceiling."

437. What is missing in the descriptions of our authors has to be supplied from the plates; and though these differ from one another, yet as much as is conducive to a common perception may be gathered by a collation of many. Plate vii. in Willis's "Cerebri Anatome" [p. 69] presents the interior texture of the corpus callosum laid bare, the trunk of the fornix being cut [*B*], and the mode by which it coheres with the corpus callosum. For the same reason the arms of the fornix are cut off which "embrace the medullary caudex near the region of the pineal gland [*C*, *C*]." From this appears the shape of the fornix, namely, that it is broader at the top and divided below; and also the "transverse medullary process, which connects the two corpora striata [the tænia semicircularis]" as far as their head [*G*, *G*]. In plate v. of his "Anima Brutorum" we see how "the anterior border of the corpus striatum insinuates itself in the direction of the corpus callosum [*N*, *N*], and the posterior towards the fornix" [*K*, *K*]. In plate vi., *ibid.*, we see in a sheep's brain how the anterior and posterior edges of the corpora striata unite in the olfactory nerve [*A*, *A*], and how the posterior edge passes even into the opposite hemisphere [*I*]; other transverse medullary tracts are also noticed there, namely, "between the optic thalami lying under the corpora quadrigemina" [*H*, *H*, *f*, *f*]; there is also another tract below parallel with this [*I*]. In plate vii., *ibid.*, the fornix is likewise represented with its two roots, and both edges of the corpora striata, together with another [*G*], which is said to be continuous with "a sinus leading from the olfactory bulb into the ventricle in the forepart of the cerebrum." The same is exhibited in plate viii., *ibid.*, where the medullary tract encompassing the corpora quadrigemina is still more spread [*M*], and from which there is "one medullary duct [*R*] towards the cone of the corpus striatum, and another [*S*] towards its base; from which by-and-by a forked branch goes forth, one branch [*r*] to the middle of the corpus striatum, and the other [*s*] to the corner

of its basis; with a transverse shoot [*T*] knitting together the aforesaid branches."

438. In Vieussens' plate iv. is seen how the olfactory nerves [*I*, *I*] encounter the anterior edge of the corpora striata, and by a transverse tract effect a conjunction with that, as well as with the inferior edge, or the "geminum centrum semicirculare." We notice also how "medullary tracts brought forth from the middle region of the centrum ovale tend towards the anterior part of the spinal marrow" [*N*, *N*]. In plate vi. is exhibited "the middle portion of the fornix, commonly so called, or the posterior part of the 'fimbriated appendage of the true fornix'" [*D*] where it spreads over the pineal gland and the corpora quadrigemina, together with the expanse of the centrum ovale [*B*, *B*, *B*, *B*]. Plate vii. shows the same part, with the choroid plexuses folded out, partly anteriorly, and partly posteriorly. When this is done "the medullary tract which is between the optic thalami" [*G*, *G*] is exposed, which "reaches to the corpora quadrigemina, invests the outermost edge of the foramen called 'anus,' and passes off into the medullary tract placed immediately before the corpora quadrigemina." In plate viii. the "fornix, or the 'fimbriated appendage of the true fornix,' is torn off across its middle region and folded back anteriorly" [*B*], with the medullary edge or ledge which is in the middle between the third ventricle and the thalami optici, and its communication with the tract placed before the corpora quadrigemina [*f*]; there are also represented the "crura fornicis" commonly so called, or the two posterior columns of the corpus callosum [*D*, *D*]. In plate ix. are seen the centrum ovale [*A*, *A*] without any other portion of the cerebrum behind it, and the base of the fornix with "the commissure, which resembles a thick nerve" [*b*]; likewise the roots of the fornix [*a*, *a*] and the posterior pillars, as well as the frænulum [*f*]. In plate xi. are exhibited the walls of the lateral ventricles [*B*, *B*, *B*, etc.], with "the basis of the fornix turned across" [*G*], and its roots spread apart and depressed [*b*, *b*]; and with "the transverse medullary tract [frænulum] occupying the anterior part of the valvula major cerebri"

[*i*], and "the exterior edge of a white and soft membrane, which is spread over the thalami optici or crura medullæ oblongatæ" [*a*, *a*, *a*, *a*]. The same also may be seen in plate xii., with "the commissura crassioris nervi æmula" cut in two, together with the transverse tract before the corpora quadrigemina and the valvula magna cerebri [*c*, *c*], and the frænulum [*d*]. In plate xiii. is exhibited the centrum ovale and "its medullary edge encompassing the corpora striata [*D*, *D*, etc.], which are deeply crased, and over which it domineers." In plate xiv. are represented "the two medullary tracts transverse and a little oblique," which are intermediate between the lower external anterior and posterior corpora striata [*D*, *D*]; with the white substance of the lobes in the base of the cerebrum [*E*, *E*], from which these tracts seem to originate; together with the medullary tracts [*I*, *I*] which are brought forward from the middle region of the centrum ovale, and while tending towards the anterior portion of the spinal marrow, subject themselves to the processes running from the cerebellum towards the medulla oblongata [*L*, *L*]. The same is shown in plate xv. after the parts have been still more deeply shaved out; and in xvi. after this shaving process has been carried on still more deeply.

439. In figure v. of Ridley's work "the fornix [*A*, *A*] is cut off at its roots and turned back, with that part of the crura fornicis [*d*, *d*] which, growing somewhat thicker as it turns off towards the lateral ventricles, runs over the optic thalami: these being very prominent in sheep and calves, help to thrust it up into such protuberances as the ancients called 'bombyces' or 'hippocampi;'" likewise "a long medullary tract [tænia semicircularis] between the thalami optici and the corpora striata" [*m*, *m*].

[Modern Authors.

439*a*. Reil.[1]—"The fornix [which Reil calls the twin-band (Zwillingsbinde)] originates in the interior of the optic thal-

[1] Archiv der Physiologie, vol. xi., Halle, 1811.

ami, from a root which is almost turned upwards. These roots lie about a line below their surface underneath a protuberance in their anterior part, near the tænia semicircularis. There the roots are lost between the upper strata of the optic thalami. From their place of origin the roots of the fornix gently descend in an antero-posterior direction, and almost perpendicularly, in the substance of the thalami. . . . Afterwards, immediately above the corpora albicantia, they almost always are divided into two or three strands; they descend in the square surface of the inner walls of the thalami, and at the posterior and lower corner of that surface, and at its lower edge, immediately behind the pituitary gland, they emerge into daylight. They now turn from within outwards, and thereby form the corpora albicantia. These corpora seem to contain interiorly some grey substance. From the corpora albicantia the roots of the fornix commence again an ascending course; in an arch-like curvature from behind forwards they press upwards in the diagonal of the above-mentioned square surface, and covered by a layer of grey substance they again make their appearance at the upper and anterior corner of that substance in the neighbourhood of the anterior extremity of the optic thalami. Before reaching the top they first receive a medullary fascicle from the optic thalami, . . . directly opposite the anterior commissure, near its concave and hollow side, immediately below the anterior extremity of the tænia semicircularis.

"The anterior roots of the fornix now ascend in an arch-like bend from the bottom of the lateral ventricles towards the corpus callosum, being sustained by the septum lucidum. They rest with their arches on the anterior commissure. The hollow edges of these arches, turned inwards, are free; but, above the anterior commissure, the septum lucidum fastens itself to the anterior and convex side of the roots. Above the anterior commissure the roots of the fornix also emit some thin medullary fascicles, which are lost in the septum lucidum, and join the peduncles of the corpus callosum.

"As far as the anterior commissure, the anterior roots or pillars of the fornix have a cylindrical form; but immediately above the commissure, in the middle of their course from the bottom to the roof of the ventricles, their shape varies; it approaches that of a ribbon, and at last it becomes like the flat leaf of a reed. Thus far also the two anterior roots or pillars are separated, so that on looking towards them from behind, the anterior commissure, which passes in front of them, is seen stretched out unattached. Not far above the anterior commissure the two anterior pillars or crura of the fornix unite, and they remain united as far as the lyra; thus as long as they are accompanied by the septum lucidum. At this point, in a posterior direction, they become separated again, forming thereby the lyra. The middle, central part, where the fornix is united, may be called its *body*, which in front and in the rear is cleft into two feet, the anterior pair of which has its roots in the optic thalami, and the posterior pair in the hippocampi.

"Where the fornix is in contact with the corpus callosum, its two portions are joined in such a manner that their interior edges incline downwards, and together form a hollow, while their outer edges are attached to the corpus callosum; and they are thus fitted to receive between them the pencil-like extremity of the ventricle of the septum. On this account the two united portions of the fornix, as far as the lyra, form here a triangular body resting between the two optic thalami, and furnishing a cover to the third ventricle.

"Further back the two lateral portions of the fornix are again separated, and they form thereby the anterior angle or point of the lyra. Henceforth the shape of the fornix is that of a mere ribbon. Of this ribbon only the interior edge is fastened to the corpus callosum, while both its surfaces and its exterior edge are free. The posterior extremity of the lyra is constituted by the thickened border (splenium or bourrelet) of the corpus callosum. Is the interior of the lyra formed by the corpus callosum covered with epithelium? or is it covered also with a thin medullary layer derived from the inner edges of the fornix? The first seems generally to be the case.

"Immediately in front of the posterior thickened border of the corpus callosum (bourrelet) a bundle of fibres leaves the interior edge of the fornix, making directly for the aforesaid thickened border. It penetrates between it and the body of the corpus callosum into the forceps-like productions of the said body, which are lost in the convolutions of the posterior lobe.

"The remaining larger portion of the fornix, its continuation proper, which pursues its way around the posterior end of the optic thalamus into the middle or descending cornu of the lateral ventricle, crosses over to the opposite lower wall of the descending cornu which is contiguous to the hippocampus. For there, where the hippocampus major is beginning to be formed, the longitudinal convolutions [the gyrus fornicatus] which pass over the corpus callosum, are bent in such a manner around its posterior part, that at the lower end of its posterior part they diverge for the purpose of entering the middle descending cornu. On this account there is exposed here on the lower surface of the corpus callosum a heart-shaped portion of its thickened border. At this place one edge of the posterior crus of the fornix is united with the radiating membrane, into which the thickened border is resolved, in order to continue therewith its way over the bottom wall of the descending cornu. Both form together a kind of channel, the beginning of the hippocampus major, which receives then the first portion of its grey substance. The posterior crus of the fornix becomes narrower, where it joins the hippocampus major, along the concave edge of which it is continued.

"One part of the posterior crus of the fornix covers the hippocampus major; another part in the form of a border folded inwards continues along its concave margin, and terminates in the posterior and interior eminence which is cleft, with which the middle lobe presses against the crus cerebri; and, indeed, it terminates in the upper part of the cleft, where it blends with the hippocampus, and behind which it terminates in the form of the pes hippocampi. The hippocampus major must be regarded as a convolution, the interior of which is turned outside. Its exterior medullary substance is probably in a great measure generated from its own depth, and in opposition to the grey substance; but it receives, besides, some additions of medullary fibres, partly from the crura of the fornix, and partly from the thickened border of the corpus callosum. The fibres of its medullary surface are very delicate; they diverge from within outwards, and are perhaps also continued around its outer margin as far as the lower wall, on which it rests. In its interior the hippocampus contains grey matter which has its beginning in a small cylindrical lump which is suspended from the thickened border (splenium) immediately before the gyrus fornicatus, which turns about the hinder part of the corpus callosum. This grey matter is indeed near the grey matter of the convolution, but it is not an immediate continuation of the same. Further on this grey matter assumes the shape of a tooth; it is continued beyond the crus or tænia of the fornix, and climbs up the cleft of the posterior and interior eminence of the middle lobe, terminating with several productions in the obtuse round end of the hippocampus, as the toes of the pes hippocampi. This grey substance in the hippocampus has a perforated space on its surface; the hippocampus, therefore, has a ganglionic nature, and a greater significance than a common convolution. Is it the continuation and extremity of the fornix? Or is it a peculiar organ existing by itself?

"The fornix begins and ends in grey substance; it passes from the optic thalami to the hippocampus major; it consists of pure medulla, and is attached to pure medulla. Its structure is fibrillous; its fibres being delicately intertwined, in the form of a bundle of flax. A central blood-vessel is contained interiorly in each of the crura, and it is besides accompanied by the choroid plexus; the conjunction of which with the fornix, and the situation of which in its neighbourhood, is certainly of great significance. The choroid plexus is almost like a gill fastened to the margin of its free edge" (vol. xi. pp. 106-111).

439*b*. JUNG.[1]—Jung in his experiments allowed the brain to reach a certain degree of putrescence; when the grey matter becomes dissolved, and with a camel-hair brush is able to be removed from the medullary substance, which resists the putrefying action longer. He writes:—

"On cutting down the two eminences forming the optic thalami and the corpora striata, so far, that they present an almost level plain, which by the stria terminalis or tænia semicircularis is divided into a larger, upper, anterior, and exterior plain, and into one which is smaller, lower, posterior, and interior; and on removing the stria terminalis itself, and wiping off carefully with a brush, in a direction from below upwards and from within outwards, the accretions of grey mass, we soon succeed in exposing closely pressed, finer medullary fibres in the optic thalami, and thicker, more expansive bundles in the medullary mass of the corpora striata. Between these two systems of fibrous layers, but intimately conjoined to each, there remains in the middle a singular formation. The more the grey masses in the thalami and in the corpora striata yield to the effects of the brush, the more a border mass, about two lines in width, and consisting merely of medullary substance, raises itself up like a ridge, . . . describing a bend around the grey masses of the thalami" (p. 5).

"This medullary mass, indeed, has been known to the anatomists for a long time; but not its minute structure, nor the important relations it occupies in respect to the roots of the fornix. Vieussens shows this mass in his plate x. . . . He is well aware that a white medullary substance is inserted between the optic thalami and the corpora striata, for he says (p. 67), 'All the medullary tracts of which the anterior processes of the medulla oblongata [the corpora striata] consist, are derived from the upper region of the centrum ovale, and they pass off into the white, medullary substance which is interposed between the aforesaid corpora striata and the optic thalami, so that that

[1] Jung (K. G.), Professor of Medicine in Bâle, "*Ueber das Gewölbe in dem Menschlichen Gehirn*" (The Fornix in the Human Brain), Bâle, 1845.

medullary substance which encircles the exterior compass of both optic thalami in the form of a semicircle, is as it were a twin centre of all white tracts which are derived from the upper region of the centrum ovale; on this account also I call it the "centrum semicirculare," which is double, namely, one on either side.'

"Vieussens, however, is in error in maintaining that this substance is continuous with the stria terminalis or tænia semicircularis, calling the latter 'semicircularis centri pars superior.' The stria terminalis has nothing whatever to do with the above border substance. Burdach also commits the same error (see vol. ii. pp. 122, 344).

"According to Reil the region of which we now speak is manifestly a part of the 'corona radiata.' For he says (xi. p. 362), 'The radiation of the cerebral crura and of the optic thalami to which I applied, not altogether properly, the term "corona radiata," encompasses the exterior border of the optic thalami'" (p. 6).

"Towards the end of the border ridge, near its edge towards the optic thalamus, after working your way still more deeply between the grey mass and the delicate fibres of the medullary substance, you suddenly notice a white medullary bundle. It is the descending root of the fornix. . . . In its very beginning it appears of the same width as throughout the whole of its course through the optic thalamus. It evidently arises from a sudden coalition of a number of medullary fibres from the border substance. For further than this substance the descending root of the fornix can never be traced. The first medullary fibres which enter into the composition of the root must be exceedingly delicate and yielding; for the root breaks off most easily at the place of its birth. . . . Not even the most delicate filaments can be noticed, when the broken end of the root is put under water" (p. 7).

"The root itself lies in a channel of the grey substance of the optic thalami. . . . The descending root of the fornix is round, with the exception of its upper extremity, where it is visibly flattened. At the distance of about two lines from the bulbus fornicis [corpus albicans] the root becomes somewhat broader, and in the same proportion it loses its round shape. Its fibres now separate from one another, it opens like a fan, and becomes unravelled; and now pushing from above downwards, and from within outwards, and at the same time turning and twisting itself completely, it encloses with its delicate fibres, which are sometimes visible to the naked eye, the little lump of grey mass which in a great measure composes the interior of the bulbus. Continuing its course from below upwards, and from within outwards, it becomes now the ascending root of the fornix" (pp. 11-13).

"It is worthy of remark here that the ascending root for some distance is embedded in grey substance, and most intimately surrounded by it. Nay, the grey substance cannot be removed from it very easily, and you have to go to work carefully, if you wish to lay bare the ascending root, without injuring any of its medullary ingredients" (p. 17).

"If on the one hand we are justified in assuming that the intimate conjunction of the ascending root with the grey mass of the bulbus fornicis [corpus albicans], contributes essentially to its immediate development, we may conclude on the other hand that the grey mass in which the ascending root is embedded, contributes not only very much to the development of the root into the fornix overhead, but influences also considerably the sending off from it of *two medullary branches.*

"The first of these branches, the *stria pinealis* or peduncle of the pineal gland, leaves the ascending root of the fornix at a very acute angle, in an interior and posterior direction. The place where it leaves the root of the fornix is usually one and a half or two lines from the surface in the grey mass of the thalamus. At first this stria appears in the form of a delicate medullary bundle, but which increases in bulk as it advances. During its passage it follows a course in an upward and posterior direction through the anterior part of the optic thalamus, at the upper surface of which it suddenly makes its appearance, about one-third below its anterior extremity. . . . It must be remembered that during the whole of its passage over the upper surface of the thalamus, during which it preserves the same width and thickness, the stria pinealis is covered by the medullary surface of the thalamus. Nay, it is so intimately connected with it, that, like the Brothers Wenzel, for a long time I took it for a mere fold of that surface. . . . As soon as this medullary tract leaves the optic thalamus, and directs its course towards the pineal gland, it grows thicker. Sometimes in the neighbourhood of the pineal gland it swells into a knot.

"I believe that Vieussens is the first author who formed a correct idea in respect to the origin of the stria pinealis. He says (p. 64), 'The medullary tract which is intermediate between the optic thalami [the peduncles of the pineal gland or stria pinealis] is a white and straight body, placed under the ceiling of the third ventricle, which seems to be composed of some white fibrils derived from the roots of the fornix, and from the anterior portion of the "centrum semicirculare."'

"*The second medullary tract* leaves the ascending root of the fornix in an outward direction: we call it the *stria terminalis*, or tænia semicircularis. It leaves the ascending root almost at a right angle. It is mostly covered only by a very thin layer of grey substance. It ascends in a posterior and exterior direction, along the anterior and exterior portion of the thalamus opticus. It usually makes its appearance two and a half lines behind the anterior pillars of the fornix. At first it is still deep down in the furrow between the optic thalami and the corpora striata. . . . Gradually it rises up higher, increases in bulk, and in proportion as the furrow in which it is originally embedded becomes shallower, it rises almost entirely to the surface, yet still covered by the medullary membrane which is spread over the optic thalami and the corpora striata. During its course backwards, it usually becomes broader, by spreading out as it were its fibrous fascicles. It accompanies closely the interior edge of the corpus striatum, and follows its posterior, narrower part to its very end; and towards the last it blends in the descending cornu with the fimbria of the posterior crus of the fornix. It forms with it a medullary lamina at the interior end of the hippocampus" (pp. 18-20).

439*c*. PITRES.[1]—"It is well known that the white fibres of the *pes* [or *crusta*] of the cerebral peduncle on penetrating into the cerebrum, from the moment of their entrance into that organ, between the optic thalami and the nucleus caudatus which are within, and between the nucleus lenticularis which is without the lateral ventricles, form a white zone, very well described and delineated by Vieussens, who noticed it in horizontal sections of the cerebrum, and therefore called it 'geminum centrum semicirculare;' while Burdach, who became acquainted with it on making vertical sections of the cerebrum, styled it the 'inner capsule' (capsula interna). After passing through the intermediate space between the central nuclei, the fibres of the 'inner capsule' seem to penetrate into the centrum ovale [corona radiata], where they are dispersed in all directions. These radiations are very well seen, when the two hemispheres are separated, and the lateral ventricle is opened, and when the grey substance of the nucleus caudatus is scraped with the handle of a scalpel. An elegant and nicely-radiating figure is then obtained, which is called the corona radiata of Reil" (p. 13).

439*d*. MEYNERT.[2]—"The descending branch of the anterior pillar of the fornix lies in the central tubular grey matter, as well as the first part of the ascending branch, before it penetrates the substance of the thalamus opticus.

"According to Meckel, Arnold, Jung, and Luys, the descending branch of the crus fornicis becomes fused, before its entrance into this grey matter, with the anterior extremity (but surely not with the whole length!) of the tænia semicircularis, and the stria pinealis. Together with the crura fornicis, the upper half

[1] Pitres (A.), Recherches sur les Lésions du centre ovale des hémisphères cérébraux étudiées au point de vue des Localisations Cérébrales, Versailles, 1877.
[2] Meynert (Th.), "The Brain of Mammals," etc., American edition, p. 683.

of the spherical corpus candicans [bulbus fornicis] becomes embedded in the inferior part of the central tubular grey matter.

"The corpus candicans [bulbus fornicis] is a ganglion which lies in a loop made by the anterior pillar of the fornix in twisting back upon itself (to enter the thalamus), and by its means a certain number of the fibres of the fornix are made to pass directly into the tegmentum cruris cerebri. It is a mistake to suppose with Jung that the fibres from the fornix simply traverse the substance of the corpus candicans, and that the superficial nerve-fibres which enclose the latter are to be referred to a different source. On the contrary, the descending branch of the crus fornicis first invests the outer and posterior surfaces of the ganglion, and then twisting on itself, invests, under the form of the ascending branch of the same crus, the inner and anterior surface.

"In the course of this process, a portion of the fibres of the fornix traverse the substance of the ganglion, which contains spindle-shaped cells, 20 to 30 μ. by 9 μ., and from the upper border of which issues the fasciculus destined for the tegmentum cruris. The greater part of the fibres of the crus fornicis, however, simply curve round the outside of the ganglion, enclosing in their course, especially in the ascending branch of the crus fornicis, nerve-cells 30 to 45 μ. by 15 μ., which lie strictly parallel to the fibres, and which appear to coincide, in point of size, with the terminal cells of this same ascending branch, which are found in the anterior tubercle of the thalamus. The fibres of the fornix, then, terminate at their peripheral extremity in cells of two kinds, of which the smaller are found in the corpus candicans, the larger in the tuberculum anterius thalami optici" (pp. 689-690).

In another place he says, "The ascending branch of the crus fornicis represents the cortex of the gyrus fornicatus and forms the superior pedicle of the thalamus. After making an S-shaped curve, in order to pass to the inside of the posterior longitudinal fasciculus (*hinteres Längsbündel*), and then to reach a somewhat external part of the thalamus, this ascending crus fornicis passes directly forwards and upwards, and forking into two parts, as may be readily seen on cross-sections, it spreads out its fibres in the *superior nucleus of the thalamus,* whose anterior extremity gives rise to the protuberance on the surface of the ganglion called tuberculum, or genu anterius" (p. 691).

Concerning the "centrum geminum semicirculare" or "inner capsule" he says: "The broad medullary tract, the '*inner capsule*' [centrum geminum semicirculare], the two parts of which, as they appear in a horizontal section, seem to unite at an obtuse angle, separates anteriorly the corpus striatum from the nucleus lenticularis [the corpus striatum outside the ventricles], posteriorly the latter from the thalamus opticus. The upper half of its layers is made up of the *first* member of the projection system,[1] the lower extremity of the respective section of the corona radiata (pes coronæ radiatæ); the lower half of the same of the *second* member of the projection system,[1] viz. the basis cruris cerebri. The extremity of the corona radiata is however, as it lies in the inner capsule, overarched by the corpus striatum, and is therefore interwoven with the crural fibres of the latter, which cross the direction of its own. The fibres of the corona radiata run from the frontal lobe into the thalamus opticus" (p. 683).

439*e*. CRUVEILHIER.[2]—"Is the fornix an antero-posterior commissure? In support of this opinion I may state that I have seen the right half of the fornix atrophied in a case of destruction of the convolutions corresponding to the tentorium cerebelli" (p. 1019).]

[1] The *first* member of Meynert's "projection system" consists of the cerebral fibres between the cortex cerebri and the central ganglia, *i.e.* the corpora striata and the optic thalami. His *second* member of the "projection system" is composed of these same fibres after leaving the central ganglia.—EDITOR.

[2] Cruveilhier (J.), "Descriptive Anatomy," etc., London, 1842.

ANALYSIS.

440. The body of the fornix is the common umbilicus or focus, the stationary axis, and the medullary centre of the appendages, motions, and determinations of the interior compages of the cerebrum. From the top flows in the fibre of the corpus callosum, from the side the medulla of the ceiling of the third ventricle [viz. of the velum interpositum, and the stria pinealis], and of what is generally understood by the fornix; from below, however, flows in the "geminum centrum semicirculare" and the medullary tract which is inserted between the corpora striata [viz. the tænia semicircularis, and the "inner capsule," as defined above by Pitres and Meynert]. Thus by distinct ways there is an influx of numerous fibres of the cerebrum, from the anterior, middle, and posterior region of its nucleus or "centrum ovale" [corona radiata]. But what the "centrum ovale," the "centrum geminum semicirculare," the medullary tract inserted between the corpora striata; again, what the fornix commonly so called, and the ceiling of the third ventricle; and, besides, what the posterior and anterior pillars and roots of the fornix, the anterior commissure, the fimbriæ, hippocampi, the frænulum, and all the other parts with their strange-sounding names are, and where in the brain they are situated—all this cannot be learned from descriptions, but from personal examinations, or from brains which have been drawn to the life; otherwise we wander about in uncertainty, and we speak without being understood. The compages or structure of the brain is like a labyrinth where there is an easy entrance, but where, unless we follow closely the fibres and the paved roads, we fall into an inextricable maze.

441. In the brain, as in the other viscera of the body, and as everywhere in universal nature, singulars are subordinated to their integrals, and these to their totals or their whole. The singulars in the brain are the cortical parts, the fibres and the blood-vessels; the integrals are the cavities, and the eminences which are called the organs of the brain; but the totals are the hemispheres, the cerebrum, the cerebellum, the medulla oblongata, and the spinal marrow. All these are separated, as well as associated together, by membranes, fibrous septa, and paved roads. And these again in a similar manner are interwoven and enveloped by medullary tracts. Some of these are more general, and others more particular; or they are more or less composite or simple. The most general medullary expanse and intertexture is the corpus callosum; to this is subjected a less general expanse and tissue, namely, the fornix usually so called, and the ceiling of the third ventricle; to this again is subordinated the posterior commissure, which is placed before the anterior corpora quadrigemina; and to this the frænulum which terminates in the surface of the valve of Vieussens. From these the tæniæ, pillars, roots, and threads in the lateral ventricles, the crura of the fornix in their bottoms, and the septa and little foramina branch out. In this manner all things are distinguished from one another, and yet they cohere by a perpetual connection, with the purpose that each single part may act in due order under the auspices of [all the parts]. As many medullary tracts as are rendered visible, just so many limits, junctures, articulations of a higher and lower order are there of bodies in a state of activity, which in alternate times are expanded, and then again subside. We learn thence the quality of the active and passive forces, and of the determination of the motion, which are in each part. The striated and grey bodies are so many active, the medullary and white bodies, however, are so many passive forces; their fibres and striæ indicating the determination of the motion; for in conformity with this they assume an oblique direction, and are associated together.

442. The fornix marks the boundary between the cerebrum

and the medulla oblongata; for it covers and guards the longitudinal axis which runs along between them; underneath it, indeed, a cleft is opened which is called the third ventricle, and between the thalami optici which are the crura and the beginnings of the medulla oblongata, the great chymical laboratory which is most copiously fitted up with organs, takes its origin. These organs are the lateral ventricles, and the third ventricle, the aqueduct of Sylvius with the glands, the crura, and the infundibulum; all of which are placed underneath the fornix in the highest region of the medulla oblongata, but within the compass of the cerebrum. Through this threshold there is therefore likewise a descent from the cerebrum to its most ornate laboratory or gland.

443. The laboratory, however, is furnished with its essences, or with its juice and spirit, from the cerebrum alone, and not from the medulla oblongata, although it is situated amid the beginnings of that body. Thus the fibres which carry [this spirit] are derived entirely from the cortical and grey substances (which are so many little origins of spirits) of the posterior and interior cerebrum, and not of the anterior cerebrum, *i.e.* of its front part and the neighbourhood of the processes of the falx, which parts are especially devoted to the senses and to voluntary motion. That the organs of the chymical laboratory are provided entirely from the posterior and interior cerebrum appears from the medullary strata, that is, the corpus callosum, the fornix, the "geminum centrum semicirculare" [inner capsule], and the rest, which derive their medullary fibres from the anterior, middle, and posterior parts of the centrum ovale, and which at once pass off into the processes, columns, and roots that flow into the lateral ventricles, the third ventricle in the middle, the aqueduct, the septum lucidum, the thalami optici as far as the posterior cornu, and in addition into the anterior tubercles of the corpora quadrigemina, and into the posterior foramen or "anus." The corpus callosum and the origins of its fibres have been treated of above. Thence also [that is, from the same origins], but interiorly, flow forth the fibres which are

proper to the fornix and the ceiling of the third ventricle; likewise those of the "geminum centrum semicirculare" [inner capsule], and the anterior commissure which is produced from the middle region of the centrum ovale. These fibres are not allowed forth any further, nor do they return to their origins, but they stop there and are consumed there; wherefore the spirituous juice which they carry is not put to any other uses. The chymical laboratory which prepares the blood contains therefore lymphs and purest essences which it has received from the cerebrum; while the medulla oblongata contains an apparatus and organs which thrive and undergo their functions also under the auspices of the cerebrum, but as it were more remotely. Thus it is enough for the cerebrum to infuse life into all organs; but the remaining functions it hands over to assistant motory powers; in such a way, however, that all things are kept properly tied to its own universal government.

444. That the cerebrum is not only a dispenser of fluids, but also a regulator of motions, appears from the partition and the flux of its medullary processes. Thus the corpus callosum, like a common awning, is spread over the cavities and enclosed members which are underneath it, and it controls each of them in general in such a manner that they undergo their motions in a mode agreeable to the nature of their functions. This is succeeded by the ceiling of the third ventricle and fornix, as by a sail or an awning not so extensive, accommodated to the particular motion of the third ventricle, and also to that of the interior edges of both lateral ventricles. Thence flow the little cords, bridles, and frænula which govern the small tubercles, the foramina, and the little doors, and their diminutive motions and vibrations in a manner conformable to the expansion of the cavities. Again, across the bottom of the ventricles, betwixt, above, and below the corpora striata and the thalami optici, there is a perpetual medullary belt [tænia semicircularis], which bursts forth from a certain common centre called the "semicircular" [the inner capsule], which by commissures is attached to the fornix, and consequently to the ceiling and the corpus callosum.

In this manner a certain infinite chain and spire is constructed which conjoins the highest parts with the lowest. In addition, the pillars and roots, as so many bonds returning from each part, are sent to the optic thalami which constitute the middle bottom of the ventricles. All parts are thus disposed and arranged so as to resemble a perpetual gyre, in which each fibre becomes conscious of all the modes and contingencies in every other fibre.

445. Besides, these medullary tracts which have respect to the body of the fornix as to the centre of their determinations, likewise lend wings as it were to the senses, and their distinct modes, in order to hurry them on in a quick flight towards the superior region of the cerebrum, and at the same time into its whole cortical and grey substance. Thus the sense of sight through the thalami optici is poured out into all that substance whence they spring, and, besides, through the pillars and roots, as well as through the ceiling of the third ventricle, and the corpus callosum, it is transmitted into its cortical and grey substance, and by these bodies and at the same time by ways around the corpora striata, it is urged into the supreme sphere, where the cerebrum acts as the general sensory and motory organ. The sense of smell also is poured forth towards the corpora striata and the thalami optici; or through the same way whence the olfactory nerves here and there derive their roots it is despatched to the individual origins of each fibre. The senses of hearing and taste also, which from the medulla oblongata by the cerebral peduncles have risen to the striated principles, terminate nowhere else than in the cortical envelope of the cerebrum. The same applies to the sense of touch, which is conveyed by the spinal marrow through the medulla oblongata to the same principles, and thence into the cerebrum, which alone sensates.

APPENDIX TO CHAPTER IX.

AN EARLIER ANALYSIS OF THE FORNIX.[1]

445*a*. From the anatomical authorities given above at great length (from no. 430 to 436), we are able to deduce the following conclusions: The cerebrum is entirely distinguished from the corpora striata by a certain medullary border into which its fibres seem to enter reflexly, and through which it seems to concentrate itself from every quarter towards the body of the fornix, which is like a bolt or beam between the kingdom of the cerebrum and the chymical laboratory established in the upper part of the medulla oblongata. Thus, in this body of the fornix, there is the last boundary of the medullary substance of the cerebrum, and the first of the chymical laboratory, and a certain centre of rest; since all the tracts, medullary as well as grey, on either side of it, are in a state of expansion and constriction, on which account it may also be styled a fulcrum. The medullary substance which is determined from the cerebrum and the corpora striata towards this central bolt, and which cistern-like encloses the ventricles, is transferred chiefly into the optic thalami, and from the fibres of that substance, by the alternate expansion and constriction of the aforesaid thalami and ventricles, the spirituous essence contained within such a copious mass of fibres is necessarily squeezed out; and this essence, under the choroid plexuses, is distilled in equal quantities into each lateral ventricle. Wherefore no other road is open into these ventricles than that natural road which leads from the body of the fornix towards the lower cornua of the lateral ventricles. That grosser liquid, however, which often clogs up the anfrac-

[1] From Codex 65, Photolithographed MSS., vol. iv. pp. 269-286.

tuosities and the medulla of the cerebrum, is derived towards the olfactory nerves, where lies the ultimate boundary of the anfractuosities and interstices of the medullary substance, as well as of the animatory motion of the cerebrum itself.

445*b*. *That the cerebrum is altogether distinguished from the beginnings of the medulla oblongata or the corpora striata, by a certain medullary border,* which from all sides as it were runs around the lateral ventricles throughout their whole extent—appears from various sections of the brain. This border which in some places is wider and in others narrower, is like an enclosing band extending from the top, as well as from the middle of the centrum ovale [corona radiata], and also from the "centrum geminum semicirculare" [inner capsule]. By Willis it was called the upper, anterior, and lower border of the corpora striata, and it was represented by him in several of his plates. This border is distinguished from the rest of the medullary substance by a marked whiteness, and a difference in the stratification and texture of the fibres. In general it may be noticed that all the active bodies of the cerebrum are surrounded by a certain medullary border; consequently also the pineal gland, and the corpora quadrigemina, on which that gland reclines as on a cushion. The same is the case with the lateral, the third, and the fourth ventricles, which are encompassed by a substance woven into a kind of retiform texture, in order that they may be expanded and constricted; since such a texture is yielding, being of a soft and dense membranous consistency, which also is wont to be consolidated into a membrane.

445*c*. *Into this border the fibres of the cerebrum seem to enter reflexly,* as is proved by observations made in respect to the ceiling of the lateral ventricles, which, according to Ridley, is continuous with the border of the corpora striata, and the "centrum semicirculare"—in such a manner, indeed, that in this border the fibres of the cerebrum seem to be interlaced and interwoven with the proper fibres of the corpora striata; for through this border alone the medulla of both is connected. It may be concluded thence that the cerebrum extends the sphere of its activity so far, and that there the action of the corpora striata begins; also that the cerebrum can arrange it so that this communication should be loose, and as it were broken, as in sleep, and on other occasions, when the cerebrum is willing to sensate only obtusely, and when it does not wish to exercise any will-power upon the muscles; and on the other hand, that this communication should be close and strict, as during a state of wakefulness, when the cerebrum is on the stretch to receive sensations, and when it determines itself as it were towards the exterior circumference of the body, or towards its external organism.

445*d*. *Through this border the cerebrum concentrates itself from every quarter towards the body of the fornix;* namely, from the centrum ovale [corona radiata] into the ceiling of the lateral ventricles, and thence through the corpus callosum into the body of the fornix; likewise through the "centrum semicirculare," and the tænia semicircularis towards its lower part, that is, towards the anterior roots or pillars of the fornix. . . . Wherefore the body of the fornix seems to derive its origin from the whole substance of the cerebrum, flowing thither both from above and from below. For that this organ is a process of the corpus callosum or its fimbriated appendage, is scarcely questioned by any one; nor is there any doubt that the "centrum geminum semicirculare" [inner capsule] flows into it from below. Here, indeed, in the meeting-ground [near the foramen Monroi] there is a kind of medullary expansion into which flows the substance which on either side encloses the corpora striata, in order that thence it may pass unitedly towards the olfactory nerves; which appears very conspicuously in the brains of calves and sheep. This substance becomes intertwined proximately with the anterior commissure, as well as with the fornix, to which it serves in the place of a base, and to which it furnishes roots.

From the lower portion of the cerebrum, and thus from the posterior corona radiata or the posterior centrum ovale, or from the lower edges of the cerebrum, no substance seems to flow into the fornix, but it rather appears to be continued thence into it from the corpus callosum; through which organ it seems to communicate with all the remaining medullary substance of the cerebrum. For thither [that is, into the lower lobes of the cerebrum] extends the corpus callosum from above, as well as the "centrum semicirculare" after it has formed the anterior roots of the fornix. It extends thither through the tænia semicircularis, which, according to Vieussens, is said to originate from the roots of the fornix, and consequently from the "centrum semicirculare" [inner capsule]. As the posterior portion of the corona radiata, however, conjoins itself with the pillars of the corpus callosum [*i.e.* with what are now called the posterior pillars or crura of the fornix], it perchance flows into these crura, but not into the actual body of the fornix.

445*e*. *The body of the fornix is like a bolt or beam between the kingdom of the cerebrum and the chymical laboratory.* For through that part of the fornix, as through its only threshold, the medullary substance of the cerebrum effects its entrance, after it has been concentrated in the manner described above. *This chymical laboratory is established in the upper part of the medulla oblongata:* its members or organs are the two lateral ventricles, the third intermediate ventricle with the anterior and posterior foramina, the infundibulum—these are hollowed out in the beginnings of the above medulla; further the aqueduct of Sylvius with the corpora quadrigemina and the pineal gland, which are situated in the neighbourhood, and which cannot be properly attributed either to the cerebrum or the medulla oblongata, as is the case also with the pituitary gland—each of which will be treated separately. Wherefore the whole of this laboratory is governed chiefly by the corpora striata, and at the same time by the optic thalami, even when the cerebrum is almost in a state of rest and when it is asleep. How the cerebellum flows into the laboratory will be stated below.

445*f*. *So that in this base or body of the fornix there is the last boundary of the medullary substance of the cerebrum, and the first* *of the chymical laboratory*—this follows from what has been said above—*and a certain centre of rest,* as appears, when the cerebrum or the corpora striata, and consequently the ventricles themselves, are supposed to undergo the motion of an alternate expansion and constriction. Then the motion extends from the corpora striata above to the corpus callosum, and is concentrated in the body of the fornix; from below also the motion is directed through the "centrum semicirculare" and the tænia semicircularis which separates the corpora striata, to the roots of the fornix; so that whatever motion comes thither from the upper and lower part is concentrated there, and hence there results an equilibrium. On this account also the corpora striata and the optic thalami have there [*i.e.* near the foramen Monroi] a meeting-ground as it were, and join their heads together; in like manner also the choroid plexus of one ventricle is joined there with that of the other. There also is the market or exchange of the ventricular liquid, which under the anterior roots or pillars of the fornix, and under the expanse of the septum lucidum, is passed from one ventricle into the other, for a place of communication is there for all powers.

445*g*. *Since all the tracts, medullary as well as grey, on either side are in a state of expansion and constriction.* By the grey tracts are here meant the corpora striata and the optic thalami throughout their whole length and depth; and consequently the intermediate, superior, and anterior medullary tracts, which are respectively passive, and are acted upon by the grey tracts. Further, we understand thereby the corpus callosum, and the very cerebrum, even from the actual animatory cortex. Consequently we mean thereby all the cavities which are formed and constructed by such a connection of the parts, namely, the lateral ventricles, the ventricle in the middle, the anterior and posterior foramina, the foramen which communicates between the ventricles, the ventricle of the septum lucidum, the infundibulum, etc., all of which in accordance with the degrees and moments of the action of the surrounding bodies are drawn open or constricted. *On this account it may also be styled a* *fulcrum*, and the rest are like levers; or again it may be compared to a pivot or the vertical beam of a pair of scales.

445*h*. *The medullary substance which is determined from the cerebrum and the corpora striata towards this central bolt, and which cistern-like encloses the ventricles, is transferred chiefly into the optic thalami.* Namely, from above the posterior crura of the fornix, which had previously as it were joined their heads near the body of the fornix, stretch themselves out thence over the optic thalami, as far as the posterior and descending cornua of the lateral ventricles, and are called the tænia hippocampi, and also bombyces, etc. The anterior crura also are inserted into the same optic thalami, and are attached to them, . . . so that the above-mentioned thalami are the chiefest body, into which the above medullary substance, after it has been collected, is poured out; with the exception of some small portion which extends over the third ventricle towards the corpora quadrigemina; . . . and with the exception of some other very small roots which embrace the septum lucidum. That posterior expansion of the corpus callosum which was called by the ancients lyra and psalterium is situated, indeed, between the optic thalami, but it communicates in such a manner with the posterior crura or pillars of the fornix, that it is but the same substance connecting the two pillars spread out for this purpose.

445*i*. *From the fibres of this substance, by the alternate expansion and constriction of the above thalami and ventricles, the spirituous essence contained within such a copious mass of fibres is necessarily pressed out.* For it is so projected over the optic thalami that when they expand and constrict themselves, this liquid must be necessarily expressed, as will be further shown in our discussion of the optic thalami, the choroid plexuses, and the lateral ventricles. Thus the above posterior pillars and crura of the fornix are extended in such a manner over the thalami; they press upon their surface, insert themselves into their substance, while continuing their course grow more slender; they spread out in the form of fringes and ribbons, their fibres are carried across them in a circular form; according to Ridley they are pale on the outside, and in their interior they are of a greyish colour, so that whatever liquid they have thus far carried with them, must necessarily be expressed. If, therefore, it is admitted that the fibres are pervious to some juice or spirit, and that at each alternate time in the animation of the cerebrum they are filled up, it follows by a certain necessity that this juice or spirit is discharged where the fibres terminate. That these fibres do not terminate in the optic nerves appears from their attenuation and diminution, as well as from the new accessory fibres which these nerves receive from the lower region of the substance of the cerebrum, and also from the grey substance of the optic thalami themselves, which likewise produces longitudinal fibres. It further appears from this fact, which may be demonstrated, that the fibres which are proper to the cerebrum do not immediately depart into any organic nerves, but are contiguous to, and govern those which depart; also, that the quantity of spirit which is conveyed to the fornix is plentiful to excess, since its fibres are collected from the whole cerebrum, the grey substance of which is most prolific in spirit, and which fibres therefore contain far more spirit, and draw the same from a much larger surface, than can possibly be expended on one single organ. To this may be added the result of the comparative anatomy of the cerebra of birds and fishes, where the fibres which enter the olfactory nerves seem to differ from those of the cerebrum. Now, inasmuch as the juice contained in the fibres, which is poured in anew at each alternate time of the animation of the cerebrum, cannot be discharged anywhere else than where these fibres terminate, and where there is an open cavity, I do not see, if even the eye is unable to perceive the trickling out of this juice, why we should regard what flows from the whole nexus of things as a mere conjecture; especially as it is confirmed by everything which we have yet to say respecting the various members of this same laboratory, among which, when they are taken altogether, there exists a certain continuous nexus of causes. So also it is not apparent to the sight where this spirit is discharged in the muscles, glands, vesicles, testicles, and in other parts; nor how it is poured into the fibres from the blood in the cortical substance; and yet, because the eye does not see this, although reason acknowledges it, shall we therefore for ever remain outside, deprived of the hope of knowledge? This juice or spirit, therefore, seems to be excreted from the very pillars or crura of the fornix which are spread out over the optic thalami; which crura, on account of springing from the higher part of the fornix, also occupy a higher position in the thalami. . . . Finally, some juice is also derived from the anterior pillars of the fornix, which apply themselves to the heads of the aforesaid thalami, and to the choroid plexuses; consequently from those pillars or crura which embrace the septum lucidum; for these are nearest to that forum or meeting-place where all the lymph of the ventricles meets together, and as regards their consistency they are soft and moist.

445j. *This essence is distilled into each lateral ventricle in equal quantities.* Thus a similar pillar and crus is transmitted to each of the ventricles; and in order that the quantity of the moisture may be the same the "geminum centrum semicirculare" meets here from both sides, as well as the tænia semicircularis, and the upper margin of the corpora striata. . . . Besides, a communication is effected by the whole of the stria pinealis, which is between the optic thalami and where the striæ appear rather longitudinal. . . . A similar communication exists between the posterior crura of the fornix by an intervening expanse [the lyra], where fibres run across from one pillar to the other, so that there results thence such a communication that a like portion of spirits must needs be doled out to each ventricle. Nay, the very body of the fornix also seems to be a kind of channel for communication and equalization, by which the spirit may be transmitted from the anterior to the posterior crura, and *vice versa;* so that at either extremity there may be a just and requisite quantity. One ventricle also by a peculiar foramen [foramen Monroi] under the septum lucidum, in the immediate proximity of the base of the fornix, shares its moisture with the other; for if one-half of the encephalon or of the medulla oblongata should act more powerfully than the other, so that one ventricle should derive more from the fibres than the other, the measure is, nevertheless, equalized by means of this intervening passage. *It is distilled under the choroid plexuses,* which will be specially discussed hereafter; so, indeed, that the volatile spirituous essence expressed from the fibres is at once fixed by a viscosity. Such a chymical process is carried on not only in the cerebrum, but also everywhere in the glands, the chiefest of which is this gland of the cerebrum, which transmits here into the blood almost the whole of its spirituous essence. For in the glands a similar process to this takes place; they have a muscular action in the place of the corpora striata which act here; also a cavity consisting of a number of compartments, into which a large quantity of nervous fibres is inserted; they have likewise a reticular plexus of blood-vessels, as in the case of the cerebrum there are the choroid plexuses. The chymical apparatus of the glands of the body is so wonderful that they secrete and mix their menstrua not only once, but again and again, until at length the proper mixture is obtained. What is more wonderful than the organs devoted to generation! where the enclosed spirit frees itself from its bonds, and compounds itself anew into a little ovum which is similar to a small brain, and attracts the moisture in which it may float; and from which it again may easily extricate itself in the uterus and the tubes, and enter the little ovum of the mother, and affix itself there to a little apex, so that each may derive its own from the maternal store, which is done with such a great avidity that the remaining eggs are meanwhile deprived of their own share. But this I merely touch upon in passing.

445*k*. *Wherefore no other road is open into these ventricles than that natural road which leads from the body of the fornix towards the lower cornua of the lateral ventricles.* For no road is open through the upper roofs of the ventricles, which consist of a medullary substance so minutely interlaced in a reticular form that it keeps back all grosser liquids, or prevents their entrance; a delicate membrane also which lines the cavity of the ventricle everywhere co-operating towards the same result. Nor is there a road open in the bottom where the tænia semicircularis or stria terminalis is, which consists of a similar texture of fibres, and is covered with a similar membrane. Nor is there any approach by the stria pinealis, or the peduncles of the pineal gland, which are placed between the optic thalami; for an entrance must first be obtained into the "centrum semicirculare geminum," and thence into the . . . anterior roots or pillars of the fornix. And yet in the same place [*i.e.* before the anterior pillars] there is but a slender intermediate septum, which by the pressure of a grosser liquid urging from without can easily be broken or cleft, as has been shown in some cases of disease, of dropsy and apoplexy, as recorded by Willis. Such a liquid, however, according to the testimony of Ridley, does not enter into a healthy brain. On this subject see also the Chapter on the Septum Lucidum. Nor is there an entrance open through the posterior crura of the fornix, because in order to reach them a liquid will have to enter the medullary border of the corpora striata, or the texture of the roof of the ventricles, which by continuity leads into these crura. Wherefore there is no entrance for any other fluid, except for that which is contained in the fibres, and between the fibres in the fascicles, that is, for the animal spirit, and the nervous juice.

445*l*. *That grosser liquid, however, which often clogs up the anfractuosities, and the medulla of the cerebrum, is derived by its pathways towards the olfactory nerves.* Thus the middle centrum ovale [*i.e.* corona radiata] and the "centrum geminum semicirculare" [inner capsule] meet in a certain expansion before the base of the fornix; and thence the medulla, after it has become united as it were, goes in a straight direction to the olfactory nerves; this seems to be a kind of royal road for the liquid, which cannot pass through this medullary expansion before the base of the fornix. *At the same time, near the lamina cribrosa there is the ultimate boundary of the anfractuosities and of the* *interstices of the medullary substance, as well as of the animatory motion of the cerebrum itself.* That the boundary of the anfractuosities is there appears from this consideration, that they, together with the falx cerebri and the longitudinal sinus, towards which the anfractuosities are directed, run out as it were from that region, or from the crista galli, as from a kind of centre. That in the same place there is the boundary of the interstices of the medullary substance, follows from this, that when the olfactory bulbs are inflated the whole mass of the cerebrum swells, especially in animals. This medullary substance is not unlike a sponge as far as its absorbing quality is concerned, although it is regular in respect to its fibres. Through this substance the liquid passes whither it is led by force; and when a portion of it is evacuated, the neighbouring portion succeeds into its place, especially the pituitous lymph; for such is the nature of every liquid that it presses upon what is contiguous to it. This same place also is the boundary of the animatory motion, because that motion depends upon the anfractuosities; on which account also the olfactory bulbs like filled wine-skins lie upon the dura mater, and its fibres are of a softish nature. On this account the gross liquid which is exterminated from the ventricles congregates there.

[Swedenborg's theory of the fornix will be found fully discussed in the light of modern science in Sub-section C of Note iii., which is entitled "The Chymical Laboratory of the Brain."—EDITOR.]

CHAPTER X.

THE SEPTUM LUCIDUM.

446. Where the corpus callosum from [the beak—*rostrum*—of] its reflected appendage [genu] runs out in an anterior direction, a certain septum is continued in the middle, which consists of an almost medullary lamella covered by a thin membrane, and which is soft, yields easily, and is irrigated by a great number of blood-vessels. It serves as a light partition for the two lateral ventricles from the top downwards, and by Galen was called the diaphragm of the brain. For the purpose of forming it the corpus callosum lets down from the top the middle of its medullary substance, to which it adjoins lateral parts which seem to contract into this expanse. The fornix, however, supplies its roots as a basis, and strengthens its interior and anterior portion; so that this septum which is intermediate between the two, or common to both these organs, from the former derives its existence, and from the latter its consistency. As this septum owes its origin to the roots of the fornix, and to the reflected surface of the corpus callosum, it very often happens that it is cleft in the middle, and thus acts the part of a fissure, into which it admits a lymph; for observers have often noticed in it a distinct lymph. The septum lucidum thus yields obsequiously to both ventricles which it separates from the top, whether the pressure is exerted from one side, or whether each exerts a pressure on the other. Below a passage is opened, leading from one ventricle into the other, which passage, at the sides, and also below, is formed by the fornix. It thus balances evenly from its centre or fulcrum the superfluous liquid of one ventricle by passing it into the other.

447. WILLIS.[1]—"On the middle surface of the fornix there is erected a thin and transparent septum, which almost throughout the whole of its extent is affixed to the corpus callosum" (p. 11).

448. VIEUSSENS.[2]—"After the chamber of the lateral ventricles has been opened, lest any of those parts which are underneath the corpus callosum escape the sight, that body by the use of a sharp instrument must be lightly removed behind from the white substance of the posterior edges of the cerebrum, and also from the body of the fornix. After this is done, if then the corpus callosum is slightly raised, the septum lucidum which is appended to its internal and anterior surface, and which reaches only as far as the anterior part of the fornix, comes into sight. On account of its great thinness it is necessarily torn when the corpus callosum is folded back towards the front. The septum lucidum, however, is a white, thin, soft, and transparent body, covered with a most delicate membrane. I am of the opinion that it is a production from the substance of the chamber of the lateral ventricles. . . . This septum is appended to the corpus callosum in its anterior portion, and is situated above the anterior part of the fornix only, with which it is also united; and although it is very thin, in its anterior portion a little above the double root of the fornix, there is contained a little cavity in which I have not unfrequently found pellucid water, which without doubt lapses into the third ventricle. . . . It is irrigated by little arteries sent out from the carotids, and by little veins which terminate in the straight sinus" (p. 59). In plate vi. of this author may be seen the lateral parts of the septum shrunk up, and drawn apart, and folded back anteriorly, with the corpus callosum in an inverted position.

449. RIDLEY.[3]—"Some of the moderns think that the septum lucidum arises from the fornix, and that it ascends thence to the internal surface of the corpus callosum. Others think that it arises by descending from the corpus callosum to the fornix;

[1] "Cerebri Anatome," etc., cap. i.

[2] "Neurographia," etc., cap. xi.

[3] "Anatomy of the Brain," etc., chap. xiii.

but most likely it derives its origin from the latter, where in its front part I have always found it double, as was first noticed by Sylvius de la Boe, and as Vieussens truly says, it often has water in its duplicature. It is a very thin, medullary, transparent body intermediate between the corpus callosum and the subjacent fornix, by means whereof the two lateral ventricles are in that part separated from each other" (pp. 119, 120).

450. WINSLOW.[1]—"The septum lucidum lies directly under the corpus callosum, of which it is a continuation, and a kind of duplicature. It is made up of two medullary laminæ, more or less separated from each other by a narrow vertical cavity, sometimes filled with a serous substance. This cavity in some subjects reaches a great way backwards; and I am apt to think, communicates with the third ventricle" (section x. no. 69). "By injection there is discovered an extremely thin membrane on the interior walls of the duplicature of the septum; though in some subjects these walls are contiguous" (*ibid.*, no. 90). "This septum adheres to the anterior double pillar or root of the fornix; but it has no total adhesion below, and therefore the two lateral ventricles communicate with each other" (*ibid.*, no. 70).

451. LANCISI.[2]—"The septum lucidum is nothing else than an internal production of the corpus callosum and of the fornix, situated likewise in the middle of the medullary portion of the cerebrum. It is a vertical production downward from a superior segment of the corpus callosum, and like a fence separates and disjoins the cavities of the lateral ventricles from each other" (p. 304).

452. MORGAGNI.[3]—"The septum lucidum arises from fibrils which come out of the anterior part of the cerebrum. Colombo maintains that it is membranous; but it evidently consists of

[1] "An Anatomical Exposition," etc., section x.

[2] *Opera*, etc., Lugd. Batav. 1718, Dissertatio vii., De Sede cogitantis Animæ.

[3] I am unable to verify this passage; although it seems probable that in some edition of Morgagni's works to which I had no access this passage occurs in "Adversaria vi., Animadversio x.," to which a reference concerning the septum lucidum is made in the index.—EDITOR.

straight fibres, drawn lengthways in an antero-posterior direction; as is also the case with the hippocampi of Aurantius."

[Modern Authors.

452*a*. Reil.[1]—"In the centre line of the *genu* [of the corpus callosum] the septum lucidum is stretched out laterally, and seems to be a duplicature of epithelium, and to bear an analogy to the mediastinum in the thorax; but in its middle it leaves open a cavity, the ventriculum septi. In front this ventricle has two short horns which to the right and to the left are produced in the *genu* of the corpus callosum; but in a posterior direction the ventricle terminates in a long pencil-like point, which goes backwards over the body of the fornix as far as the *lyra*" (p. 177).

452*b*. Todd.[2]—"The anterior cornua of the lateral ventricles are separated from each other by a vertical septum situated on the median plane, very thin and transparent, the *septum lucidum*. . . . The septum is of a triangular form with curvilinear base, which is directed forwards, and fits into the anterior reflection of the corpus callosum. Posteriorly it fits in between the corpus callosum and the anterior extremity of the horizontal portion of the fornix. The septum lucidum, although so extremely delicate and transparent, is very obviously composed of two layers, enclosing a space or cavity called the *fifth ventricle*. . . . Each of these laminæ consists of four layers, as may be easily observed by examining the margin of the section: the outer one is derived from the lining membrane of the ventricles; immediately within this is a layer of a pale greyish matter continuous with a similar layer which covers the optic thalami and the internal surface of the third ventricle, consisting of clear nucleus-like particles homogeneous in texture; a third layer is composed of white or fibrous matter; and a fourth consists of an extremely

[1] Reil (J. C.), *Das Balkensystem oder die Balkenorganisation des Gehirnes*, in "Archiv der Physiologie," vol. ix., Halle, 1809.

[2] Todd (R. B.), M.D., F.R.S., "The Descriptive and Physiological Anatomy of the Brain," etc., London, 1845.

delicate membrane, probably covered by ciliated epithelium, which lines the internal surface of the fifth ventricle. This ventricle is closed at every point, and has therefore no communication with the lateral or other ventricles. . . . In a few rare cases fluid has been known to accumulate in this cavity. In the fifth month of uterine life, according to Tiedemann, this ventricle communicates with the third through a small space, situate between the anterior pillars of the fornix and above the anterior commissure" (pp. 147, 148).

452*c*. QUAIN.[1]—"In the human embryo, and also in some animals, the cavity of this ventricle communicates with that of the third ventricle in front and below; but in the adult human brain it forms a separate and insulated cavity. Tarin described a small fissure in it between the pillars of the fornix; but this is unusual. In disease it is sometimes distended with fluid" (ii. p. 543).]

[1] "Elements of Anatomy," eighth edition, London, 1876.

ANALYSIS.

453. There is nothing in the brain which does not conspire and transpire; and nothing which is not a distinct entity in itself, and yet continuous with the whole. Such is the case with the septum lucidum. It is able to conspire; for it is continued from the edges of the corpus callosum; also from the anterior edges of the corpora striata; likewise from the vaults of the ventricles. Underneath also it is a little connected with the "geminum centrum semicirculare," and at the sides with the fornix, and its body; with this it is also united by its roots, or anterior pillars. Finally it is connected with the thalami optici by twigs of the choroid plexus, which continues its course under its margin, and winds itself inwards. The septum lucidum therefore conspires with its circumjacent parts, and thereby with the remote parts of the whole cerebrum and the medulla oblongata. It transpires also not only in its individual fibres and interstices—for it is thin and soft—but also in itself, because it is hollow, and cleft.

454. It is intermediate between the cortical pole of the cerebrum and the medullary centre. The cortical pole of the cerebrum is the starting-place of the sinuses and of the process of the falx, and also of the convolutions and gyres of the cerebrum. Its [medullary] centre, however, is the body of the fornix. The septum lucidum is in the direction from the one towards the other; although it does not touch the pole, it nevertheless has relation to it in its diameter. It also occupies the first place in the longitudinal axis; for this is continued from the septum lucidum through the third ventricle, the aqueduct of Sylvius, the fourth ventricle, the calamus scriptorius, and thus into the spinal marrow, by a cavity which, however, is interrupted by

septa and as it were by little doors. The station of the septum lucidum is therefore tranquil; for as many points as there are of the axis, so many centres are there of motion. And therefore this septum is a delicate and transparent membrane.

455. It occupies also a sort of middle place between the very first beginnings of the medulla oblongata, that is, between the heads of the corpora striata, which at this place mutually incline towards one another. By these it is drawn a little into opposite directions, and again is pressed closely together; and indeed at alternate times. By this concourse of motions its hollow duplicature, its minute ventricle, is filled with juice, and again emptied; the same also is the case with the choroid plexuses which are attached to its membrane, and with the fimbriated roots of the fornix which embrace its walls.

456. This juice is expressed into the little foramen by which it communicates with the ventricles. The same is the case with the purified serum of the plexus, and the spirituous essence of the roots of the fornix. There results hence a well-tempered and mingled lymph, from which the third ventricle derives a share. For as often as the corpora striata are expanded, and their heads strike against one another, the septum lucidum is compressed and lengthened out, and the lymph is expelled; but as often as these bodies subside, and are constricted, the receptacle is expanded and lymph is supplied to it. With the shoots of the plexus and the roots of the fornix the case is the same; but the body itself of the fornix, whence the roots spring forth, is quiescent. The septum lucidum contributes thus the first offering or essence whereby the organs of the laboratory are provided.

CHAPTER XI.

THE LATERAL VENTRICLES AND THE FORAMINA WHEREBY THEY INTERCOMMUNICATE.

457. THE lateral ventricles, which are also called the anterior, the major, the first and second ventricles, and likewise caverns, cavities, and cisterns, are laid open when the brain with a sharp large dissecting-knife is cut through horizontally in a level plane in an antero-posterior direction; or, likewise, when its hemispheres are drawn apart from the top down to the corpus callosum, and the fornix underneath and the substances are then taken out from the [inner] side. When this is done, two caves or hollow recesses are exposed, which in a collapsed dead subject are not very deep, and in a natural brain are even narrow. They lie at a greater distance from the upper surface of the brain than from its anterior surface; and are lined with a polished, thin and soft membrane, of the colour of an onion or garlic, but which in some cases is quite grey. By the corpus callosum, under which the septum lucidum is continued in an anterior direction, and by the fornix, the two ventricles are separated. Their bottom and also the greater part of their sides is occupied by the corpora striata, or by the two topmost beginnings of the medulla oblongata; and also by the crura or the posterior beginnings of the same medulla, or what is the same thing, by the optic thalami with their small greyish nuclei. These thalami extend like wings or arms through the whole length of the ventricles on either side. Where the two swelling bodies just mentioned are depressed gently, frequent little streams of blood flow through the branches and villi which are scattered over the surface of the upper bodies. The medullary

partition which separates the two ventricles offers a passage to some foramina. Two of these on either side lead into the third ventricle, and thence convey their juice into the infundibulum; and by a third one the above partition is entirely pierced, and through it the lymph of one ventricle communicates and mingles with the lymph of the other. By removing the partition and the ceiling of the third ventricle one large cavity is made of the three ventricles. The figure of each of the two lateral ventricles, in accordance with the bow-shaped form of the expanses of the corpus callosum, is curved from above into a semilunar vault, and thence in accordance with the depression of the prominent back of the corpora striata, it gradually pursues its way backwards in an oblique downward direction. There in the curved form of horns the lateral ventricles excavate narrow and sharp sinuses [the posterior cornua], called by Aurantius "ventriculi bombycini" or those of the hippocampus. Thence the ventricles are reflected under the posterior expanse of the corpus callosum in the direction of its upper portion, which they join again near the body of the fornix. In this wise they form on both sides a cavern, the walls and bottom of which are inclined from a higher to a lower level, and thence up again towards the higher level in the direction of the two foramina leading into the third ventricle. They thus present the appearance of a perpetual gyre ever returning into itself; and in agreement with the form, and the motion harmonizing with the form, whatever the less distended lips of the aforesaid foramina, and thus whatever the third ventricle cannot absorb from the surging lymph, the cavities of the so-called [posterior and descending] cornua receive in themselves; and what they thus receive at each alternate time of the gyratory motion, they send back again; so that the very last drop of what they drink is again regurgitated. The genuine form of the ventricles may be seen in Ridley's plate v., where, if you follow the white zone which encompasses the corpora striata, you will see that in their descent they are a little winding. Consult also Willis's plate viii. and Vieussens' plate vi. In his plate vii. the ventricles are more deeply excavated, and in plate viii. they are expanded below; in plates xi., xii., xiii., however, they appear too much distended laterally, and thus deformed.

458. There are two foramina which from [each of] the lateral ventricles lead into the third ventricle. One is almost under the "nates"—the anterior tubercles of the corpora quadrigemina—and under the pineal gland, and the other near the fornix; the former by the ancients is called "anus," and the latter "vulva." They open immediately into the [third] ventricle and likewise into the aqueduct. They are raised up and down, and are opened more or less widely, just as the corpora striata and the optic thalami contort the ventricles and their medullary walls. The actual orifices of the foramen "anus" are encircled by fibres sent out from the medullary tract which is inserted between the thalami [the stria pinealis], and they are obliterated when the thalami are forcibly drawn apart. Its edges, according to Vieussens, terminate in the uppermost coast of the third ventricle.

459. Willis.[1]—"While the three-sided fornix extends at the bottom of the chamber or cavity which has been prepared by a complication of the cerebrum, the septum distinguishes the conspicuous cavity into three compartments as it were, and thus causes three ventricles to be represented in it" (p. 11). "In dropsical subjects these cavities or ventricles are always seen filled with water" (p. 76). "In reality, the transit of humours in the living animal body is not effected simply through ducts and open canals; but a watery and attenuated liquid makes its way through the solid and compact bodies of the nerves as through bits of sieve, and also through fibres and membranes, so that it is transferred from place to place through imperceptible narrows or straits" (p. 77). "What then should prevent a liquid from trickling down through fibres fastened to the holes of a cribriform or sieve-like bone? For although these parts seem impervious in deceased subjects, nevertheless as long as they are in the vigour of animal life, the passages of the nervous

[1] "Cerebri Anatome," etc., cap. i. and xi.

bodies and the blind ducts, so long as they are dilated by spirit and animal heat, transmit without any difficulty the copious humour, with which they are irrigated. . . . Not long ago a young woman was afflicted with a terrible headache, and daily amid excruciating pains much yellow serum was discharged through her nose. Last winter this secretion stopped for some time, when at last she became ill, and her head becoming worse she was seized with frightful convulsions and stupor; within three days she died of apoplexy. On opening her head it was found that this same kind of yellow serosity flooded the deeper convolutions of the cerebrum, as well as its interior cavity, or the ventricles" (p. 80).

460. VIEUSSENS.[1]—"Several sanguiferous ducts irrigate the lateral ventricles, the cavity of which presents a semilunar rather than any other form. Their size cannot be defined, since they appear sometimes larger, sometimes smaller; just as the bounds of the brain itself are sometimes of a larger, and sometimes of a lesser extent. Their surface, besides, is lined with a polished and soft membrane, which is thinner than the skin of an onion; and their colour is partly white, and partly cineritious. Thus the interior part of the chamber and of the lateral portions, which first strikes the eye, is white; of that colour also appear the crura of the medulla oblongata (thalami optici), so long as they are not exposed to the air; but when they are exposed to it, they assume a whitish-grey colour; and when they are dried or boiled, they become of an altogether cineritious colour. The anterior processes of the medulla oblongata [corpora striata], however, are of a cineritious colour" (p. 62). "The figure of the lateral ventricles is somewhat oval. Almost the whole vault of these ventricles is formed by the corpus callosum. Its walls, however, are constructed of medullary fibrils which emerge out of the grey substance of both hemispheres of the cerebrum. The upper of these fibrils, that is, those which originate in the convex part of the hemispheres, incline on both sides first outwards, and afterwards, together with some other

[1] "Neurographia," etc., cap. xi.

lower medullary fibrils with which they coalesce, they are inflected inwards, and embrace proximately, throughout their extent, the anterior processes of the medulla oblongata, and its crura; so, indeed, that by the coalition of these medullary fibrils, and by their being inflected as it were upon themselves, in the middle region of the cerebrum two caverns as it were are formed, which are separated from each other by the intervention of the septum lucidum and the fornix. It is sufficiently plain that all the medullary fibres of the above viscus (with the exception of those which terminate in the tænia semicircularis) where they emerge out of the cortex, run from these ventricles around the anterior processes of the medulla oblongata, and around its crura, and in a measure become one with them (where, indeed, they pass off into the above ventricles); so that they terminate in one spongy body as it were, which occupies the oval compass of the above ventricles. On this account we have called it the 'centrum ovale;' although towards the back it is bent inwards, so as to touch the posterior part of the corpus callosum, and to be united with it, and hence it does not quite present an oval shape" (p. 58).

"The 'vulva' is nothing else than a foramen near the anterior region of the lateral ventricles, which is hidden under the fornix, and hollowed out near its roots; by its means the lateral ventricles communicate with the third ventricle. The 'anus,' however, is another foramen which is hidden under the hinder part of the fornix, and is hollowed out near the 'nates,' or the anterior tubercles of the corpora quadrigemina; by means of this the lateral ventricles communicate in like manner with the third ventricle. These foramina, however, the names of which seem to have been taken either from their shape or their position, are entirely obliterated when one of the optic thalami is disjointed from the other; and their margins terminate in the highest strand of the open third ventricle" (p. 64).

461. RIDLEY.[1]—"By cutting asunder the fornix near its roots, and turning it backwards over the corpora quadri-

[1] "Anatomy of the Brain," etc., chap. xiii.

gemina and the pineal gland, the three ventricles appear to be but one; those on each side being called the lateral ventricles, which hold the corpora striata, the thalami optici, and crura medullæ oblongatæ; the cleft, however, so far as it is covered with the fornix, and divides the crura medullæ oblongatæ, is the third ventricle" (p. 117). "Within this cavity of the brain there are also two passages into the infundibulum, and thus into the pituitary gland; of which the one nearest the front is called by the odd name 'vulva,' and the one more in the back part the 'anus,' from their situation, and which together with the rima or cleft between them are called the third ventricle. The places from which all the water of the cerebrum gradually issues, by the more modern anatomists are described under the name of the 'tria foramina,' situated so as to give passage from all the eminent regions of the brain, from whence access can be had to them for the water (or rather lymph, properly so called) to fall into the aforesaid infundibulum. The first of these is near the 'testes,' under the pineal gland, or at the beginning of the rima, where two [foramina] meet in a certain aperture under the corpora quadrigemina [the aqueduct of Sylvius], by Vieussens called 'aquæ emissarium;' and the last is at the end of the rima, or just under the roots of the fornix; and all end at length in the infundibulum—though by two different passages" (pp. 124, 125).

462. WINSLOW.[1]—"Under the corpus callosum are two lateral cavities, much longer than they are deep, and very shallow, separated by the septum lucidum. These cavities are generally named the anterior and also the superior ventricles of the cerebrum, to distinguish them from two other smaller ones; but the name of lateral or great ventricles, given them by Steno, is more proper. The lateral ventricles are broad, and rounded at those extremities which lie next to the septum lucidum. They proceed from before backward, contracting in breadth, and separating from each other gradually in their progress. Afterwards they bend downward, and return obliquely

[1] "An Anatomical Exposition," etc., section x.

from behind forward in a course like the turning of a ram's horn, and terminate almost under their superior extremities, only a little more backward and outward. At the place where they begin to bend in order to run downward and then backward, there is on each side a particular elongation which runs from before backward, and terminates in a triangular-pointed cavity turned a little inward, the two points resembling horns [the posterior cornua]. These ventricles are everywhere lined with a thin membrane" (section x. nos. 65-67). "Where the convex parts of the two anterior corpora quadrigemina join the convexity of the thalami optici, an interstice is left between these four convexities which communicates with the third ventricle. Instead of the ridiculous name of 'anus' which has been given to this opening, it may be called 'foramen commune posterius,' to distinguish it from another, the 'vulva,' to which we give the name 'foramen commune anterius'" (*ibid.*, no. 81).

463. MORGAGNI.[1]—"I have been accustomed to dissect the cerebrum chiefly in its own seat, because I noticed, that by the very weight of the deposited brain, and by a subsidence of the same, many of its parts are disturbed out of that position which they naturally occupy; which applies particularly to the thalami optici, and the corpora striata. These protuberances, indeed, as long as the brain is kept within the walls of the cranium, do not exhibit that form which is presented in most plates, which have been drawn mostly from the brain after it had been torn out of its seat; or in other words, they do not constitute the basis of the lateral ventricles, but also in a great measure their sides. Wherefore these very same ventricles in reality are very much narrower than they appear in the deposited brain, and if there is any superfluous humour contained in them, by their greater declivity it flows on either side through their sides and their base down into the third ventricle" (p. 13).

[1] *Opera*, etc., Leyden, 1740, Adversaria vi., Animadversio x.

[MODERN AUTHORS.

463*a*. QUAIN.[1]—"*Lateral ventricles*, or *ventriculi tricornes*.—These ventricles form part of the general ventricular space within the cerebrum; they are serous cavities, and are lined by a delicate epitheliated structure, the *ependyma ventriculorum*, which, at certain parts in the adult, and probably throughout its whole extent in the fœtus, is provided with cilia. In the natural state the walls of the ventricles are moistened internally with a serous fluid, which sometimes exists in considerable quantity even in a healthy brain. . . . From the central part or body of each lateral ventricle the cavity is extended forwards, backwards, and downwards, thus forming an anterior, a posterior, and a middle or descending cornu.

"The *body* of each lateral ventricle is roofed by the corpus callosum, and is separated from its fellow by a vertical partition, the *septum lucidum*, which descends from the corpus callosum to the fornix. In the floor of the ventricle there is seen behind one half of the *fornix*, which is a thin layer of white brain-substance, broad behind and narrow in front; external and anterior to this is the *choroid plexus of the lateral ventricle*, a red vascular fringe, forming the border of the *velum interpositum*, a fold of pia mater extending inwards, on which the fornix rests: external and anterior to the choroid plexus is the anterior and outward part of the *optic thalamus*, appearing from beneath it; outside and in front of the thalamus is the *corpus striatum;* and between these two bodies is a narrow flat band, the *tænia semi-circularis*.

"The *anterior cornu* is the blind anterior extremity of the ventricle, projecting a little way into the white substance of the frontal lobe. It is covered by the corpus callosum, and turns forwards and outwards round the anterior free extremity of the corpus striatum, descending as it proceeds, and bounded behind by that body, and in front by the reflected part of the corpus callosum.

[1] "Elements of Anatomy," eighth edition, London, 1876.

"The *middle* or *descending cornu* turns round the back part of the optic thalamus, which appears in its cavity and forms its anterior boundary, while its remaining boundaries are formed by the hemisphere. At its commencement it is directed backwards and outwards; then, passing downwards with a sweep, it curves forwards, and at its extremity has a marked inclination inwards. The principal object seen upon the floor of the cornu is the *hippocampus major* (pes hippocampi or cornu Ammonis), a large white eminence extending the whole length of the cornu. The hippocampus major becomes enlarged towards its anterior and lower extremity, and is indented or notched on its edge, so as to present some resemblance to the paw of an animal, whence it has been called the pes hippocampi. The white fibres of its surface form only a thin layer, and beneath them is cineritious matter continuous with that of the surface of the hemisphere. Along the inner edge of this eminence is seen a narrow white band, named *corpus fimbriatum* or *tænia hippocampi*, which is prolonged from the fornix; to the inner side of the tænia is a part of the choroid plexus, and next to that the back of the optic thalamus. This cornu differs from the others in this respect that it is not a mere cul-de-sac, but, by the separation of the membranes, can be made to communicate in its whole length with the surface of the brain by the fissure through which the choroid plexus enters.

"The *posterior cornu* projects backwards into the substance of the posterior lobe. At its extremity it is pointed, and directed inwards. On its inner side is a curved and pointed longitudinal eminence, named *hippocampus minor*, or *calcar avis;* and at the junction of the posterior with the descending cornu, between the hippocampus major and minor, is a smooth eminence, named *eminentia collateralis*, or *pes accessorius*, which may extend some way down the descending cornu behind the great hippocampus" (ii. pp. 539-542).

463*b*. "*Foramen of Monro.*—Immediately behind the anterior pillars is an interval on each side between the anterior part of the fornix and the groove where the optic thalamus and corpus striatum meet. This interval leads from the lateral ventricle to the third ventricle. The openings of opposite sides, passing downwards and backwards, meet in the middle line below, and thus is produced a passage, single below, but dividing into two branches above, somewhat like the letter Y, and forming a communication between the third ventricle and both lateral ventricles" (ii. p. 544).

463*c*. MONRO.[1]—"*Of the Communication of the Ventricles of the Encephalon with each other.*[2]—After laying open one of the lateral ventricles of the brain in the usual way, leaving the septum between the ventricles entire, let the gutter which is between the corpora striata and the thalami nervorum opticorum, the bottom of which is occupied by the substance called 'centrum semicirculare geminum,' be traced inwards, and it will be found to lead to the forepart of an oval hole, large enough to admit a goose-quill, under the forepart of the fornix. From this hole a probe can be readily passed into the other lateral ventricle, showing in the first place that the two lateral ventricles communicate with each other. When the fornix is next divided transversely, we find that this passage has the anterior crura of the fornix at its forepart, and the joining or middle part of the choroid plexuses of the lateral ventricles at its back part, and that its middle part is over a passage downwards named the 'iter ad infundibulum' or 'vulva,' which should rather be called 'iter ad tertium ventriculum.'

"When we afterwards carefully raise, and turn backwards the body of the fornix, we find that the choroid plexuses of the lateral ventricles are connected together by a broad vascular membrane which adheres closely to the fornix about it, and to the thalami nervorum opticorum below it. Hence, too, this membrane covers and shuts the hole called 'anus,' and prevents the lateral ventricles from communicating with each other, or with the third ventricle, at any place but that before described.

[1] Monro (A.), "Observations on the Structure and Functions of the Nervous System," Edinburgh, 1783, folio.

[2] On this subject see "Note iii., subdivision D," in the Appendix.—EDITOR.

In this membrane two large veins may be observed, which further back unite to form a vein known to Galen and named after him. Two small veins on each side of the brain, one from the septum lucidum, the other from the corpus striatum, run upon the upper and posterior edges of the hole by which the lateral ventricles communicate, and terminate in the veins [leading to the vena Galeni].

"Under this vascular membrane, the extent of which, and the degree of its adhesion to the fornix and thalami nervorum opticorum, have not been sufficiently attended to, I find that the thalami, even in children, are inseparably united by medullary matter. Under the accretion of the thalami, and between them and the subjacent crura cerebri, the middle part of the third ventricle is situated. From the third ventricle a passage, universally well known, leads to the fourth ventricle, or calamus scriptorius, which is placed between the tuber annulare [pons Varolii], with the medulla oblongata on the forepart, and the cerebellum, with the valvula Vieussenii and nates and testes [corpora quadrigemina] behind; so that this ventricle ought to be considered as a ventricle of the cerebellum, rather than of the brain [cerebrum].

"The bottom of the fourth ventricle has *no such communication* with the cavity of the spinal marrow, as Dr. Haller supposed [foramen Magendii!!], being completely shut by its choroid plexus and pia mater" (chap. iv. section i. p. 12, etc.)

463*d*. BURDACH.[1]—"Galen already knew the foramen of Monro; for in order to raise up the fornix, he suggests that the operator should introduce the handle of a scalpel into the apertures, whereby the vessels enter into the lateral ventricles, because here the lateral ventricles communicate with the third (Anat. administr., lib. ix. c. 4, p. 105).

"Berengarius[2] (fol. 436) also declares that the lateral ventricles communicate by an opening in front, near their

[1] Burdach (C. F.), "Vom Baue und Leben des Gehirnes," Leipzig, 1822.
[2] Berengarius (Jacobus), "Commentaria," etc., Bologna, 1521.

base, and close to the infundibulum, where both are connected, and where the third ventricle commences.

"Vieussens[1] described the foramen of Monro under the name 'vulva,' as an aperture near the anterior pillars of the fornix, whereby the lateral ventricles communicate with the third (c. xi. p. 64).

"According to Rudolphi[2] (Abhandlungen, p. 150), Marchettis[3] also was acquainted with this foramen.

"Nevertheless, on the whole, the foramen Monroi remained unnoticed, so that, for instance, Haller (Elementa, iv. p. 55) maintained that in a healthy condition of the body the third ventricle was not connected with the lateral ventricles, but was closed up by the velum interpositum.

"Monro, therefore, rendered a service to science by carefully examining this foramen, and illustrating his description by drawings. According to him this foramen is bounded anteriorly by the anterior pillars, and behind by the velum interpositum. It is continued below in the 'iter ad infundibulum,' and connects laterally the anterior ventricles.

"Vicq d'Azyr[4] really described this aperture before Monro, namely, in 1781. For through this foramen he blew air from the third into the lateral ventricles; but not so well *vice versa*, because in the latter case the fornix was not raised up by the air (vi. p. 237).

"It seems strange that Gall (Système, i. p. 296) should not have found this foramen.

"Some by the 'aditus ad infundibulum' seem to have understood the foramen of Monro, and others the anterior, lower part of the third ventricle. Either of these two openings was the

[1] "Neurographia," etc.

[2] Rudolphi (Carl Asmund), "Anatomisch-Physiologische Abhandlungen," Berlin, 1802.

[3] Marchettis (Dominicus de), "Compendium Anatomicum," Padua, 1652. In describing the contents of this volume, Haller ("Bibliotheca Anatomica," vol. i. p. 446) says, "According to him the lateral ventricles open into the third."—Editor.

[4] Vicq d'Azyr (Felix), "Œuvres," Paris, 1805. The above statement he made in the "Mémoires" of the Academy for 1781.—Editor.

'vulva' spoken of by Casserio [1627], Vesling [1641], Marchettis [1652], Molinetti (p. 81). According to Sömmering[1] the 'vulva' is a continuation of the third ventricle between the anterior pillars (p. 109). . . . Vieussens calls the approach to the infundibulum 'hiatus ad infundibulum;' Winslow styles it 'orificium commune anticum.' Lieutaud calls it 'foramen profundum;' Haller (Elementa, iv. p. 57), 'ostium anterius ventriculi tertii;' Malacarne (Encefalatomia, ii. p. 60), 'apertura anterior ventriculi tertii.' In Monro's 'Observations,' etc. (p. 12), it figures as 'iter ad infundibulum,' or more correctly, according to him, as 'iter ad ventriculum tertium'" (ii. Anmerkung 218, p. 379, etc.).

463*e*. MIERZEJEWSKY.[2]—"The ventricles of the brain and their ependyma which years ago had been most carefully observed, in modern times, when the whole doctrine of the brain has experienced most sweeping changes, have not been treated with that attention which their significance in many pathological cases seems to demand. On this account I undertook, under the direction of Dr. Merkel, a thorough histological and topographical examination of their parietes, as well as of the communications which exist between them, and likewise between them and the neighbouring parts.

"*The Ependyma.*—Respecting the histological place of the ependyma, the results obtained show that it consists of epithelial cells, which rest on a layer of reticular connective tissue with a granulated substance. This layer is succeeded by the medullary portion of the brain. The epithelial cells are a direct continuation, both in form and position, of the cells of the central canal of the spinal cord; even as its substantia gelatinosa centralis is nothing else than a reticular connective substance. According to their situation, even in very young animals, the epithelial cells are of a diverse form. They either represent hollow cylinders, or exhibit

[1] Sömmering (Sam. Thom. v.), "De basi encephali et originibus nervorum e cranio egredientium," libri v., Göttingen, 1778.

[2] Mierzejewsky (Dr. J.), "Die Ventrikel des Gehirns," at the Anatomical Institute in Göttingen. In "Centralblatt für die medicinischen Wissenschaften," tenth year, September 28, 1872, Berlin.

the form of pavement-epithelium (*i.e.* they are scaly or tesselated). Through intermediate stages these forms gradually pass over into one another. Towards the higher or upper parts of the ventricles the cylindrical or columnar cells are always ciliated. In the direction of the substance of the brain they are furnished with many productions which like roots penetrate the inferior layers. The epithelium is met with everywhere, in man, in the ox, the calf, the dog, the cat, the sheep—in all uninjured preparations, be they fresh, or hardened in alcohol, chromic acid, or Müller's fluid. If these cells are isolated in osmic acid, which can be very easily done, it appears that their interior productions have the considerable length of 0·063 m. A connection between them and the cells of the reticular connective tissue could never be observed, even when the process of isolation was carried on most delicately.

"In respect to the topographical division of the cells of the ependyma, in the central canal of the spinal cord the cells of the anterior central wall are more than twice as high, and they are furnished with longer productions, than those of the posterior dorsal side. There is a continuous transition of one species of cells into the other. The arrangement of the cells in the ventricles of the brain is exactly the same; for, as mentioned above, these cells are a direct continuation of the epithelial layer of the central canal.

"In the fourth ventricle the cells of the roof have become so low that they represent a genuine pavement-epithelium. In the infundibulum, following the analogy of the cells in general, those of its posterior wall are higher than those of its anterior wall. The only exception apparently is furnished by the corpus callosum, where the surface which is turned towards the ventricle is covered with high columnar cells. This exception, however, is easily explained by the fact of the corpus callosum being a part of the floor reflected upwards. In those places where there is a passage from the ventricles into the sub-arachnoidal space, the columnar epithelium loses its cilia, and is gradually changed into the scaly or tesselated epithelium of that space." [1]

463*f.* "*Channels of Communication.*—In order to find out in which way the ventricles of the brain communicate with one another and with the neighbouring parts, injections were made with coloured liquids and congealing substances. The brain was injected either *in situ* through an olfactory bulb which had been laid bare; or else, after having been removed uninjured, it was injected from various places. *The place where the ventricles communicate was found to be in the neighbourhood of the pineal gland* [and thus, in the meeting-place of the posterior foramen of either side, called *anus*, as pointed out by Swedenborg and others.—EDITOR]. From this point the fluid passes out of the injected lateral ventricle into the three other ventricles. Only after the injection has been continued for some time, and when a stronger pressure is exerted, that communication between the lateral and third ventricles which is above the optic thalamus [*i.e.* the foramen Monroi, which has been called 'vulva' by the ancients] is utilized. Out of the fourth ventricle the coloured mass flows into the central canal of the spinal cord, and fills it throughout its whole length.

"The coloured injecting fluid, moreover, also leaves the system of ventricles, in order to pass into the sub-arachnoidal space. It escapes in definite and identical places. The coloured mass is always discovered first in the base of the cerebrum, whither it makes its way through the descending cornu of the lateral ventricle, and over the hippocampus major. The

[1] Luschka in his paper entitled "Ueber die Structur der die Hirnhöhlen auskleidenden Membran" (On the Structure of the Membrane investing the Ventricles of the Brain), says in respect to the layer of connective tissue on which the epithelium of the ventricles rests, that "it is a framework of various forms of connective tissue, which is at the same time the bearer of delicate blood-vessels. It is composed (*a*) of structureless lamellæ which in many places lie close to the epithelium; . . . (*b*) of filaments (Fasern)." In conclusion he says, "Should we be called upon to characterize more particularly the quality of the ependyma, we would have to define it as a modified continuation of the pia mater" (Amtlicher Bericht über die Versammlung deutscher Naturforscher und Aerzte, Göttingen, 1860).

fissure through which the communication is effected extends from the corpora quadrigemina to the gyrus uncinatus. From the base the liquid ascends and spreads over the hemispheres; their hinder portion only being supplied, together with the anterior portion of the cerebellum, from a large reservoir on the corpora quadrigemina, which, as mentioned above, communicates with the descending cornu of the lateral ventricles.

"The fourth ventricle has three constant apertures through which a discharge is effected. Two of these apertures are symmetrical, and are situated in the form of closed passages between the hinder portion of the pedunculus cerebelli and the luxuriant villi of the choroid plexuses. These passages wind around the caudex of the cerebellum, as far as the flocculus (or sub-peduncular lobe), whence the injected fluid ascends to the top of the cerebellum, and especially advances towards the anterior surface of the medulla oblongata. The third single aperture (foramen Magendii) is situated above the calamus scriptorius; and thence the injected liquid ascends on the posterior surface of the cerebellum, and in a descending course fills the whole sub-arachnoidal space of the spinal cord."

463*g*. Key and Retzius.[1]—"The dispositions which we are about to set forth, we have first observed in transverse sections of frozen brains, which in their frozen condition were placed in Müller's fluid and in alcohol. Afterwards we succeeded in corroborating our results by observations made with brains, the interior parts of which were well hardened in alcohol" (p. 104).

"In such preparations it becomes apparent that the lateral plexus is not simply furnished with projections which are thrown out in all directions; and further, that it is not suspended freely from the edge of the fimbria in the ventricle; but that in reality it consists of two leaves, an upper and a lower one. Either close by, or at a very short distance from, the fimbria, the two leaves are joined into one common, very narrow leaf or ribbon which is attached to the edge proper of the fimbria. The two leaves in the arrangement of their walls bear some similarity to a boat

[1] "Studien," etc., vol. i., Stockholm, 1875.

lying on its side, the keel of which represents the common edge by which the leaves are fastened to the border of the fimbria. Or perhaps the relation is still better represented thus, that from the thin, sharpened edge of the fimbria there runs out as it were an immediate continuation of the same, namely, a thin, narrow outgrowth, which we may call the root (or keel) of the plexus. This root very soon, sometimes close to its origin, is cleft into two very thin leaves, which bend asunder describing the form of an arc. The *upper leaf* turns upwards towards the roof of the ventricle, following the same as far as the lateral edge of the ventricle itself. There it ends in an edge which is mostly free. In this position it is held by blood-vessels which here and there pass into it from the roof of the ventricle. These blood-vessels are lined with the ependyma, whereby the roof as a whole is covered. This upper leaf, therefore, is comparatively free. Both its surfaces are covered with epithelium, which is a continuation of the epithelium lining the ependyma; and from both these surfaces, on either side, choroid projections or villi are shooting out. In the edge of this leaf is the vena choroidea which runs along in loops. With the velum interpositum this upper leaf has no connection whatever."

463*h*. "The *lower leaf* occupies a different relation altogether to the velum interpositum, as well as to the wall of the ventricle. As is shown in the accompanying plates, it extends from the common root, along the edge of the fimbria, towards the bottom of the ventricle; and at some distance from the tænia semicircularis, between the corpus striatum and the optic thalamus, it passes over immediately into the ependyma of the optic thalamus. Often the ependyma is a little thickened where the leaf is attached to it. The epithelium of the ependyma is naturally continued only on the upper surface of this leaf. From this surface there shoot out the choroid projections in various, peculiar forms which cannot be described here, and which are like small folded leaves, and so forth. These projections shoot out either directly, or through the mediation of a trabecular structure which is more or less membranous. Where the lower leaf is fastened to the thalamus, long projections or villi are usually thrown out which are directed outwards, so that with their extremities they cover the thalamus, and reach the border of the corpus striatum. The optic thalamus is thus almost altogether covered with choroid projections. The lower leaf now enters into a most intimate conjunction with the edge of the velum interpositum. As may be seen from the illustrations, to which reference has been made, this lower leaf covers the intermediate tract between the fornix and the optic thalamus, in which the velum interpositum is situated; but by the oblique course of the choroid leaf this intermediate tract is prolonged outside the edge of the fimbria in such a manner that it is continued between this leaf and the optic thalamus until the former becomes attached to the latter" (p. 105).

463*i*. "Before leaving the subject of the choroid plexuses in the lateral ventricles, we must call attention to some points in their general arrangement. The *lower* or *bottom leaf* is most copiously developed, and has its greatest width in the anterior portion of the choroid plexus. It abounds much more in villi than the upper leaf, or that of the ceiling. Its exterior edge which is fastened to the thalamus, in front, close to the foramen Monroi and behind the same, is at a greater distance from the tænia semicircularis; but presently it approaches the same, and for a greater or lesser distance it runs parallel with it in such a manner that the thought arises, whether the singular tænia semicircularis with the vein under it does not stand in some genetic relation to this lower leaf of the choroid plexus. In a posterior direction, where the choroid plexus together with the fimbria descends into the middle or descending cornu, and where the edge of the fimbria approaches nearer and nearer to the tænia semicircularis, the width of the lower choroid leaf decreases proportionately, and at last it is reduced to a narrow border bearing choroid villi; which border is extended between the fimbria and the tænia semicircularis. The *upper leaf*, however, is developed much less abundantly in its anterior portions. It begins a little behind the foramen Monroi, in the form of a border terminating in an acute angle in the edge of the fornix. When—as is usually the case in brains which are not well hardened—the upper leaf is loosened from the ceiling of the ventricle, and it has sunk down on the lower leaf, it usually appears there as a delicate veil, with its edge a little thicker, covering the lower leaf. Soon it increases in width, and in the narrower part of the ventricle, sidewards from the optic thalamus, it is just wide enough to reach the lateral edge of the ventricle. In its anterior portion the choroid projections are scanty; yet some are seen shooting out from both of its surfaces; most copiously, however, from its anterior edge where it grows narrower, and likewise close to the place where it is fastened to the fornix, and along the outer edges of the leaf. In its posterior direction the upper leaf is more and more developed, and that part of the choroid plexus which is called *glomus*[1] belongs entirely to the upper division. In the middle or descending cornu the upper leaf has a comparatively great width. It always extends there, through the lumen of the cavity, to its ceiling, or to that portion of its surface which corresponds to the ceiling, and there it is inclined outwards. Still its lateral extent along the ceiling, to which it is attached by a thickened edge, abounding in choroid villi, and inclined outwards, is not so very considerable. As the lower leaf, however, is very much reduced in width, but the upper leaf, on the contrary, is strongly developed in the form just now described, the choroid plexus in the descending cornu approaches to a certain degree in respect to its shape the figure of a rail on a railroad, cleft longitudinally. The foot

[1] "The passage of the lateral choroid plexus into the descending cornu," says Luschka ("Die Adergeflechte des menschlichen Gehirnes," Berlin, 1853), "is marked by a nodose swelling, to which attention has first been called by the brothers Wenzel. . . . The glomus is a constituent part of the choroid plexus which is pointed above and below, and in the middle is enlarged like a spindle. Its length is $1\frac{1}{2}$ cm.; and its greatest thickness 3 mm. With its posterior edge, which is rounded, strongly convex and thick, it extends into the beginning of the descending cornu. . . . The 'medullary' substance which Bergmann thought he distinguished in it, is nothing else but connective tissue in all its various manifestations. . . . Attention is directed to the glomus in adults, mostly on this account, because it is most frequently the seat and the source of the so-called hydatids" (p. 147).—EDITOR.

cleft in half represents the lower, narrow leaf which spreads out between the fimbria and the tænia semicircularis; the remaining portion of the cleft rail is represented by the upper leaf with its inclination outwards. Usually the upper leaf is pushed a little inwards on the fimbria, so that the choroid plexus, as Henle observes in respect to its situation here, covers more or less the upper surface of the fimbria."

463*j*. "A glance on fig. 4 of plate iv. shows that by the arrangement of the choroid plexus, according to the above description, each lateral ventricle, from the beginning of the anterior portion of the optic thalamus, is divided into two compartments; an *exterior* one, which is outside of the fimbria of the fornix, and which by the gutter-like fornix, that is, really by its upper leaf, is separated from the *interior* portion of the ventricle, which lies between the body of the fornix and the corpus callosum. . . . Not much information on these points can be gained from brains the interior parts of which are not well hardened; especially if they have been kept for some time, and the roof of the ventricles is pressed down towards the bottom. The fornix especially suffers many alterations in its form under such conditions.

"As appears from the above description, the two compartments of each lateral ventricle, which are caused by the upper leaf of the choroid plexus, are by no means completely detached from each other. For first of all the upper leaf is only loosely attached to the ceiling; wherefore a liquid may pass from one compartment into the other, and indeed, as it appears, much more easily from the median or interior compartment into the lateral or exterior, than *vice versa*. . . . A more copious secretion seems to take place during life in the exterior or lateral compartment than in the internal or median compartment; for there is a much more abundant development of choroid villi in the former than in the latter division. In front, indeed, the great mass of the choroid projections is situated in the exterior compartment" (pp. 106, 107).

The bearing which the facts, to which Key and Retzius direct our attention, have on Swedenborg's analysis of the function of the lateral ventricles, will be fully shown in Note iii., Subsection D, which treats of the Function of the Lateral Ventricles and their Foramina.—EDITOR.]

ANALYSIS.

464. GLANDS consist of membranes, blood-vessels, lymphatic vessels, nervous fibres, muscular tissue, little pipes or tubes, an emissary duct, a common cavity. They have an expansile and constrictile motion of their parts, and a motion also as wholes. In them a juice is prepared, which differs in the various glands. Each gland is a laboratory fitted up with organs and a chemical apparatus, preparing a fluid for every possible use of the kingdom. Hence the lymph of the thoracic duct, the gastric juice, the saliva, the bile, the milk, which are constantly being generated, and many other fluids too numerous to mention. Such also is the case with the brain. It is encompassed with membranes, for instance, as the dura and pia mater; it is fitted up with vessels and plexuses, with blood-vessels from the carotid and vertebral arteries, and also with lymphatic vessels; for the arachnoid membrane is a continuous duct of lymphatics. In the place of a muscular tissue the brain has its most active beginnings or principles, the cortical substances, which constitute a dense circumference, and nervous, or an infinite number of medullary fibres. So also it has little pipes and passages between the fibres, and the fascicles of fibres; it has its follicles or ventricles; its emissary opening or pointed infundibulum; and, besides, its pituitary gland which filters and secretes the liquids. It has also its cavernous receptacles, its emissary sinuses, and finally a general cavity, the receptacles of the lateral sinuses. And in addition, like all the other glands, it has an expansile and constrictile motion of its parts, and also as a whole. In this complex apparatus the spirit or the inmost essence of the blood is prepared. The brain is thus a large gland

and it is, indeed, the chiefest of all glands, and the model in which we may behold as in a type and image all the remaining glands of the body. As each gland, however, is a workshop, that is, a laboratory fitted up with chemical instruments, so also is the brain. In what follows we shall use therefore terms employed in such a workshop, or in other words, we shall use chemical language; for in the brain there are as it were flagons, vials, alembics, retorts, pipes, hot and cold baths, filters, receivers, and the like, of which we shall treat in their turn.

465. The lateral ventricles are those large vats, casks, bottles, or flagons into which through fibres, little pipes, and vessels a copious liquor is poured, and in which menstrua are mixed, and urged towards their outlets. They are also cold baths or chambers; for the temperature which prevails there is cold, and most fitted for blending together the most active forces of nature, namely, the spirits, with inert particles. The ventricles accordingly mix up and fix the various essences, which in the cavities and filters of the organs next succeeding to them, by the process of expansion and constriction, are separated and reduced into order. Thus, to perceive distinctly the operations of the brain, we must represent to ourselves every part as living; that is, we must regard every part as set in motion, and not as it is represented to us in a corpse, collapsed and extinct.

466. That the lateral ventricles by an alternate motion are opened and closed, appears manifestly from the copious medulla by which they are surrounded, and also from the corpora striata and the crura of the medulla oblongata (thalami optici) which occupy their upper walls, and also their bottoms. For the whole medullary kernel of the cerebrum, or the centrum ovale, encompasses them; the corpus callosum also with the fornix underneath expands itself overhead; and the "centrum semicirculare" [inner capsule], between the beginnings of the corpora striata, furnishes an intermediate medullary tract. Besides, a cineritious and very striated substance is largely spread out in the medulla oblongata under the optic thalami and the corpora

striata which are prominent in the cavity itself. It hence follows necessarily that when the cerebrum and the medulla oblongata rise and subside by an alternate motion, the enclosed ventricles and chambers undergo a like movement; for the common action converges thither. Yet before treating of the mode of their expansion and constriction, we shall have to premise some general rules respecting the correspondence of the motions of the cerebrum, and of its parts, and respecting the determination of the fluids.

467. *First rule.* Each larger, smaller, and least cavity, as well as each medullary tract, nay, each fibre, artery, vein, and sinus, all except their outlets, are constricted at the times when the cerebrum and medulla oblongata, that is, the cortical and grey substance, opens itself, and is expanded; and *vice versa.*

Second rule. Each larger, smaller, and least cavity, each medullary tract, nay, each fibre, vein, and sinus, at the times when they subside and are constricted, are lengthened out, and corrotated (*conrotentur*) in respect to their width; and *vice versa.*

Third rule. The liquid which is contained in cavities, anfractuosities, sulci, and fissures, at each constriction, that is, at each systaltic movement, is pressed towards the poles, and thus towards the centres of rest and the axes; at the time of expansion, however, or during the diastaltic movement, it is driven towards the circumferences. These rules will be found confirmed in all that has preceded, and also in all that will follow in the present work concerning the cerebrum, the cerebellum, the medulla oblongata, and the spinal marrow.

468. Both lateral ventricles are constricted whenever the corpora striata and the optic thalami rise, which takes place when the cortical cerebrum also is expanded; then also the medulla of the centrum ovale, corpus callosum, fornix, "centrum semicirculare" [inner capsule], and of the remaining tracts, is constricted: so likewise the cavity which is enclosed within them; for the corpora striata with the thalami optici constitute the upper wall and the bottom of the ventricles, and the

remaining medulla is circumambient, and constructs the ceilings or roofs of the same. And *vice versa.*

469. Each lateral ventricle during the time of its constriction, that is, during its systole, is lengthened out, and contracted in width, and *vice versa;* for the corpora striata, the beginnings of the medulla oblongata, whose backs bulge out in the cavity, then swell throughout their whole length, and spread out laterally: wherefore the medulla which encloses these bodies, runs through them, and is inserted between them, is lengthened out, and therefore diminished in respect to its other dimensions. It hence follows that the posterior and descending cornua, which are also called the ammonites and the ram's horns, then subside and close up completely, and the upper or broader parts of the ventricles become very narrow and are contracted.

470. When the posterior and the descending cornua close up, and the ventricles are contracted, the liquid which they contain is urged towards the centres of rest—the pineal gland and the body of the fornix—and thus towards those two foramina called "anus" and "vulva," or towards the axis. For during the period of the constriction of the ventricles a certain sulcus or byway is hollowed out between the corpora striata and the thalami optici which are then swelling; and, indeed, along the intermediate medullary tract [tænia semicircularis], which tends towards the anterior foramen. And the same is repeated in the lower part of the optic thalami, in a direction towards the posterior foramen.

471. The liquids of both cavities are thus squeezed out by a sort of contortion towards their centres, foramina, and outlets, so that not even a drop remains; and anon these cavities are unfolded in the direction of their circumferences, and hence their character of receptacles is again restored to them. The mode in which the ventricles are folded up, and again unfolded, can be seen and determined clearly not only from the flux of the corpora striata, and the medulla which encompasses them, and which is inserted between them, and likewise from the flux of the blood-vessels which pursue their way between them, but

also from the form of the cavity itself; and likewise from this circumstance, that the posterior and descending cornua are the first which begin to be closed, and the last to be opened again.

472. At the time of the constriction of the ventricles those two foramina are opened, of which the anterior leads into the associate lateral ventricle, and communicates to it its lymphs, so that the burden may be borne equally, and shared out by an even balance; for otherwise an unequal effect and a diverse action would result in each hemisphere. The posterior foramen, however, under the "nates" or anterior tubercles of the corpora quadrigemina, and under the pineal gland, [then] opens into the third ventricle.

473. The anterior foramen opens under the middle of the body of the fornix, and is drawn apart by the aid of the fimbriæ and roots of the fornix, which thence [*i.e.* from the middle of the body of the fornix] branch out in an anterior and posterior direction. Thus when the septum lucidum and the third ventricle, and likewise the corpus callosum, are lengthened out, and when the thalami optici are swollen and exert a pressure forward, then those bonds are relaxed by which this aperture during the period of the dilatation of the ventricles is constricted. The posterior foramen, however, is opened by the fibres of the little transverse medullary tract placed before the "nates" [posterior commissure]. This commissure is then stretched out, and it relaxes the reins of the sphincter by which the margin of the foramen is constricted. This foramen, besides, is situated low down, and almost at the base of the ventricles, so that when their cavity is constricted, with an open mouth it sips in the liquids which flow towards it. It is, however, raised up when the ventricles are dilated, so that with a descending trough it may pour the lymph which it has received into the third or middle ventricle.

474. There appear also as it were two little crura over the widest portion of the thalami optici, not far from the anterior foramen; they are like two breasts or mammillæ which protrude from the parent thalami as from their chest, turning their broad

or olive-shaped parts likewise towards the third ventricle. It has not yet been explored, however, whither they send out their fibrils, and whether they serve to open the anterior foramen, or that orifice which opens from the third ventricle into the infundibulum.

[Swedenborg's theory of the Function of the Lateral Ventricles and their Foramina will be found fully discussed in the light of modern science in Note iii., Sub-section D.—EDITOR.]

CHAPTER XII.

THE CORPORA STRIATA.

475. The corpora striata, by others also called the upper anterior corpora striata, the apices of the medulla oblongata, the extremities, the anterior, the superior, and the lentiform processes, and also the upper crura or beginnings, are situated in that region where the grey or cortical substance prevails. This substance, with the medullary substance acting in a mediating and copulating capacity, seems to be as it were wedded to and worked into the substance of the brain, and chiefly into its anterior province. For when the grey substance mixed with the medullary passes down under the lateral ventricles, on reaching the cavity of the ventricles, it raises itself into a long and so to say serpentine space, and by a perpetual irradiation forms prominent bodies or backs which are called "striata," and which are commonly called the beginnings of the medulla oblongata. Of these beginnings there are two, and in the aforesaid ventricles the superior or higher share their couch with the inferior or lower partners of the same marriage-bed, and indeed a little further down; I mean with the crura of the medullæ oblongatæ or the optic thalami. These corpora striata within the ventricles rise to a certain acclivity, and in accordance with the whole shape of the cavity flow down from its higher towards its lower level, and in a great measure construct the wall of the ventricle. Upwards towards the septum lucidum, and under the expanse of the corpus callosum, these bodies swell out broadly with a rounded surface, but presently like drops or tears of glass each tapers off into a more slender stem or tail, which is curved a little in its descent. Their surface

by the intertexture of grey substance is of a greyish colour, and it is variegated by streaks consisting both of grey and medullary substance; and by the diversity of light and shade prevailing in it, it contrasts with the remaining part of the walls. When, however, this outer surface is lightly scraped off, thinner striæ come into sight, like evanescent rays, or like the last forces of a fatigued light. Upon entering more deeply into their bosom or belly, they present scarcely any other appearance than that of streaked ivory; and as the knife or scalpel opens the ways or smooths out a plane, rays appear which according to the [higher or lower] elevation of the surface are either circular or run diametrically across, but in a winding course, seeking the lower medulla; there, however, they insinuate themselves into a certain striated plane, which is continued downwards in an oblique direction. When these bodies are sliced in front, the radiation presents there such firm roots that the fibres which run between, like little nerves, suffer themselves to be raised up a little. In persons who have died of paralysis, or of a severe resolution of the nerves, all these portions, according to Dr. Willis, are very much heavier (*graviora*), and of the colour of the dregs of olives with the striæ much obliterated. In recently-born puppies they are much more indistinct, and only present some shades of striæ. A certain medullary edge encompasses these bodies, and as it were entwines them, and when the bottom of the ventricles, and thereby the interior compages of the aforesaid corpora, is scraped down, this edge or margin also by degrees is varied, and at last becomes slender like a thread, and finally vanishes; if the abrasion is continued further and more deeply, this edge reappears, so that it is continued on both sides. This encompassing zone or medullary shore along its winding course inside the ventricles carries veins with it as far as the foremost heads or beginnings of these corpora. Near its interior edge where the thalamus opticus reclines as another acclivity and eminence, where it is also called the crus of the medulla oblongata, there is a certain indentation or depression in which the white medullary substance runs like a cord marking the intermediate boundary; this is called by Vieussens "the medullary tract, transverse and a little oblique" [tænia semicircularis], and when laid open more deeply he calls it "the geminum centrum semicirculare" [the inner capsule]. This medullary tract also is obliterated in its descent, and turned into a striated plane. The above medullary cord [tænia semicircularis], covered in the bottom of the ventricle with pia mater, and attended by a little venous trunk which sends its shoots into the corpora striata and their grey substance, runs in the direction of the fornix, following the course of both processes [*i.e.* the corpora striata and optic thalami], which are inclined in the same direction, and, as mentioned in the preceding chapter, it conjoins itself with the anterior edge or anterior roots of the fornix, which are inflected so as to meet and to embrace the cord. From that conjunction arises the "chorda nervi æmula," which is also called the commissure conjoining the corpora striata [the anterior commissure]. In this wise the above-mentioned medullary tracts pass into the other lateral ventricle, and are inflected in a like manner around and between the corpus striatum there; so that these two beginnings of the medulla oblongata which are situated in both ventricles, by this twin bond of union which is drawn around them on both sides, and also by the striated plane in the bottom, from their first origins are associated together so as to accomplish all their common work in harmony. The grey substance occupies a considerable space in the corpora striata, and it multiplies its power by collecting its forces together into one. Of what shape the space is which is thus occupied by the corpora striata, appears from different sections made deeper by degrees, and also by parallel sections made on the same plane. The firmer therefore the striæ are, the more distinct the rays; and the better their connection with the medullary band or girdle, so much the more vigorous is the brain, and the more watchful over the organs of sense. In infirm, obtuse, silly, paralytic subjects, and also in such persons as have lost acute sensation, likewise in infants and puppies, the striæ appear obliterated, confused, and unconnected. The grey substance of these bodies occupies a considerable space richly furnished with striæ; and with their backs bulging out in a cavity, these bodies can freely expand: and hence it follows that in activity these bodies excel all the remaining members of the encephalon.

476. WILLIS.[1]—"The corpora striata, or 'prominentiæ lentiformes,' in the common dissection of the head are found within the lateral ventricles; for they are the summits or apices of the crura medullæ oblongatæ, to which the corpus callosum is immediately affixed. . . . If they are dissected longitudinally in the middle, in part, indeed, they will be found to consist of medullary substance—namely, where they are joined with the corpus callosum—but their interior substance will appear striated throughout; that is, medullary striæ appear to ascend and descend forwards and backwards" (p. 12). "Their heads, which are wider and more obtuse, incline towards one another, and are almost contiguous; from this angle of inclination arises the twin root of the fornix. Under these roots is a certain transverse medullary tract [anterior commissure] which seems to connect the corpora striata. The lower extremities of these bodies, however, having become more pointed, are bent outwards, and constitute as it were two sides of an acute triangle; with the anterior surface of these sides the corpus callosum coheres for a long stretch in the middle" (p. 15). "Each of these bodies appears like a cylinder rolled about into an orb; but where constituting the summits of the crura [*i.e.* of the medulla oblongata] they are not of a spherical, but of an oval shape, and in their direction backwards are a little curved. The ampler part of this surface is conjoined to the medullary substance of the cerebrum; some part of it, however, is free from this cohesion with the cerebrum, and constitutes an eminence by itself; it also forms that protuberance which is conspicuous in each of the lateral ventricles. If these bodies are dissected longitudinally in the middle, they appear marked with medul-

[1] "Cerebri Anatome," cap. i. and xiii.

lary striæ, almost in the form of rays. These striæ have a two-fold affection or tendency; for some of them descend from the top of the body, and meet those which have been mentioned above; . . . and it is worthy of observation that no other part in the whole head appears striated in a similar manner" (p. 83). "Under these conditions the corpora striata are found constantly in man and in quadrupeds of every kind and shape, and in every one of them they are striated or streaked in a similar manner; they are also as it were like internodes by which the cerebrum coheres with the medulla oblongata" (p. 85). "Where these corpora striata terminate on either side they are succeeded by medullary substance—the optic thalami—of a darkish colour, which is continued for some distance, and is distinguished from the remaining contiguous parts by a peculiar acclivity" (p. 86).

"The corpora striata present a finished and highly charming appearance; the form of each verges a little towards the conical, and presents the appearance of an inflected and curved cone. Its outermost and upper surface is globose and cortical, which is irrigated by blood-vessels, and to some extent covered by the choroid plexuses. Their middle and lower compages consist of medullary substance interspersed with cortical. Their sides, or both edges, the higher as well as the lower, are white, like medullary nerves. Between these edges most dense medullary streaks, like cords, of various sizes, and stretched out like large nerves, connect both shores. The anterior edge is everywhere conjoined with the corpus callosum, so that all and each [*i.e.* the whole medullary substance] from the one seems to be borne to the other, and again carried back; we suspect that these medullary ducts thus carry on intercourse. The posterior edge of the corpus striatum receives in its upper part medullary processes sent thither from the corpora quadrigemina, and besides it accepts in its bosom others from the thalami optici. In its middle and lowest part, both its edges are affixed to the crura of the medulla oblongata; and near the base of the fornix, the lower edge of one corpus striatum is continued into the edge of the other corpus, so that these bodies also have a mutual intercourse between them" (*De Anima Brutorum*, cap. iv.).

477. VIEUSSENS.[1]—"The anterior processes of the medulla oblongata are called by Willis at one time corpora striata, and at another apices medullæ oblongatæ. These two bodies, which on their outside are of an ashy-grey colour, are situated in the anterior and upper region of the medulla oblongata; and they are distinct or separated from each other by the fornix and the intermediate optic thalami. Interiorly they consist of white tracts separated from each other by the interposition of grey matter, and consequently they appear whitish grey. On scraping off the first surface of the corpora striata, the exterior and smaller medullary tracts of which they consist come into sight. But on continuing the abrasion more deeply, their interior and thicker tracts are exhibited to view, which are so arranged that together with the grey substance (which being intermediate separates them from each other) they present somewhat the appearance of bodies variegated by striæ or streaks. Thence no doubt Dr. Willis called the aforesaid processes of the medulla oblongata, 'corpora striata.' On taking into consideration their situation, I shall call them the upper anterior corpora striata, in order to distinguish them from the remaining striated bodies of the medulla oblongata" (p. 66). "The medulla oblongata is that part of the brain taken at large which is contained partly within the surrounding space of the centrum ovale, and partly is subjected to the cerebellum; so that it extends from the foremost region of the lateral ventricles to the end of the fourth ventricle, where it passes over into the spinal marrow" (p. 82). "The medullary tracts [on the base of the cerebrum] are so disposed, that together with the grey substance with which they are intermixed they have the appearance of streaked or striated bodies. On this account, taking into consideration the shape and situation of this interior substance of the base of the cerebrum, I call it the lower exterior corpora striata [nuclei lenticu-

[1] "Neurographia," etc., cap. xi. and xiii.

lares], dividing them besides into anterior and posterior parts; because on either side the medullary substance in the shape of a thick nerve is interposed between them transversely and a little obliquely, on which account I call it 'the medullary tract, transverse and a little oblique.' This medullary tract, however, which is double [that is, in each hemisphere], seems to consist of certain fibrils which after emerging out of the lobes of the base of the cerebrum coalesce; and it unites with the lowest portion of the 'commissura crassioris nervi æmula' [anterior commissure]; so that by its interposition not only the lower exterior corpora striata [nuclei lenticulares] mutually intercommunicate, but also the animal spirit, which fills the upper parts of the cerebrum, visits the animal spirit which is in its base, and is able to establish with it some communication, and to entertain some intercourse with it. This every one may easily understand if he first takes into consideration that the 'centrum semicirculare' [tænia semicircularis and inner capsule], which on both sides is interposed between the upper anterior corpora striata [nuclei caudati] and the upper posterior corpora striata [optic thalami], and the medullary tract, which on both sides is inserted between the lower exterior, anterior, and posterior corpora striata [*i.e.* the 'laminæ medullares' in the nuclei lenticulares], are as many receptacles of animal spirit, and that they intercommunicate through the ministry of the anterior commissure. The white or medullary tracts, of which the anterior part of the lower exterior corpora striata [outer division of nucleus lenticularis] consists, terminate on either side in the above 'medullary tract, transverse and a little oblique;' but the white tracts which are noticed in the posterior part of the lower exterior corpora striata [*i.e.* of the nuclei lenticulares] terminate in the white tracts which emerge out of the middle region of the centrum ovale [corona radiata]. If after an examination of the lower exterior corpora striata [nuclei lenticulares] the base of the cerebrum is so deeply abrased that this, together with the 'medullary tract, transverse and a little oblique,' on both sides is removed, other lower corpora striata are seen, which in consideration of their situation I call lower interior corpora striata [the inner capsule separating the nucleus lenticularis from the nucleus caudatus]; and which differ from the exterior corpora [nuclei lenticulares] in this respect, that the exterior are hidden within the lobes of the base of the cerebrum, while the interior occupy the anterior part of the base [crusta] of the medulla oblongata [*i.e.* of the crura cerebri]; and are not distinguished from each other by any medullary tracts. Besides, the white tracts of the lower exterior corpora striata [nuclei lenticulares] are derived from the medullary substance of the lowest part of the cerebrum; while the white tracts of which the lower interior corpora striata [inner capsule] consist proceed from the lowest region of the centrum ovale [corona radiata], and by a somewhat oblique course terminate in the medullary tracts which emerge out of the 'middle corpora striata.' After an examination, and a thorough abrasion, of the lower interior corpora striata, other corpora striata come into sight which are intermediate between the upper corpora striata and the lower interior corpora striata which are found in the medulla oblongata [*i.e.* between the 'tegmentum' and 'crusta' of the crura cerebri];[1] and on this account we call them the 'middle corpora striata.' These differ from the rest in this particular, that their white tracts consist of many medullary fibres, and consequently they are thicker than the white tracts of the remaining corpora striata. Besides, the white tracts of which the 'middle corpora striata' consist are derived from the middle region of the centrum ovale [corona radiata]; and are different from the medullary tracts of the upper anterior corpora striata [nucleus caudatus], as well as from the strata of the lower corpora, both the exterior [nucleus lenticularis] and the interior [inner capsule], and do not terminate within the confines of the cerebrum. Nay, on the contrary, after emerging out of the grey substance [locus niger?], into which

[1] Concerning the terms "tegmentum" and "crusta" of the "crura cerebri" see no. 480*a*.—EDITOR.

they are inserted, they tend in a little winding course towards the anterior region of the spinal marrow; so that they pass off partly into the spinal marrow, and partly into the anterior roots of the spinal nerves. Where the above medullary tracts, which are seen in the corpora striata, are continued towards the spinal marrow, before leaving the cranium they climb over other medullary fibres of the pons Varolii; so that the medullary tracts which emerge out of the middle of the corpora striata and the medullary fibres of the pons Varolii are crosswise interlaced with each other; nay, and intercommunicate. There is one point to be noted here; namely, that the white tracts which are observed in the corpora striata which have been described above, just like the medullary fibres of the processes which are brought forth from the medullary centre of both hemispheres of the cerebellum, unlike the fibres of which the medulla of the cerebrum and cerebellum is composed, occupy not an indefinite, but rather a definite position" (pp. 83-87).

478. Ridley.[1]—"The corpora striata, or processus lentiformes, are two prominences situated somewhat higher than the sides of the thalami optici; in human beings, however, a great part of these corpora is on each side of the thalami optici; although Dr. Willis says that where the corpora striata end, the thalami optici begin, which is the case, however, only in brutes. They are called so from the many striæ or streaks appearing in them, and descending obliquely to the medulla oblongata, with grey substance coming between them, seen when they are cut horizontally. They run down on each side of the thalami optici, as far as where the corpus callosum begins to wind back upon the crura medullæ oblongatæ, towards their hinder part. I had them delineated in my plate exactly (though by neglect without the striæ), finding that all the cuts of them in Willis are from animals, except one which is badly done; and those of Vieussens are quite inaccurate, except in figure viii., which wants the striæ" (pp. 120, 121). "Between the

[1] "Anatomy of the Brain," chap. xii

corpora striata there is a medullary space on each side, which in a bending manner encompasses the thalami themselves, and receives the extremities of the striæ in the corpora striata, as they descend from the centrum ovale, and is therefore called by Vieussens 'geminum centrum circulare,' by Willis the posterior edges of the corpora striata" (p. 122).

479. WINSLOW.[1]—"The corpora striata received that name, because in scraping them with the knife we meet with a great number of white and grey lines alternately disposed, which are only the transverse section of the medullary and cortical laminæ, mixed together in a vertical position in the basis of the cerebrum, as appears manifestly by incisions made from above downwards. These two eminences are of a greyish colour on the surface; they are oblong, roundish, pyriform, and larger on the fore than on the back part, where they are narrow and bent. They lie in the bottom of the superior cavity of the lateral ventricles, which they resemble in some measure in shape, their anterior parts being near the septum lucidum, from which they separate gradually as they run backward and diminish in size. They are in reality the convex bottoms of the ventricles, and it is at the lower part of the interstice between the largest portions of them that the 'anterior commissure of the cerebrum' communicates with the bottom of the corpora striata by a turn towards each side" (section x. nos. 73, 74).

480. As it is, however, just as important to have a knowledge of the cortical and cineritious substance of the cerebrum as of the medullary substance, it is worth while to examine the plates. In Ridley's plate v. the corpora striata are exhibited in their true position [Δ, Δ], together with "a long medullary tract between the thalami optici and the corpora striata" [*m, m*]; and likewise with "a venous branch on each side entering the choroid plexus, whence there are many slips branching out upon the corpora striata" [*k, k*]. In Vieussens' plate vi. these venous branches are seen with others flowing on the heads of the corpora striata, and terminating in veins

[1] "An Anatomical Exposition," etc., section x.

flowing through the third ventricle. They are likewise seen in his plates vii., viii., xi., where these corpora are not yet scraped down to the striæ. In his plates ix. and xii., where the first surface of the corpora striata only is scraped down, the exterior and smaller medullary tracts which are oblique towards the lower parts, or which bend themselves towards the medullary tract which distinguishes these bodies from the thalami optici, become visible, wherefore Vieussens calls them the "upper anterior corpora striata" [nucleus caudatus]. These corpora appear more deeply scraped down in plate x.; there the interior and thicker medullary tracts [*D*, *D*, *D*, *D*, *i.e.* the "geminum semicirculare centrum"] are exhibited, together with the centrum ovale [corona radiata] on one side, and the centrum semicirculare on the other. The corpora striata posteriora [thalami optici] are also exhibited there, where "with their exterior substance a little scraped down, innumerable and exceedingly thin medullary tracts are presented to the eye" [*E*, *E*]; these with some more interior tracts seem to incline towards the region of the corpora quadrigemina. In plate xiii. are seen "the upper anterior corpora striata" [nucleus caudatus] deeply scraped down, and the interior and thicker medullary tracts are exhibited [*D*, *D*, *D*, *D*], which are brought forth from the medullary edge or margin of the centrum ovale embracing the corpora striata in its compass, and which is considerably above them, as they are thus deeply scraped out. In plate xiv. are shown "the lower exterior and anterior corpora striata [nucleus lenticularis], the striæ or the white tracts of which terminate in 'the medullary tracts, transverse and a little oblique' [*D*, *D*]." There are also exhibited there "the lower exterior posterior corpora striata [interior division of the nucleus lenticularis], the white tracts of which are drawn out of 'the medullary tracts, transverse and a little oblique,' and terminate in the white tracts which are derived from the middle region of the centrum ovale" [*I*, *I*]. In his plate xv. are exhibited "the lower interior corpora striata [the inner capsule between the nucleus lenticularis and the nucleus caudatus], the white tracts of which brought forth from the lowest region of the centrum ovale [corona radiata] [*A*, *A*, *A*, *A*], by a somewhat oblique course terminate in the medullary tracts which emerge out of the middle corpora striata;" together with the lowest part of the centrum ovale [*A*, *A*, *A*, *A*] where the strata coalesce, "the medullary tract, transverse and a little oblique" being obliterated. In plate xvi. "the middle corpora striata whose white tracts by a little inflected course descend towards the anterior region of the spinal marrow," are seen. In the middle, however, where the transverse medullary tract runs out at the top, there is a certain juncture of the striæ, under which, in an inverted brain, the lowest part of the "centrum semicirculare" is visible. In Willis's plate viii. the corpus striatum is represented cut open in the middle. In plate v. of his "Anima Brutorum" the corpus striatum is seen horizontally scraped off with its anterior and posterior edges. In plate vi. the same is exhibited in a bovine brain; the corpora striata are there scraped down in a like manner, but from the anterior province, with various medullary tracts, and the olfactory bulbs. In plate vii. the corpus striatum is seen scraped down with the anterior and posterior edges, and likewise "with the sinus leading from the olfactory bulb into the ventricle of the forepart of the brain." In plate viii. the medullary tracts of the corpora striata and of the thalami are seen extending towards the corpora quadrigemina.

[Modern Authors.

480*a*. Swedenborg and the anatomists of his time understood by the corpora striata and the optic thalami the upper and lower beginnings of the medulla oblongata as far as the pons Varolii, where the fibres of the cerebrum are joined by those of the cerebellum. That portion of these beginnings, where the fibres of the corpora striata and the optic thalami are gathered together into one trunk, is now considered as a separate organ, and called the *crura cerebri*, or the *cerebral peduncles;* and the terms "corpora striata" and "optic thalami" are now limited to the ganglionic masses whence the crura emanate. The lower and anterior portion of these crura, which, according to Swedenborg (no. 496), is formed of the corpora striata, is styled by the modern authors the *basis* or *crusta*, while their upper and posterior portion, which arises from the optic thalami, is now called the *tegmentum*. Between the crusta and the tegmentum is a stratum of grey substance—the *locus niger*—which is the beginning of the central grey mass extending through the medulla oblongata and the spinal cord.

From this explanation it follows that in complementing from modern sources the information which Swedenborg collected from the authorities of his time concerning the corpora striata and the optic thalami, we have to include the modern facts concerning the crura cerebri as well.—EDITOR.

480*b*. QUAIN.[1]—"The *corpora striata*—anterior cerebral ganglia—situated in front and to the outer side of the optic thalami, are two large ovoid masses of grey matter, the greater part of which is embedded in the middle of the white substance of the hemisphere of the brain, whilst a part comes to the surface in the body and anterior cornu of the lateral ventricle. This *intraventricular* portion of the corpus striatum—*nucleus caudatus*—is of pyriform shape, its larger end being turned forwards, and its narrow end being directed outwards and backwards, so that the optic thalami of the two sides are received between the diverging corpora striata. On cutting into it, there may be seen at some depth from the surface white fibres, which are prolonged from the corresponding cerebral peduncle, and give it the streaked appearance from which it has received its name. The *extraventricular* portion of the corpora striata—*nucleus lenticularis*—is separated from the intraventricular part by a layer of white substance, and is seen only on section of the hemisphere. Its horizontal section resembles that of a biconvex lens, being wider in the centre than at either end, hence its name. Its antero-posterior diameter corresponds closely with that of the island of Reil, and its greatest width is opposite the

[1] "Elements of Anatomy," eighth edition, London, 1876.

anterior edge of the optic thalamus. On a transverse vertical section through the middle it appears triangular, the apex of the triangle being directed inwards, and two clear lines, parallel to the outer side, divide it into three zones, of which the outer is striated, and the inner slightly reddish in tint. On its outer side is the grey lamina termed the *claustrum*" (ii. p. 547 *et seq.*).

"The *corpus striatum* contains much grey matter, arranged in two chief masses. One of them, the intraventricular, is seen in the lateral ventricle; the other, the extraventricular, situated more externally and inferiorly, is hidden in the white mass of the hemisphere. It is separated from the first by the white substance of the corona radiata, which appears on a horizontal section as a broad white band extending from behind forward between the two grey masses, and traversed by streaks of grey matter passing from one to the other. The intraventricular part, also named the nucleus caudatus (corpus striatum proper of Henle and others), is connected below with the lamina cinerea, and with that part of the grey matter of the optic thalamus which is seen in the third ventricle. The extraventricular part, named nucleus lenticularis, is continuous below with the caudate nucleus and with the grey matter of the anterior perforated space. Striæ of grey matter pass from one centre to the other. Between the lenticular nucleus and the island of Reil, which lies opposite to it, there intervenes a thin lamelliform deposit of grey matter, the *claustrum* (Burdach), *nucleus tæniæformis* (Arnold), which, in transverse section, is seen as a thin line" (ii. p. 564 *et seq.*).

480*c*. "Along the inner border of each corpus striatum, and in a depression between it and the optic thalamus, is seen a narrow whitish semi-transparent band, named *tænia semicircularis*, or *stria terminalis*, which is continued backwards into the white substance of the roof of the descending cornu of the ventricle. In front it reaches the corresponding anterior pillar of the fornix, and descends in connection with that cord of white substance" (ii. p. 549).

480*d*. "From the front of the pons Varolii two white masses extend, marked on the surface with longitudinal striæ, and having somewhat the appearance of large bundles of fibres. They pass forwards and outwards to enter the inner and under part of the right and left cerebral hemispheres, of which they are the *peduncles* or *crura*. Immediately before entering the corresponding hemisphere, each is crossed by a flattened white cord, named the *optic tract*, which adhering by its upper border to the peduncle, is directed forwards and inwards, and meets in front with its fellow of the opposite side, the optic commissure, from the forepart of which the optic nerves proceed. Limited behind by these diverging peduncles, and in front by the converging optic tracts, is a lozenge-shaped interval, called the *interpeduncular space*, in which are found, in series from behind forwards, the posterior perforated space, the corpora albicantia, and the tuber cinereum, from which is prolonged the infundibulum attached to the pituitary body" (ii. p. 533 *et seq.*).

"In the *crura cerebri* the grey matter is collected into a dark mass—the *locus niger*—which lies between the crust and the tegmentum, and is also diffused among the fasciculi of the tegmentum; it extends through the whole width of the crus, and from the anterior edge of the pons to the corpora albicantia, and is continuous behind with the grey matter of the pons and medulla oblongata. . . . In the upper part of each tegmentum is a round reddish-grey centre, *the nucleus of the tegmentum* (the red centre of Schilling, the superior olive of Luys), lying near the side of the third ventricle" (ii. p. 563).

480*e*. TODD.[1]—"When sections are made through the deep portion of each corpus striatum, the surfaces appear to be traversed by very numerous bundles of fibres. It is necessary that the sections should be made obliquely from below upwards in a direction parallel to the inferior layer of the crus cerebri. The bundles of fibres are thicker and more closely approximated to each other inferiorly: but as they ascend, they diverge, and radiate, some forwards, others outwards, and others backwards;

[1] "Anatomy of the Brain," etc., London, 1845.

some pass nearly vertically upwards. A section made quite in the horizontal direction cuts all these fibres more or less transversely, so that the cut surface presents a grey colour interspersed with white spots of variable size, according as the bundles have been cut transversely or obliquely; but when the section is made obliquely, as above directed, then the surface presents a striated appearance like numerous and regular white veins in black marble, the bundles of fibres being cut lengthways. In tracing the bundles of fibres through the corpus striatum, we find that they divide and subdivide and occasionally anastomose. Each subdivision becomes clothed as it were with grey matter, which fills up the space between it and the adjacent ones. The grey matter ensheathes these bundles of fibres, as the areolar tissue does the coarse fascicles of large muscles, and it may be dissected away from them, as we remove the areolar tissue from the muscular bundles" (p. 224 *et seq.*).

480*f.* HENLE.[1]—"The nervous fibres which are conveyed by the crura cerebri to the hemispheres, in their relation to the ganglia [corpora striata and optic thalami] and nuclei of the cerebrum, may be divided into three classes: (*a*) they either pass through their grey substance, or (*b*) terminate in it, or (*c*) they pursue their course towards the surface of the brain between the various grey masses. To the first class belong the fibres of the tegmentum, . . . by far the greater part of which certainly depart again from the optic thalami. Fibres of the second class we have seen branching off from the medulla of the crura cerebri, and entering into the nucleus caudatus and the nucleus lenticularis of the corpora striata. The white medullary mass which in sections made in every direction distinguishes the nucleus lenticularis from the optic thalamus and the nucleus caudatus, consists essentially of fibres of the third class. It is a continuation of the basis of the crura cerebri, which from its entrance into the optic thalamus, by a change of direction of the fibres, arranged into various strata, appears streaky" (p. 261).

[1] Henle (Dr. J.), "Handbuch der systematischen Anatomie des Menschen," vol. iii. section ii., "Nervenlehre," Braunschweig, 1871.

480*g*. MEYNERT.[1]—"The two great anterior cerebral ganglia, the nucleus caudatus [the intraventricular corpus striatum], and the nucleus lenticularis [the extraventricular corpus striatum], are so disposed that their largest ends, the head of the nucleus caudatus (caput nuclei caudati) and the base of the wedge-shaped nucleus lenticularis, look towards the frontal extremity of the cerebral lobe. While these ganglia are anteriorly so strongly developed, they dwindle in size posteriorly, the one to an insignificant tail-like extremity, the other to a thin jagged edge" (p. 678 *et seq.*).

"Each of these ganglia has, morphologically speaking, two poles as it were, the one *central*, that which receives the superior [or first] member of the projection system,[2] the other *peripheral*, that from which the second member of the projection system, the crus cerebri, emerges. . . .

"The ganglia of origin of the *crusta cruris cerebri* are—(1) the nucleus caudatus; (2) the nucleus lenticularis; (3) the locus niger (substantia nigra, Sömmering), which lies between the crusta and the tegmentum cruris cerebri.

"The form of the *nucleus caudatus* (intraventricular corpus striatum) is that of an arch, concentric with that formed by the entire hemisphere, and surrounding . . . the transversely disposed, wedge-shaped nucleus lenticularis, whose base is directed outwards, and whose point inwards. . . . The two ganglia [composing the corpora striata] are actually united together at the frontal end of the arch formed by the nucleus caudatus, through

1 "The Brain of Mammals," in Stricker's "Manual of Histology," American edition, New York, 1872.

2 By the "projection system" Meynert means the fibres which are projected from the cortex of the brain into every part of the body. This projection system is divided into segments, because the fibres of the brain before leaving the cranial cavity and the vertebral theca have to pass through internodes of grey substance. "The superior or *first* member of the projection system," says Meynert, "consists of a system of medullary fibres which spring from the cortex cerebri, generally in radiate lines, and which find their peripheral termination in the grey matter of the ganglia [*i.e.* the corpora striata and the optic thalami] From out the interrupting nodal masses of the ganglia springs the second member of the projection system, the crus cerebri" (p. 654).—EDITOR.

the fusion of the caput nuclei caudati with the third [or innermost] division of the nucleus lenticularis; and also at the temporal end of the same arch" (p. 681).

480*h*. "The caput nuclei caudati, extending beyond that portion of its body which is visible in the lateral ventricle, curves downwards to the base of the brain, where its inferior portion constitutes the grey matter which lies just above the anterior perforated space. Gratiolet gave to this inferior region the *olfactory district.* I am able to bear witness to the justice of this designation by confirming the fact that this inferior district of the corpus striatum is invested by a thin layer of cortical substance, whose continuity with the cortex of the olfactory lobe may be easily demonstrated both as regards the neuroglia and the nerve-cell stratum of the latter. This stratum of grey substance coalesces posteriorly with the gyrus uncinatus" (p. 681).

480*i*. "The first member of the projection system [*i.e.* the medullary fibres which spring from the cortex cerebri] enters the nucleus caudatus under four different forms:—

"1. As fibres belonging to the corona radiata, coming from the hemispheric arch throughout its entire length.

"2. Under the form of a bundle of fibres—the tænia semicircularis—which runs from the cortical substance of the temporal extremity to the most anterior part of the caput nuclei caudati, following an arch-shaped course along the inner border of the latter ganglion.

"3. Under the form of fibres which connect the cortical substance of the olfactory lobe with the corpus striatum, whether it be the superficial fibres which take their rise in the bulbus, or the deeper laid medullary substance of the olfactory lobe. That portion of the olfactory medullary substance that enters the anterior commissure seems merely to traverse, without interruption, the substance of the corpus striatum. The medullary fibres of the olfactory lobe also pass, in arching lines, through the nucleus septi lucidi.

"4. Under the form of the pedunculus septi lucidi which unites the cortical substance of the septum with the inferior region of the corpus striatum" (p. 682 *et seq.*).

480*j*. "The manner in which the nucleus caudatus gives rise to its contingent of the *crus cerebri* is very simple, for the fibres which go to form the latter converge like radii from the concavity of the arch made by the former towards the base of the brain, and unite in the crusta of the crus cerebri.

"In general terms—the tænia semicircularis being left out of consideration—the *outer*, which is at the same time the *upper* border of the nucleus caudatus, represents its 'central' pole,—that which receives the fibres of the corona radiata; while the *inner* or *lower* border represents its 'peripheric' pole,—that from which the fibres of the crus cerebri emerge.

"The crural fibres of the nucleus caudatus [*i.e.* those which tend towards the crus cerebri] traverse in their course the upper layer of the 'inner capsule' [centrum geminum semicirculare, Vieussens] to reach its lower layers. This broad medullary tract, the inner capsule, the two parts of which, as they appear in a horizontal section, seem to unite at an obtuse angle, separates anteriorly the nucleus caudatus of the corpus striatum from the nucleus lenticularis, posteriorly the latter from the optic thalamus. The upper half of its layers is made up of the first member of the projection system, namely, the lower extremity of the respective section of the corona radiata (pes coronæ radiatæ); the lower half of the same by the second member of the projection system, namely, the crusta of the crus cerebri. The extremity of the corona radiata, however, as it lies in the inner capsule, is overarched by the nucleus caudatus, and is therefore interwoven with the crural fibres of the latter, which cross the direction of its own" (p. 683).

480*k*. "The course of certain fibrous bundles, coming from the nucleus caudatus within the crus cerebri itself, is somewhat complicated. That is to say, after removal of the optic tract, certain bundles are seen to be running transversely and parallel to the tract, which emerge from among the external fascicles of the crus cerebri, and disappear again among its internal fascicles.

These bundles are made up of fibres which have come from the cauda nuclei caudati, which is situated rather externally to the rest of the ganglion. Their downward course to the spinal cord lies in the inner portion of the crus, and to reach this position they are obliged thus to pass superficially across the intermediate fascicles" (p. 683).

480*l*. "The *nucleus lenticularis* [the extraventricular portion of the corpus striatum], the second ganglion of origin of the crusta cruris cerebri, is of precisely the same histological structure with the nucleus caudatus [the intraventricular portion of the corpus striatum]. . . . The shape of this ganglion is that of a wedge. The base of the wedge is directed towards the frontal lobe and the island of Reil; its point passes over into the crusta cruris, and posteriorly it terminates in a thin, jagged, saw-like edge. On cross-sections of this ganglion its nerve-fibres appear disposed in two general directions, namely, in lines radiating from the point of the wedge, towards its base, and in layers concentric with the curved base of the wedge, the component fibres of which layers run downwards from the inner capsule [centrum geminum semicirculare, Vieussens] towards the base of the brain. These latter fibres form the concentric partitions, the laminæ medullares, which divide the nucleus lenticularis into its three so-called members or divisions, the innermost of which is intimately connected with the origin of the crus cerebri, while the outermost is separated only by the thin medullary layer of the outer capsule from the claustrum, which belongs morphologically to the cortical substance of the island of Reil. This external capsule is not connected by nerve-fibres with the surface of the nucleus lenticularis on which it lies, but the two are united by means of loose connective tissue. A few slender and seemingly inconstant nerve-fibres, which penetrate the surface of the ganglion, form an exception to the general rule.

"The two inner divisions of the nucleus lenticularis are distinguished from the much larger third division by their great richness in medullated fibres, which gives them the name of the *globus pallidus*. This is due to the fact that the third division, while containing, in virtue of its position at the base of the wedge, more grey substance than does either of the others, is traversed only by as many fibres as arise within its own limits, while the inner divisions are traversed by fibres coming from the third division and bound for the crusta cruris, as well as by their own. Just as the nucleus caudatus of the corpus striatum stretches its slender posterior extremity forward to the point of the temporal lobe, so also the nucleus lenticularis thrusts its temporal process (pedunculus nuclei lenticularis), which is of inconsiderable size in comparison with its frontal portion, toward the same lobe to receive its medullary rays" (p. 684 *et seq.*).

480*m*. "The upper border of the nucleus lenticularis represents its 'central' pole, where the fibres of the corona radiata, leaving the inner capsule [centrum geminum semicirculare, Vieussens], penetrate into the ganglion substance. That which appears in cross-sections as the lower border of the nucleus lenticularis, and its inner extremity, represents the 'peripheral' pole of the ganglion, from which a large part of the fibres of the crusta cruris proceed. It is evident from the form of the nucleus lenticularis that its contingent of fibres received from the cortex of the frontal and parietal lobes must be incomparably greater than from the occipital and temporal lobes. Apart from the quantitative distribution of fibres, however, the lenticular nucleus must be regarded as standing in connection with all parts of the cortex cerebri. . . .

"The fibres of the first and second members of the projection system which traverse the nucleus lenticularis—considering them for the moment as forming one continuous system, unbroken by the intervention of the ganglion-cells—take by no means the shortest and most direct path through the ganglion; but, on the contrary, describe complicated spiral lines, made up of descending portions, which are concentric with the convex surface of the ganglion and radiating portions which are directed inwards, namely, towards the crus cerebri" (p. 685).

480*n*. "A certain proportion of the fibres of which the *laminæ* *medullares* are composed do not, in their further course, traverse both or even one of the inner divisions of the lenticular nucleus, but run along the interior surface of the ganglion directly into that part of the inner capsule which belongs to the crus cerebri. On the surface, obtained by cross-section, of the crus cerebri, the latter fibres occupy its innermost segment, in order to reach which position they not only pass the lower surface of their parent ganglion, but also cross transversely the external and central fasciculi of the crus cerebri in the form of a sort of sling, which is pretty nearly parallel with the optic tract, and is designated as the sling or ansa of the lenticular nucleus. This so-called sling forms the lowest stratum of the ansa peduncularis of Gratiolet, or of the substantia innominata of Reil" (p. 686).

480*o*. "In cross-sections which pass through the posterior end of the third ventricle the formation of the crusta cruris appears completed, not only as regards that part of its fibres which are derived from the nucleus caudatus and nuclèus lenticularis, but also in respect to the fibres derived from the cortical substance of the occipital and temporal lobes, which form the most external fascicle of the crusta cruris. This group of fibres is, at its entrance into the crus, covered over by the posterior tubercle of the thalamus and by the corpora geniculata, and in cross-sections, therefore, is to be seen just in advance of these ganglionic masses" (p. 686).

480*p*. "While descending through the region of the mid-brain —corpora quadrigemina—the crusta cruris, however, receives a contribution from the third of its ganglia of origin, the grey substance of Sömmering—*locus niger*, substantia nigra. This broad, thin mass of ganglionic substance lies like a partition between the crusta and the tegmentum cruris cerebri. It stands in connection 'centrally' with a thin, fan-shaped layer of fibres belonging to the corona radiata, which terminate in it, while 'peripherally' it sends out fibrous bundles which appear on the transversely cut surface of the crus cerebri in the form of a well-defined network, which cuts up the inner and central part of the section into minute divisions. This network encloses straggling elements belonging to the system of large pigmented cells, to which the ganglion owes its name of 'substantia nigra,' and besides them a number of very small cells. The external division of the crusta cruris, that which is derived directly from the cortex cerebri, remains free from admixture with the fibres of the substantia nigra of Sömmering" (p. 686 *et seq.*)

480*q*. "The crusta cruris has, then, four different regions of origin: (1) The cortical substance of the occipital and temporal lobes; (2) the nucleus caudatus; (3) the nucleus lenticularis; (4) the locus niger. The fibres furnished by these ganglia are so distributed that the most external region of the crusta is made up of fibres derived directly from the cortex cerebri, the innermost region unquestionably of fibres furnished by the nucleus lenticularis (sling of the nucleus lenticularis), and the intermediate region, the largest of all, of fibres from the nucleus caudatus and the nucleus lenticularis in common. The fibres from the locus niger are distributed among those from the other ganglia over the inner and central regions of the crusta cruris" (p. 687).

480*r*. "The relative increase in the size of the ganglia of the caudex in man affects the nucleus lenticularis far more than the nucleus caudatus, which is probably due to the fact that the development of the latter is dependent upon that of a region of the brain which is but poorly represented in man, namely, *the olfactory lobe*" (p. 687).]

ANALYSIS.

481. THE corpora striata which are placed in the summit of the medulla oblongata are those sublime portals through which there is an access into the courts of the cerebrum. From the kingdom of the body to the court of the cerebrum there is a royal road through the medulla oblongata as far as its apices, that is, the corpora striata; and thence it is continued by an infinite number of little pathways or fibres towards the highest and spacious cortical envelope where the soul rules its orb by its nod, *i.e.* where it receives sensations, judges, and governs. The cerebrum devotes all its thought and care to the affairs of its kingdom, but to the corpora striata it has assigned a viceregal office; that with their necks they may sustain all things, and may execute the decrees and commands of the empress or queen. It is, however, a most noble object to inquire more deeply into the form of this government, for then it will appear how the one organ flows into the other.

482. Each medullary substance of the cerebrum has respect to the corpora striata as to two balances and fulcra, or as to two bars or goals whither its fibres and its assemblages of fibres aim. Thus from the higher and lower, the posterior and anterior region of the cerebrum, the fibre is brought forth and led into the centrum ovale [corona radiata], the corpus callosum, the fornix, and the "geminum centrum semicirculare" [inner capsule]. There the corpora striata are spread around each of them. The corona radiata encompasses these bodies on all sides, and embraces and enwraps their upper edges. The corpus callosum extends like a sail over them on both sides, and fosters their apices; the "geminum centrum semicirculare" [inner capsule],

and in addition a certain medullary tract [the laminæ medullares of the nucleus lenticularis], go down below like a meandering shore, and close the corpora in that direction. But what is worthy of notice, everywhere in the medulla of the cerebrum one fibre is brought to meet another; they cross each other and become interlaced, and in this wise weave a certain inextricable knot, which becomes closer and tighter the more it is stretched and drawn apart. These contextures of fibres, together with the universal medullary cerebrum, as said above, have respect to the corpora striata (which are stretched out from the base of the fornix to the posterior and descending cornua), as to balances, fulcra, goals, and bars. Thence also there is a descent into the medulla oblongata and the spinal marrow, and by nerves into the kingdom of the body.

483. The medullary substance of the cerebrum, except that which is expended in the chymical organs, not only envelops the corpora striata, but also enters thoroughly into their compages, and there it adjoins itself to, and interlaces itself with, freshly-born, new fibres peculiar to these bodies; for there is an access to, and an entrance into, them from every quarter. Indeed, the texture of both edges of the corpora striata, *i.e.* both of the upper and the lower, is loose and pervious; and their own texture also is interpolated with striæ, which from their upper surface tend like rays downwards and inwards. Their strata of grey substance are at some distance from one another, and allow space to the fibres which arrive. Their medullary striæ are dense, and similar to nerves, and it is impossible that they should be born at once from a new grey substance. Autopsy also proves this influx. Thus the fibres of the cerebrum not only penetrate here towards the interiors of these bodies, but also everywhere they flow from the base of the cerebrum into those corpora striata which are continuous with them, and which are called lower [nucleus lenticularis], upper [nucleus caudatus], exterior, and interior. These fibres, therefore, which are associated with those which are indigenous and peculiar to the [beginnings of the] medulla oblongata [*i.e.* to the corpora striata],

tend towards their new conjunction with fibres from the cerebellum in the pons Varolii, and again with these they tend towards a new conjunction with those which are peculiar to the spinal marrow. At last, after having entered into so many confederacies, they are distributed into fascicles and nerves, as into so many squadrons, and they press through the open doors outside their bony walls, and construct a kingdom which they rule with their united votes.

484. The cerebrum, however, has reserved to itself the control and the highest power; that is, it has separated itself from the corpora striata; for it has placed edges and boundaries all around them, and at the same time it has interwoven its own fibres into their striæ, and thus has bound them to itself in such a manner that they are unable to act without leave being given, *i.e.* to expand and constrict themselves of their own accord. For every fibre of the cerebrum is extended when its cortex expands; unless, therefore, the fibre of the cerebrum which flows around so copiously, which vaults the roofs of the ventricles, and which has thoroughly embedded itself in the corpora striata, should extend itself and constrict its little tubes, the corpora striata could not, under any circumstance, raise themselves into eminences within the ventricles, and thus swell. Their grey substance has a constant tendency to expand, but is held down by so many bonds and fetters that the cerebrum itself must give the sign and issue the decree, and thus control the motion. When an opportunity is given, then the fibres of the corpora striata, and the rest which are associated with them in their action—those from the medulla oblongata as well as those from the cerebellum and the spinal marrow—expand together, *i.e.* they act at the same time upon and through their fibres. Such also is the case in general as well as in every particular. The cerebrum thus by its own beckoning rules its orb, and keeps subject to its own good pleasure those bodies the striæ of which exercise proximately the viceregal power, and which by their shoulders sustain all.

485. In respect to sensation, however, matters are differently

constituted; for sensations creep up from the outermost to the inmost parts, or from the organs of sense to the cerebrum; or again they flash up through the spinal marrow or the medulla oblongata even to the apices, the corpora striata, and thence through that universal medulla which is poured around them, and through its individual fibres into the whole cortical envelope of the cerebrum. Thus the cerebrum cannot sensate and perceive except in accordance with the mode in which the corpora striata transmit to it these modifications, and thus in which they minister to it; and again the corpora striata cannot submit these modifications to the cerebrum and minister to it, except in accordance with the manner in which the senses receive these impressions, and as it were narrate them. The infantile cerebrum depends yet entirely upon the senses as its masters, and from these transmissions and the phenomena which they have recorded, infants begin to perceive the objects before them in a suitable manner, and afterwards to judge, think, will, and determine. In this manner the cerebrum manages the reins in the determination of motions, or thus it administers the government. But in receiving the objects of the senses, the organs of sense hold the first, the corpora striata the second, and the cerebrum itself the last place. This is the reason that in infirm, silly, paralytic persons, and in those who have lost the use of the senses, in infants, and in puppies, the corpora striata appear obliterated, unconnected, distorted, and confused. Also why terrible phantasies sometimes come up, and sometimes convulsions are caused to those with whom the ventricles are filled with a yellow or acrid ichor. And again, why some have inferred from these phenomena that the seat of the soul is in these corpora; which indeed squares with the facts obtained from the brains of birds, in which the cortical substances for the greatest part are situated around the ventricles. But we have spoken enough of the influx of the motions and the sensations by means of the corpora striata, we shall now treat of the offices which they fulfil in the excitement of the organs belonging to the chymical laboratory.

486. The alternate motion of the ventricles, their expansion and constriction, depends proximately upon the corpora striata, which by their backs hold here a commanding position; but remotely, and chiefly, as has been said, this motion depends upon the cerebrum. The cerebrum causes the beginning, the continuation, and the perpetuity of the motion of all the parts of its kingdom. Thus while the grey substance in these bodies expands its strata or its areas, these bodies themselves swell into an acclivity, and thereby limit and contract the space of the ventricles, so as nearly to fill it up altogether. No opportunity of swelling is given to these bodies or corpora except into the cavity nearest to them. On this account, wherever there is any grey substance, there is always a hollow space either within or without, in the form either of anfractuosities, sulci, fissures, or clefts; otherwise that substance would have no power of rising; for no action ensues from the mere state of potency or power. Thus the corpora striata are the prime motors of this laboratory and its organs; from them an effect is continually exerted upon the cavities which are appended to them, and by which they are succeeded. In order that these bodies, however, may unfold themselves, they are engirded by medullary fascicles which are called their edges. These edges are yielding, and at the same time they mark out the sphere and the limits of motion. Hence also, and likewise from the abundance and the direction of the striæ, from the very extent, the curvature, and the cylindrical form of these corpora, from the quantity of the same substance which is underneath them, and which decreases towards the posterior and descending cornua, it appears manifestly what form of motion these corpora exert, and how they determine the liquid which is contained [in the ventricles] towards the two foramina, as towards the middle termini of the confluences, or as towards general foci.

[The functions of the corpora striata, as defined by Swedenborg, are discussed in the light of modern science in Note iv.—Editor.]

CHAPTER XIII.

THE OPTIC THALAMI OR THE CRURA OF THE MEDULLA OBLONGATA.

487. The optic thalami, by others also called the crura, processes, heads, corpora striata, or "principia superna inferiora" of the medulla oblongata, are lying nearest to the before-mentioned corpora striata, although a little lower; being separated from them only by an intervening medullary zone which encompasses the margins of both organs. The vaulted expanse of the roofs [of the ventricles], the intermediate medullary tract together with the ceiling of the third ventricle having been thoroughly removed or folded back, the optic thalami are laid bare; and they then appear scarcely otherwise than as buttocks which also in a similar manner converge in the middle in a gap or cleft, and thence pass off in the shape of genuine crura or thighs, where they bear a close resemblance to that part on which we sit. If, however, they are raised from their tracts and expanses, they appear in a much more slender form; they spread far apart, and in the direction of the descending cornu of the ventricle the thighs seem shrivelled up into tibiæ. This form probably has furnished the old writers with a reason for giving to the neighbouring tubercles and orifices the names "nates," "testes," "vulva," and "anus." The corpora striata occupy the farther or more remote bottom and wall of both lateral ventricles, while the optic thalami occupy the other or the nearer bottom and wall. These two bodies also in each ventricle are like married partners or consorts of the same marriage-bed, which divide among one another the government, and mark their limits by a medullary boundary, and finally by the body of the fornix, which serves to both as an appointed

limit. In this wise they show manifestly that the power of each organ of acting within its own conical shape is distinct from that of the other. The fornix, as said above, is divided into two [pairs of] horns which are called its crura, pillars, or roots; the lower or posterior ones of these, like two collars, are thrown over the crura or thighs of the optic thalami, and spread over them scarcely otherwise than as if they were intimately rooted in them; thus, as if they were tied and sewed to them underneath, down to their extremities, and as if they covered and bound some of their portion; so that from the middle of the optic thalami down to their tarsus or heel, where they are finally rolled together into nerves, they are constantly bound by the fornix and the corpus callosum. These crura are covered with a soft, whitish, medullary membrane, which upon being exposed to the air assumes an ashy-grey colour, and upon being still more dried and boiled, becomes brownish. When the surface is lightly scraped, exceedingly small, thin, and numerous striæ may be observed by such as are sharp-sighted, especially if their eyes be assisted by magnifying glasses. If, however, the thalami be scraped with a rasp, these striæ disappear; they are, consequently, not of the same consistency and clearness as in the corpora striata. The interior striæ, intermixed with fibres and grey matter, are also inclined in the direction of the corpora quadrigemina and of the pineal gland. The series underneath, however, with the bottom plane of the thalami, in the end inclines towards the medulla oblongata. Just as the top ridges of the thalami from their origin run down the knee-joint as it were, where they are inflected into nerves, so also the two choroid plexuses like flowing manes run down from their necks. Where the two crura encounter each other under the corpus callosum and the fornix, they form a cleft, the third ventricle, under which they by-and-by coalesce. A medullary transverse tract or a process similar to a nerve [the posterior commissure] runs out from the top or the upper roof of the third ventricle in front of the anterior tubercles of the corpora quadrigemina, joining the two thalami. They are also united by processes of the corpus callosum and of the fornix. In animals the optic thalami are divided by medullary transverse tracts, one of which runs forth from between the corpora striata, as it does in human brains; the other tract divides a certain upper region from the lower; from the upper region proceed the optic nerves; below, however, are the very crura, beginnings, or heads of the medulla oblongata [the corpora striata], which again and again are separated by medullary tracts running parallel with each other. Interiorly there is a tract leading to the infundibulum; below is the glandula magna [pituitary gland]; further down [behind] is a cleft continued from the upper cavity dividing the medulla oblongata into two halves. In birds the optic thalami are like two succenturiate brains with an enclosed cavity. When the more intricate fabric of more perfect brains is compared with these, we may learn from the greater simplicity [which prevails in the latter] what are the effects and the ends of the brain when at work; whither the striæ tend, what is the business of the glands, the ventricles, and clefts; *i.e.* what is the meaning of this labouring and most intricate machine regarded as a whole, with its parts, and the forms of the parts.

488. Willis.[1]—" If the hinder portion of the brain is divided from the neighbouring parts, and inclined in an anterior direction, the crura of the medulla oblongata [the optic thalami] appear, quite bare and altogether distinct from the cerebrum and the cerebellum, except in some places where the crura are appended to the former" (p. 9). " Behind the corpora striata the optic thalami pursue their course for some distance by themselves, afterwards they meet each other and are united in the same caudex, which is composed as it were of two stems" (p. 12). " Where the corpora striata terminate on either side they are succeeded by medullary substance of a darkish colour, which is continued for some distance, and is distinguished from the neighbouring parts by a peculiar acclivity. This was called by Galen the ' thalamus nervorum opticorum ;' for the optic nerves

[1] " Cerebri Anatome," cap. i., ii., xiii.

emerge hence in the highest part on either side, and after being carried downwards with some encompassing substance [the optic tract], they are united near the infundibulum. After being again divided, and after passing over some additional space, the optic nerves leave the cranium on the direct road towards the organs of sight. Although the optic nerves originate here from the medulla oblongata [*i.e.* the crura cerebri], nevertheless its inmost or its whole substance is not expended upon them, but these nerves are inserted in the medullary caudex, as branches in the stem of a tree" (p. 86). "In birds and fishes this thalamus of the optic nerves assumes great dimensions, and is scarcely inferior in size to the cerebrum itself" (p. 87). "I knew some one who was greatly affected with a loss of the imagination and the memory; and after these infirmities began to disappear, he was afflicted with blindness.[1] . . . The aforesaid crura with man are very much larger than with brute animals; indeed, they seem to consist as it were of numerous medullary cords fitted together. They are apart from one another, leaving a declivitous opening which is the passage to the infundibulum. In most quadrupeds they are separated from each other only below, where they have a cleft for the infundibulum. Their ridges, however, where the optic nerves have their origins, are somewhat conjoined, and they coalesce for the space of half an inch; wherefore in animals the one foramen is placed before this coalition, and the other is placed near it; both of them, however, lead to the infundibulum. . . . It must be observed that in human beings the optic thalami, from the point where they are appended to the cerebrum, proceed in a larger angle of inclination, being bent in their direction; in animals, however, the two members lie almost parallel to one another" (p. 16).

489. VIEUSSENS.[2]—"The optic thalami are two white bodies, covered exteriorly with a thin and soft membrane, and situated in the upper region of the medulla oblongata, where they are

[1] I am unable to verify this passage.—EDITOR.

[2] "Neurographia," cap. xi.

placed between the corpora striata, or the 'anterior processes of the medulla oblongata.' They are separated from each other by the interposition of the third ventricle and the foramen anterius and posterius, or the 'vulva' and 'anus;' and yet in man their ridges are always conjoined by the interposition of an intermediate medullary tract, and the ceiling of the third ventricle; and I maintain this in the face of Dr. Willis, who says that for the most part they are apart from each other, and altogether separated. In their anterior part a white, entirely round body, and of the same substance with the thalami themselves, is prominent. The white membrane with which the optic thalami are covered is a thin and very soft body, which is composed of white fibrils derived either from the medullary tract spread over the ceiling of the third ventricle, or from the upper part of the 'centrum semicirculare' [tænia semicircularis] on either side, which is in close proximity to its thalamus. But where this membrane, which is not unlike a thin skin, is produced near the posterior region of the optic thalami, its fibrils gradually incline towards each other, until at last they coalesce from both sides, and together with certain white tracts which emerge out of the posterior part of the above-mentioned thalami, they pass off into the optic nerves; whence it is that the crura of the medulla oblongata are not inappropriately called 'thalami nervorum opticorum.' When the white membrane is removed with which the thalami optici are covered, and when their substance is a little scraped off, by means of the microscope, nay, and even without the microscope, innumerable and most slender medullary tracts are discovered in them, which are so arranged that together with the grey substance with which they are interwoven, they present a likeness in a certain way to bodies marked with striæ; on this account also, taking into consideration their situation and interior conformation, I call them the posterior, upper corpora striata. Their very slender medullary tracts are derived from the 'geminum semicirculare centrum' [inner capsule], or from the posterior region of the oval centre [corona radiata]; they tend towards the spinal marrow, unless you except some which pass off into the optic nerves" (pp. 67, 68). "The optic thalami appear of a white colour so long as they are not exposed to the air; but when they are exposed to it, they assume a whitish-grey colour; when, however, they are dried or boiled, they become altogether grey" (p. 62).

490. RIDLEY.[1]—"The optic thalami are two prominent bodies, more purely medullary on their exterior surface than within, which meeting together like the two topmost strokes of Y inverted, constitute the uppermost part only of the crura medullæ oblongatæ in that form, the other or lower side being quite of another figure. Now seeing that they are the immediate continued productions of the globose medulla of the cerebrum—contrary to the old opinion of Praxagoras and Philotimus, asserting the brain to be only a germination of the spinal marrow, of late revived by Bartholin—if any precedency of parts as to time may be allowed, I look upon them to be rather the origin than the production of the medulla oblongata and the spinal marrow too, and they may more properly be called the capita or heads than the crura of the medulla oblongata. The tops or ridges, as already observed, incline closely to one another, yea, they join together (as Vieussens has rightly observed, contrary to Willis, whose figures of that part are utterly false), unless where the rima or cleft leading to the infundibulum parts them, leaving, like the corpora striata, an obtuse angle between them. . . . The reason why they are called thalami nervorum opticorum is from certain fibres supposed to be in them, arising from their true medullary surface, by Vieussens called a medullary membrane, and some from within their own substance, which at last meeting together, make up the bodies of the optic nerves. . . . As for my part, I never could find any fibres at all appearing in their external medullary part, so those within are very small at best, and scarcely discernible. On the outside of these I have always found and often showed to bystanders a very fair medullary tract [tænia semicircularis] running all along between the corpora striata

[1] "Anatomy of the Brain," chaps. xiii. and xv.

and from the hindermost extent of the corpora striata in an anterior direction, down to the very roots of the fornix, with which they seem to be continuous" (pp. 121-123). "The crura are only the lower part of the thalami optici, which in their extremities become continuous with the under side of the medullary hinder part of the cerebrum. . . . Upon a diligent inquiry it appears that these crura are more deeply immerged and knit to the globose medulla of the cerebrum in an interior direction, by means of the corpora striata, as also by the medullary part of the cerebrum itself, which there, from the back or undermost winding part of the corpus callosum, is perfectly mingled with it. Where these two crura begin to come closely together, the pons Varolii, made up of the second process of the cerebellum, begins to cover the medulla oblongata" (pp. 139, 140). "The medullary tracts in the thalami optici on their passage downwards run out obliquely towards the side of the subjacent crura and the medullary caudex."

491. Winslow.[1]—"The optic thalami are so named because the optic nerves arise chiefly from them. They are two large eminences placed by the side of each other, between the posterior portions or extremities of the corpora striata. Their figure is semi-spheroidal and a little oval; and they are of a whitish colour on the surface; but their inner substance is partly greyish and partly white, so that in cutting them we see streaks of different colours almost like those of the corpora striata. These two eminences are closely joined together, and at their convex part they are so far united as really to become one body, the whitish outer substance being continued uniformly over them both. This substance is very thin, and falls to pieces only by the weight of the lateral parts of the brain when taken out of the cranium. . . . [Immediately within this common substance, these two eminences are closely contiguous till about the middle of their thickness; and from thence] they separate insensibly toward the bottom, where by the space left between them a particular canal is formed, named the third ventricle, one

[1] "Anatomical Exposition," etc., section x.

extremity of which opens forward, the other backward. Some anatomists have mistaken the superficial connection of these eminences for the pons Varolii. At the bottom these two eminences are elongated downward towards both sides, into two thick, round, whitish cords, which separate from each other like horns, by a large curvature, and afterwards by a small curvature turned forward in an opposite direction to the former, and representing the tip of a horn, they approach each other again. The size of these cords diminishes gradually from their origin to their anterior reunion" (section x. nos. 75-78).

492. Consult also Willis's plates in the "Anatome Cerebri," iii., iv., vii., viii., and in the "Anima Brutorum," v., vi., vii., viii.; Vieussens' plates vi., vii., viii., ix., x., xi., xii., xiii., xiv., xv., xvi.; and likewise Ridley's plate v.

[MODERN AUTHORS.

492*a*. QUAIN.[1]—"The *thalami optici* (posterior cerebral ganglia) are of an oval shape, and rest on the corresponding cerebral crura, which they in a manner embrace. On the outer side each thalamus is bounded by the corpus striatum and tænia semicircularis. The upper surface, which is white, is free and prominent, and is partly seen in the lateral ventricle and partly covered by the fornix. The part which is seen in the lateral ventricle is more elevated than the rest, and is named the *anterior tubercle*. The posterior and inner part of the upper surface, beneath the fornix, is likewise prominent, and is termed the *posterior tubercle* (*pulvinar*). The posterior surface, which is also white and free, projects into the descending cornu of the lateral ventricle. The inner sides of the two thalami are in partial contact one with the other. They present grey substance uncovered with white, and are generally connected together by a transverse portion, which forms the middle or soft commissure of the third ventricle" (ii. p. 549).

"The *optic thalamus* consists of grey matter which is mingled

[1] "Elements of Anatomy," eighth edition, London, 1876.

very uniformly with the interlacing fibres of which it is in great measure composed. . . . The *middle* or *grey commissure*, connecting the two thalami, consists of small cells, densely massed together, and containing yellow pigment" (ii. p. 563).

492*b*. "The *optic tracts* . . . are attached to and embrace the under side of the corresponding [cerebral] peduncles, and may be traced back to the thalami. Each tract is somewhat cylindrical towards the optic commissure, where it is connected with a deposit of grey matter adjacent to the tuber cinereum. It becomes flattened and broader as it approaches the thalamus, and makes a bend as it turns round the peduncle to reach the back part of that body. Near this bend, which is named the *knee* (genu), and to the outer side of the corpora quadrigemina, are placed two small oblong and flattened eminences connected with the posterior extremity of the optic tract. They are small masses of grey matter about the size and shape of coffee-beans, placed one on the outer and one on the inner side of the genu of the optic tract, and hence they are named respectively *corpus geniculatum externum* and *internum*. They send fibres into the optic tract and also into the thalamus of the same side. Other fibres go directly from the optic tract to the thalamus, passing between the outer corpus geniculatum and the crus cerebri, and others to the anterior corpora quadrigemina. The fibres of the optic tract are therefore derived from three sources, viz. the thalamus, the corpora quadrigemina, and the corpora geniculata" (ii. p. 551 *et seq.*).

"The *inner corpus geniculatum* contains small nerve-cells similar to those of the corpora quadrigemina, mingled with fibres which pass through it from the same source. Among them are also nuclei lying in clear spherical spaces. The *outer* is densely filled with large yellow branching and fasiform cells, and among them pass the fibres of the outer portion of the optic tract, gathered in four or six laminæ, which alternate with thicker layers of cellular substance" (ii. p. 563).

492*c*. Todd.[1]—"In the internal concave surface of each

[1] "Anatomy of the Brain," etc., London, 1845.

corpus striatum the optic thalamus is placed. The latter body is therefore posterior and internal to the former. The lighter colour of the optic thalamus distinguishes it at once from the corpus striatum. The optic thalami come into close relation to each other by their inner surfaces, which form the lateral boundaries of the third ventricle. Each optic thalamus, like the corpus striatum, presents a free and an attached portion. The former projects into the ventricle—the *intraventricular* portion; the latter adheres to the inner side of the corpus striatum and to the mass of the hemisphere, and posteriorly to the olivary columns, the corpora quadrigemina, and the processus cerebelli. The superior surface is free and forms part of the floor of the lateral ventricle; the internal surface is likewise free and forms the lateral wall of the third ventricle, being, however, interrupted in a very small space by the adhesion of the soft commissure. A portion of its external and posterior surface is also free, and projects backwards and outwards into the inferior horn of the lateral ventricle, presenting a pointed extremity in that situation. These free surfaces are smooth and moist, being covered by the membrane of the ventricles. The velum interpositum, which is itself overlapped by the fornix, rests upon the superior surface of the optic thalamus. The thalami are placed obliquely, so that they are nearer each other at their anterior than at their posterior extremity. Each measures about an inch and a half in length, nine to ten lines in height, and about eight lines in breadth" (p. 227 *et seq.*).

492*d*. "In point of structure the thalamus resembles a ganglion much more closely than does the corpus striatum. A light reddish grey is the colour of the surface when cut into; it has been not inappropriately compared to that of coffee mixed with a large proportion of milk (*café au lait*). When thin sections are examined, they are found to consist of very numerous fibres interlacing freely, with nerve vesicles occupying their intervals. The fibres are not collected into bundles as in the corpus striatum, nor do they take a radiating course in the thalamus. The reticulation which they form is very like that in the ganglia on the posterior spinal roots. . . . The fibres of each optic thalamus are extremely numerous, and have most extensive connections. Along its ventricular surface they are evidently continuous with those of the hemisphere, which appear to radiate from it to the grey matter of the convolutions. Posteriorly the fibres of the processus cerebelli ad testes and those of the olivary columns pass into it. The anterior pillars of the fornix are connected with it in front, and derive from it some nervous fibres; and below and within, a cylinder of fibres emerges from it to the corpora albicantia [bulbi fornicis]. Thus the optic thalami are connected with the hemispheres on the one hand, with the olivary columns and with the cerebellum on the other hand. . . . It is important to bear in mind respecting the optic thalami that they are directly continuous with the superior portion [tegmentum] of the crus cerebri, so that in viewing a vertical section of the encephalon we see no line of demarcation between. The thalamus grows as it were from the superior extremity [tegmentum] of the crus; it is recognised from the latter by its swelling into an ovoid mass. It is emphatically, as Willis long ago expressed it, an *epiphysis* upon the crus cerebri" (p. 229 *et seq.*).

492*e*. REIL.[1]—"The *optic thalamus* consists of several layers; and each layer is composed of grey and medullary substance; of which the former is situated interiorly, and the latter exteriorly along the outer edge of the thalamus. The arrangement of its fibres is radiate. The *uppermost* stratum seems to follow an antero-posterior direction; at least it is most easily lifted off from behind forwards. Between this and the following stratum lies the inverted root of the anterior pillar of the fornix; immediately under it is the radiation of the interior corpus geniculatum; it gives birth to the tænia semicircularis and terminates in the optic nerves. From the whole of its exterior upper surface, consequently from the surface of the optic thalamus itself, there

[1] "Das Hirnschenkel System oder die Hirnschenkel Organisation im grossen Gehirn," in the "Archiv der Physiologie," vol. ix., Halle, 1809.

descends a medullary membrane in the direction of its outer edge. Along the edge it is resolved into numberless flax-like threads, which are gathered up in a bundle, and from before backwards are wound around the margin of the thalamus, like a cloth around a turban. These threads lie immediately on the corona radiata, in a canal running along the outer edge of the optic thalamus, which is more or less smooth. The posterior and interior part of this medullary lamina gives out threads to the optic nerve. The grey substance of the corpus striatum is contiguous to this bundle, covering it; blood-vessels pass along between the two, and the epithelium of the ventricle spreads over this boundary-line between the optic thalamus and the corpus striatum. This organization it is which is usually called the *tænia semicircularis*. . . . In the descending cornu the extremity of the thalamus is divided into the optic nerve, and into a blunt thickened border which is situated under the optic nerve and covered by it, and which spreads out its fibres in the descending cornu in the form of rays, under the *tapetum*. If this layer is lifted off, the tænia is removed with it, and the corona radiata appears. In front the tænia terminates immediately above the anterior commissure.

"The *second layer* is a production of the interior corpus geniculatum. It spreads out on both sides. With its exterior portion it seems to pass over the outer edge of the crus cerebri, encircling the same like a ribbon in the inner capsule of the corpus striatum. It radiates anteriorly and passes in the direction of the corona radiata.

"The next layer in order is the *third* composed by the *lemniscus* (*Schleife*), which is the *lowest* in the direction of the crus cerebri."

492*f*. "The optic thalamus is thickest in its interior side. Towards its exterior edge it gradually becomes thinner. The medulla coming from the whole of its substance directs its course towards its exterior edge, where it forms a raphë, and merges in the corona radiata. If, therefore, the crus cerebri is severed immediately behind the optic thalamus, and if then its various layers, first the upper, then the second, and afterwards the third layer in the locus niger, are lifted up; and if these removals are continued to the exterior edge of the optic thalamus, it appears manifestly that the whole of the exterior edge of that body merges in the crus cerebri; that it interlaces with it, decussates, and forms a raphë, such as is found in various places, *e.g.* near the ganglion of the fifth pair. The corona radiata, consequently, is formed from above by the optic thalami, and from below by the crura cerebri. After the third layer in the locus niger, immediately above the basal surface (Grundfläche) of the crus cerebri, has been removed, it may be clearly seen how the crus cerebri spreads out underneath; how it preserves its peculiar radiated structure; how it remains almost unmixed, and pursues its course by itself as far as the raphë of the corona radiata; and how only in the raphë it becomes interlaced with the medullary radiation of the optic thalamus, the two together forming the corona radiata.

"The optic thalamus is so intimately related to the system of the crura cerebri, that it may be regarded as an integral constituent of the same, and that both may be considered as inseparable parts of one organization. The thalamus increases the bulk of the crus cerebri, and by this addition its radiation receives a circular direction. The corona radiata, which like a halo of rays surrounds the optic thalamus, is a continuation of both, *i.e.* of the crus cerebri and the optic thalamus. Under the optic thalamus the crus cerebri spreads out almost in the form of a circle, the focus of which is the optic thalamus itself as it winds around the crus cerebri. This circle commences anteriorly in the frontal lobe, opposite the genu of the corpus callosum; it passes over the Sylvian fissure, is continued through the anterior, posterior, and descending cornua of the lateral ventricle—ever around the optic thalamus; the exterior edge of which, just like the radiation of the crus cerebri, encompasses the trunk of the latter in a circular form. The circle ends in the descending cornu in the point of the temporal lobe, and at the entrance of the Sylvian fissure. The circles of the two hemispheres face one another vertically, their interior sides being turned towards each other, while with their exterior sides they form the lateral portions of the cerebrum.

"In order to exhibit to view this organization, a vertical section of the cerebrum must be made through the raphë of the corpus callosum. Afterwards the nucleus caudatus of the corpus callosum has to be removed in the anterior cornu of the lateral ventricle, and the tapetum in the posterior and descending cornua. The preparation must now be laid so that the outer side of the hemisphere is below, and its lower edge towards the beholder, when it will be seen how the rays of the corona radiata surround the optic thalamus, forming almost a complete circle around it which is interrupted only by a break in the entrance of the Sylvian fissure" (ix. p. 153 *et seq.*).

492*g*. MEYNERT.[1]—"The principal ganglia of origin of the *tegmentum* [see no. 480*a*] are: 1. The thalamus opticus. 2. The corpus quadrigeminum. These ganglia have in common, besides their connection with the spinal cord, a connection with the tractus opticus also. This latter connection they share with the corpora geniculata, which may therefore be regarded as an appendage to these ganglia. The tegmentum, moreover, receives fibres from: 3. The corpus albicans. 4. A ganglion embedded in the crural sling (ansa peduncularis). 5. The pineal gland" (p. 687).

492*h*. "The *thalamus opticus*, distinguished by the colour of its belt of white fibres, the stratum zonale, from the grey surface of the nucleus caudatus, seems at first glance to present its own grey ganglionic substance, exposed and uncovered, at that part of its surface which appears in the third ventricle. This ventricular grey substance forms in reality a layer foreign to the thalamus itself, and, together with the neighbouring tuber cinereum, with which it is continuous, with the infundibulum and the posterior part of the pituitary gland, belongs to the tubular grey matter" (p. 687 *et seq.*).

[1] "The Brain of Mammals," in Stricker's "Manual of Histology," American edition, New York, 1872.

492*i*. "An entirely false idea is formed of the shape of the thalamus opticus, if the superficial grey matter, of which we have just been treating, be regarded as making part of the ganglion. In that case it would appear as if the anterior extremity of the thalamus reached to the very base of the brain, whereas, in fact, this extremity is farther removed from the base of the brain than any other part of the ganglion; for the anterior extremity, which is the thinnest part of the thalamus, lies not only above the crus cerebri, but also above a part of the wedge-shaped nucleus lenticularis. . . . At the region of the tuberculum posterius the breadth of the thalamus is greater than at any other part; just in front of the axis comes its greatest thickness, and at its anterior extremity both dimensions are less than anywhere else" (p. 690).

492*j*. "The more or less complete separation of the substance of the thalamus into different nuclei is due on the one hand to the manner of entrance of the fibres of the first member of the projection system [see footnote on p. 552], and on the other to the mode of origin of the fibres of the crus cerebri within the ganglion; and the study of these two points will make clear to us the position of the supposed special nuclei.

"The superior member of the projection system then, coming from the frontal lobe, from the walls of the fossa Sylvii, and from the temporal lobe, penetrates in fourfold manner into the anterior extremity of the thalamus. In three directions blunt processes, so to speak, project from the substance of the thalamus to meet the fibres from the corona radiata, and unite with the compact masses of medullary substance as with *pedicles*.

"1. The *anterior pedicle* of the thalamus penetrates from the frontal lobe, between the corpus striatum and the nucleus lenticularis, directly into the anterior extremity of the ganglion, taking part, on its way, in the formation of the inner capsule of the nucleus lenticularis. Once within the substance of the thalamus, this compact group of fibres splits into a cone of diverging rays, in consequence of which the anterior part of the thalamus appears on longitudinal sections under the form of a blunted cone. The most superficial portion of this pencil of rays helps to form the stratum zonale, before it penetrates into the substance of the ganglion proper.

"2. The *inferior pedicle* of the anterior tubercle of the thalamus enters from the substantia innominata of Reil, splits up in like manner into a pencil of radiating fibres, and some of its bundles, especially in the inner division of the thalamus, may be traced a long distance backwards. This pedicle forms at its origin the third stratum of the ansa peduncularis. Its fibres spring from the cortex of the fossa Sylvii, and from that of the temporal lobe.

"3. The above third stratum of the ansa peduncularis is succeeded by a fourth, which also penetrates, but by a more indirect route, the substance of the thalamus, namely, by joining itself to the component fasciculi of the stratum zonale, which pass in spiral curves over the surface of the ganglion preparatory to entering the superficial layers of its grey matter. . . .

"4. The fourth mode in which the fibres of the first member of the projection system enter the anterior part of the thalamus is that adopted by the ascending branch of the crus fornicis, which represents the cortex of the gyrus fornicatus, and forms the *superior pedicle* of the thalamus. After making an S-shaped curve, in order first to pass to the inside of the posterior longitudinal fasciculus (hinteres Längsbündel), and then to reach a somewhat external part of the thalamus, this ascending crus fornicis passes directly forwards and upwards, and forking into two parts, as may be readily seen on cross-sections, it spreads out its fibres in the superior nucleus of the thalamus, whose anterior extremity gives rise to the protuberance on the surface of the ganglion called the tuberculum, or genu anterius" (pp. 690, 691).

492*k*. "The internal capsule of the nucleus lenticularis contains fibres destined not only for the anterior extremity, but also for the body of the thalamus opticus, which have their origin in the posterior part of the frontal lobe, and in the temporal lobe. . . . The merit of having first demonstrated on section-preparations the radiation from the inner capsule ['centrum geminum semicirculare,' Vieussens] into the thalamus opticus belongs to Kölliker" (pp. 692, 693).

492*l*. "In the posterior region of that part of the thalamus which is still exposed in the third ventricle, *i.e.* the part anterior to the posterior tubercle, the ganglion is in direct contact with the cerebral medullary substance proper, since at this region the inner capsule is no longer present, its limits being the same with those of the nucleus lenticularis, which does not extend so far posteriorly.

"In this region the thalamus may be separated into an upper and a lower division, marked off from each other by a process of medullary substance that projects between them. The grey substances of the upper and the lower divisions of the thalamus coalesce completely, and the two are traversed conjointly . . . by exactly similar radiating fasciculi that are arranged in layers, which alternate with layers of grey substance of about equal thickness in which the fibres terminate. . . .

"The radiating fibres, which are all apparently of the same nature, and which terminate thus in the conjoined superior and inferior divisions of the thalamus, have nevertheless two distinct centres of origin. Those of the *superior* division are to be traced, apparently without exception, to the medullary substance of the cerebral lobe of the same side, *i.e.* they originate in the cortex cerebri; while those of the *inferior* division come evidently from the tractus opticus, *i.e.* from the retina, forming the so-called 'middle-root' of the tractus. The latter set of fibres pass from the medullary substance of the optic tract between the external corpus geniculatum and the crusta cruris, about 12 mm. in front of the posterior border of the tuberculum posterius, into the substance of the thalamus" (pp. 693-695).

492*m*. "It is the fibres passing from the cerebral lobes into the thalamus by way of the *anterior and inferior pedicles* that run longitudinally through the inner district of the thalamus, and enter the *posterior commissure*. . . . These fibres are disposed in layers, which alternate regularly with layers of grey substance of about the same thickness with themselves, and in the cells of this grey substance . . . they terminate their course as cerebral fibres, and proceed again as crural fibres" (pp. 695, 696).

492*n*. "The posterior *external* district of the thalamus bears a certain resemblance, in point of structure, to the nucleus lenticularis, for here as there the medullary fibres of the cerebral lobes, as they pass in radiating lines towards their terminal cells, are intersected in their course by concentric fibrous laminæ, which, in both ganglia, are made up of fibres destined for the crus cerebri. Of these concentric laminæ within the thalamus, anatomists have given their attention to the innermost only, which Burdach designates as *lamina medullaris,* and which is described as separating the so-called external and internal nuclei of the thalami. . . . Luys describes this medullary lamina as enclosing, in the midst of the substance of the thalamus, a nucleus called by him the 'centrum medianum,' which is thereby sharply defined. . . . The cells of this mass do not differ in form or size from those of the rest of the thalamus. It receives its entering fibres from the anterior pedicle of the thalamus. This lamina medullaris, however, which encloses the inner nucleus of Burdach, the centrum medianum of Luys, is no independent formation, but only the innermost of a number of medullary laminæ, which contain bundles of fibres that run directly into the tegmentum cruris cerebri of the same side, without crossing the median line, as do those which pass through the posterior commissure" (p. 696).

492*o*. "While the anterior regions of the thalamus rest immediately upon the fasciculi of the inner capsule, or, in other words, upon the crusta cruris cerebri, which is still in process of formation, farther backwards two fan-shaped fibrous expansions from the corona radiata make their way between the crusta cruris and the thalamus into the substance of the latter.

"The fibres composing the *upper* of these fan-shaped groups form, by their convergence, a cylindrical body that becomes the centre of organization for its respective half of the tegmentum, and which receives the name of 'red centre of the tegmentum,' because it takes up among its fibres a large number of nerve-cells, and thereby swells to a ganglionic mass. . . . The *second* and more slender fan-like expansion of fibres, situated below the first, attaches itself to the pointed, outwardly-directed extremity of the locus niger. . . .

"After the entrance of these groups of fibres, the thalamus lies directly upon the crus cerebri, one of whose two parts, the *crusta*, presents a fully-formed structure, while the other, the *tegmentum*, becomes a complete structure only on the arrival of certain fibres destined for the spinal cord, which are contributed by the corpora quadrigemina, and its neighbouring ganglia" (pp. 696, 697).

492*p*. "The corpora quadrigemina and thalamus opticus, besides being in connection with the crus cerebri, both receive fibres, in common with the corpora geniculata, from the optic tract. . . . In the regions where the optic tract begins, or, more properly speaking, where it terminates its course, the posterior extremities of the thalami (tuberculi posteriores pulvinaris) diverge from each other, thereby leaving room for the insertion of the corpora quadrigemina, and project beyond the limits of the crura cerebri, which lies more towards the median line. Instead of upon these latter, the posterior tubercle rests upon the two corpora geniculata, and the fasciculi of the stratum zonale of the thalamus converge towards the commencement of the tractus opticus. In fact the stratum zonale is, as we have seen, made up of those fasciculi which come through the tractus from the retina, and of an arched tract of fibres which come from the medullary substance of the temporal lobe, and run parallel with the optic tract. This tract has then a twofold connection with the thalamus, once by way of the *superficial* fibres just mentioned, and again by way of the *deeper-seated* fibres described in no. 492*l*" (p. 697).

492*q*. "The tegmentum cruris, which is directly continuous with the posterior region of the pons Varolii, is not, strictly speaking, in a condition of complete organization even at the lowest extremity of the crus cerebri, but continues to receive additional fibres within the uppermost section of the pons" (p. 707).]

ANALYSIS.

493. THE cerebrum is the general motory as well as sensory organ, and it is also the general laboratory of the fluid essences of its body. The optic thalami as well as the corpora striata afford a vicarious aid to the cerebrum in these threefold functions.

494. In respect to *motion*. The optic thalami, like the corpora striata, depend upon the sole auspices and beckoning of the cerebrum, and they are not moved until the cerebrum begins to turn the hinges; for the optic thalami are furnished with striæ like the corpora striata, but with thinner ones; these striæ also in a like manner flow down from the upper circumference, but obliquely. The cerebrum with its medullary substance encompasses them in a like manner; it also sends out its fibres, and interweaves them with the native fibres of the thalami themselves; for the posterior region of the centrum ovale [corona radiata] passes around them, and ministers to them. The fibres of the thalami attached to, and entwined by, the fibres of the cerebrum, are altogether unable to act from their own forces, powers and origins, unless the cerebrum grants them permission; thus they do not depend at all upon the fibres of the corpora striata, but solely upon those of the cerebrum; for the former tend another way, being bent in an anterior direction, and by the interjection of the 'centrum semicirculare' they are forbidden to enter into the province of the thalami. Hence both corpora striata, that is, both the upper [or the corpora striata proper] and the lower [or the optic thalami], depend equally and distinctly upon the general motory organ, the cerebrum, and not upon each other.

495. The corpora striata and the optic thalami divide among one another the offices, and at the same time the provinces, of the medulla oblongata and the spinal marrow which are subjected to them. Thus the fibres of the corpora striata tend towards the anterior portions of the medulla oblongata and the spinal marrow; but the fibres of the thalami descend towards their posterior parts; for they run out in an oblique or downward direction, and are bent towards the corpora quadrigemina and the fourth ventricle, and so forth. This is manifestly shown by the striæ in brains that have been scraped, and also by the anatomical plates; in the brains of quadrupeds it is very conspicuous. The corpora striata are thus distinct bodies by themselves; and they, as well as the thalami, are the vicegerents of one and the same cerebrum, ministers of the same kingdom, and consorts of one bedchamber or of one ventricle; each having assigned to it its peculiar province, the government being divided among the two. They are, however, unanimous generals; for one does not proceed faster than the other; but both advance at the same rate as the cerebrum itself, because they all act, or are compelled to act, from one and the same beginning or origin of motion.

496. In respect to *sensation*. The corpora striata are placed over the sense of smell,[1] but the optic thalami over that of sight,[2] wherefore they are also called "thalami nervorum opticorum;" and both together minister to the senses of hearing, taste, and touch. For the roots of the olfactory nerves or bulbs are inosculated in the medullary tracts around the corpora striata.[1] The visual or optic nerves are immediately continued into the optic thalami;[2] but the nerves of hearing and taste are inrooted in the medulla oblongata, and those of touch in the spinal marrow. These two striated beginnings receive the modes of sensation running towards them; and after receiving them, they despatch them towards the cortical expanse, and towards the grey compages of the cerebrum; that is, the

[1] See Meynert in nos. 480*h*, 480*i* (3), 480*r*.—Editor.

[2] See Meynert in nos. 492*l*, 492*p*.—Editor.

corpora striata through the fibres of the medulla of the centrum ovale [corona radiata] which are poured around them in every direction; and the optic thalami through the fibres of the centrum semicirculare [inner capsule], the corpus callosum, and the fornix. In this wise the modes of sensation are directed into every quarter, the upper as well as the lower, the anterior as well as the posterior, of the hemispheres of the cerebrum; wherever, indeed, anything of the cortical and cineritious substance shows itself or lies hidden; for every cortical and cineritious particle is rendered conscious of the modes and of the least difference of each sense.

497. The sensory nerves of sight and smell derive their first roots from the fibres of both hemispheres of the cerebrum; those of hearing, taste, and touch from both these regions, as well as through the mediation of the medulla oblongata, and the spinal marrow; for the roots of every nerve are collected from the anterior and at the same time from the posterior part of their respective medulla or marrow. The sensual rays thus flash both through the anterior way to the corpora striata, and through the posterior way to the optic thalami; and from these bodies they are continued into the medullary ocean, and at the same time towards the common umbilicus, that is, the body of the fornix, against which both these bodies lean their heads, and to which they are joined. Thence as from a new centre, or from out a prison, they burst forth through the columns of the fornix into a spacious camp, even towards the ultimate goals of the fibres. In this wise these two striated bodies collect these rays into one, while they pour them forth at the same time into the circumferences. In addition there is a common and fundamental striated plane which is placed underneath the corpora striata, the thalami optici, and the pons Varolii; thence there is a continuous, orderly passage into the smallest, individual planes. Thence as through a royal road the modes of sensation seem to be transferred into both striated bodies [*i.e.* the corpora striata and the optic thalami], and thus to the medullary centre of the cerebrum. For whither the stream of the striæ leads, thither

also leads the stream of the rays, and indeed the continuous action of forces.

498. But in respect to the *chemical operations* of the cerebrum, the corpora striata are the general motors of its organs; while the optic thalami are not only the motors, but also the regulators and dispensers of the fluids. Thus to each its task is appointed by the cerebrum, which is the governor or ruler of all.

499. These bodies [*i.e.* the optic thalami] are the general motors; since they occupy the very bottom of the ventricles, and extend to their extreme cornua. By their alternate motion of expansion and constriction they excite not only the ventricles, but also the remaining cavities and organs, into their motions, and into their offices. If we scrutinize more closely the form of their curvature, the fibres of their surface, and the compages of their striæ, it appears that they inflect and wind themselves back in the manner of a slow helix or spiral line, and that thus they go through their alternate motion of expansion and constriction with a higher power. This appears plainly from their superficial fibres, which have an oblique direction, and which are followed by those which are peculiar to the bodies themselves; it appears also from the commissure of the optic nerves, which wind themselves back in the form of knots, and are reunited by an opposite flexure. It likewise appears from the descending cornua, and the posterior part of the cerebrum, the edges of which are incumbent upon the tentorium, which here is reflected in an anterior direction; and which edges at each expansile motion wind back in conformity with this bent; such also is the case with the posterior cornua which are dug into this part of the cerebrum. This is a general principle, that the efforts of all the parts of the brain are into spiral windings, or into lines which are perpetually circular. The ventricles thus not only fold themselves together, and unfold, with perfect ease, but the corpora striata also in this manner exert a strongly urging power upon the cavities, and stimulate every organ into its function.

500. The optic thalami, however, are not only motory powers,

but also general regulators; for they extend their broad upper part, or their heads, between the two centres or fulcra, that is, between the body of the fornix and the pineal gland, and thus also between the two foramina which connect the ventricles. They also enclose between them the fissure which is called the third ventricle. This ventricle is compressed into a rima or cleft whenever the thalami unfold and press upon it, and it is expanded into a ventricle whenever they fold themselves together and subside. In a like manner they extend the sphere of their activity into the infundibulum; they also send out fibres towards the orifices of the infundibulum, as well as towards the anterior tubercles of the corpora quadrigemina and the pineal gland, and besides towards the valve of Vieussens, the fourth ventricle, the calamus scriptorius, and so forth. The thalamus of one ventricle is also joined to the thalamus of the other lateral ventricle through the interposition of a medullary tract [the posterior commissure]; and it thus feels and equalizes, whenever an irregularity happens in either of the two bodies. The optic thalami are thus the common regulators of the organs of the cerebrum; for every singular or least particular has its universal placed over it, otherwise the singulars would be scattered; and unless they had respect to the common ends they would be distracted. The function of these bodies as dispensers will be discussed in the following chapter, which treats of the choroid plexuses.

[The functions of the optic thalami, as defined by Swedenborg, will be found discussed in the light of modern science in Note iv.—EDITOR.]

CHAPTER XIV.

THE CHOROID PLEXUSES.

501. The choroid plexuses are expanses of singular form and structure, where a retiform texture is formed by blood-vessels decreasing in a series, and also increasing in a series. Vessels more conspicuous and large keep near the shore, and they throw a texture obliquely across from border to border. They also at acute angles send off shoots to the opposite border, where they pass along forming knots or loops. In the quadrangular or reticular spaces thus obtained there are inserted tissues following the same direction; and at last there are added to them capillary threads more slender than the rest and filled with blood. All these, which succeed one another in an undulating manner and in serpentine windings, show that this whole meshed texture may be expanded in breadth and extended in length, and that like a fisherman's net it can be unfolded and stretched into more or less angular, open, and rhomboid forms. There are as many of this kind of woven expanses, or skilful webs, called choroid plexuses, as there are ventricles. The two larger plexuses, of which there is one in each lateral ventricle, are carried along the thalami optici from the descending cornu of the lateral ventricle to the body of the fornix, like little roots through the soil, or like dewlaps, or finally like a long and crisp body of hair. Their extremities depend upon the arteries whence they originate, and their sides upon shoots from the parent arteries, and also upon veins; their middle portion, however, upon the knots or loops which bind together the shoots and twigs. The plexus of the third ventricle is continued under the anterior root of the fornix near the septum

lucidum; into this plexus the two former lateral plexuses are as it were folded and twisted back; and in a straight line the two branches pursue their course together through the third ventricle towards the pineal gland and the corpora quadrigemina. These they seem to embrace in a reticular manner by a certain expansion, and to fix themselves still more deeply into the entrance to the threshold of the passage which is underneath the corpora quadrigemina [the aqueduct of Sylvius]. Thence innumerable venous capillaries, as well as somewhat larger branches, enter into the straight sinus, and through this are carried to the surface, and hence into the lateral sinuses, and afterwards into the jugular veins. The choroid plexus of the fourth ventricle does not penetrate down to the bottom [*i.e.* to the calamus scriptorius], as it does in the lateral ventricles; but under the cerebellum which presses upon it, it stops up and interweaves the lateral extremities of the ventricle. At its own extremity, however, one plexus goes across and embraces that on the other side; and thus, like the two lateral plexuses, the twin plexuses also here form one continuous texture. In the velum interpositum, the septum lucidum, the isthmus, and in other places whither the pia mater is continued, there is presented manifestly a similar network of sanguineous capillaries. Those textile, and in a certain manner pendulous choroid sails cherish in their bosoms also glandular forms which are inserted into them, and in which the last threads of the arteries and veins terminate. Morgagni observed in the hindermost vault of the ventricles large vesicles collected as it were into clusters, and distinct from blood-vessels; others have discovered follicles and hydatids swollen with serum, which on account of the winding of the vessels and their little anfractuous gyres, they thought to emulate glands. Willis, Vieussens, Ridley, Winslow, and others saw several most prominent instances of this kind in diseased as well as in healthy brains; they were most prominent in the case of hydrocephali; in the obsolete and superannuated brains of old persons they discovered almost continuous follicles forming a watery and bloodless plexus. A continuous lymph-duct from the pineal gland was seen by Nuck and another by Ridley. The anterior choroid plexuses sometimes derive some blood from the carotids, but their chief supply is from the vertebral arteries. For in the bottom of the cerebrum on the pons Varolii, between the pituitary gland and the infundibulum, there is a place where the carotids send down, or the vertebral arteries united in one stem send out, branches; these meet together and with their combined blood they descend into the lateral ventricles, and originate those twin plexuses of a larger size, a little before entering the cavities. After being thus born, each climbs up to its thalamus opticus as far as under the anterior pillars of the fornix; and there, after coalescing into one body by a mutual inosculation, they make a turn and pursue their way backwards along the third ventricle. Out of the common trunk of the vertebral arteries [the basilar artery], after it has described a short arc, between the optic thalami as far as the top edge of the pons Varolii, another branch runs out below, which after joining the above-mentioned common branch, forms a broad, reticular expanse, enveloping the pineal gland and the anterior tubercles of the corpora quadrigemina, and thence passing towards the fornix where the plexuses of the three ventricles coalesce; and thus on the one side, according to Ridley, there enters the plexus of the third ventricle, and on the other the plexus of the fourth ventricle. Two veins [the veins of Galen] also run out from the fornix, pursuing their way along the whole length of the third ventricle as far as the straight sinus, and joining together in the middle, but presently [in the torcular Herophili] they divide again in a downward and then upward direction.

502. WILLIS.[1]—"The choroid plexus seems to be suspended above the pineal gland, as by a clasp. This plexus, however, is composed in the following manner: from either side of the medulla oblongata, where the edge of the cerebrum is connected with it, two arteries arising from the posterior branches of the carotids where they are united to the vertebral arteries, ascend

[1] "Cerebri Anatome," etc., cap. ii., xii., xiv.

in a straight line. These upon being divided, like so many little rivulets placed together, are carried towards the pineal gland, and there they seem to terminate by meeting with one another. In that place venous shoots which are sent forth from the straight sinus above the pineal gland, proceed on both sides; these upon being divided in a like manner into filaments encounter the capillary arteries, and are inosculated into them in many places, and are likewise woven together in different modes; so that these vessels, copiously interwoven with one another, and interspersed with glands, form wonderful plexuses. These plexuses of blood-vessels, with two wings as it were spread out, are stretched on both sides over the thalami optici as far as the corpora striata; they are, however, only incumbent upon their surface, and are not affixed to them by the insertion of blood-vessels; nor are they attached to the medulla oblongata, nor to the corpus callosum; so that the blood, no supply of it being made to the parts underneath, seems simply to be brought to these places, and to be taken away again" (pp. 19, 20). "It must be maintained that a serous liquid distils into the ventricles from the glands interspersed into the choroid plexuses when they are too full. I have often in cases of dropsy in the brain noticed these glands swollen like barley-grains, and burst by too much moisture, becoming flaccid, so as to be unable to retain the serum conveyed to them, and continually emptying it into the cavity underneath. In cases of dropsy of the brain these cavities or ventricles are always found replete with water. . . . In order, however, that the serum which pours everywhere out of the vessels may so much the better trickle into the ventricles, it has been arranged so that the larger plexuses of blood-vessels, interspersed with glands, should be placed near each of the ventricles of the brain; wherefore the choroid plexuses are not only placed in the brain near the meeting-place of the three ventricles; but a second plexus, and by no means an insignificant one, with larger glands, has been placed in the neighbourhood of the cerebellum, near the fourth ventricle" (p. 76). "For it must be observed that the choroid plexuses are thickly studded and interwoven with a large number of smaller glands; . . . for this reason the pineal gland which is of larger size is placed where all the blood-vessels meet, in order that it may receive and contain the serosities which are deposited there in greater abundance. . . . I have often noticed in cases of dropsy of the brain that this gland with its roots too much loosened by moisture, and not seldom torn off, was removed from its place, suffering the choroid plexus to collapse by its own expansion, and to sink down lower; nay, it allowed also its vessels to be inordinately complicated" (p. 90).

503. VIEUSSENS.[1]—"After the fornix, while it is still preserved in its natural position, has been inspected, the choroid plexuses are brought into view. They are an aggregate of little arteries and little veins, which together with the interspersed glandules constitute one reticular body. In the lateral ventricles two choroid plexuses are found, which extend from the posterior region of the above ventricles to the double [anterior] root of the fornix, where they terminate. These plexuses, as well as that which is observed in the fourth ventricle, are called choroid because the blood-vessels of which they consist emulate in a certain measure the intricate structure and peculiar form of the vessels which irrigate the membrane called chorion" (p. 61). "After the vertebral arteries, during their course under the cranium, have sent out two branches which are distributed over the posterior part of the dura mater, they at once throw out two or three shoots. Some of these during their passage towards the interiors are bent down and incline towards the posterior and lateral parts of the spinal marrow; others, however, have an upward tendency; they climb over the olivary bodies on both sides, and after passing over the posterior edges of the fourth ventricle, they meet at its extremity a great number of little veins which tend towards the fourth ventricle; many little glands also are placed between them, so that one plexus is formed of the many little arteries, veins, and glands which are in this wise woven together. The structure of this

[1] "Neurographia," etc., cap. xi., vi., xvii.

plexus is not unlike that of the two choroid plexuses which belong to the lateral ventricles of the cerebrum" (p. 33). "Some shoots of the branches of the basilar artery, being inserted into the sides of the medulla oblongata, and coupled there with certain little arteries from the carotids, in an ascending direction enter into the posterior part of the lateral ventricles of the cerebrum; and in their ascent give out certain most slender little branches to the pineal gland, the corpora quadrigemina, and to the internal surface of the fourth ventricle. At last the farthest anterior shoots of these arteries, after entering the ventricles of the cerebrum, recline on the thalami optici, and there together with little veins tending towards the straight sinus and emptying into it, they form a choroid plexus on each side. Not a few glands are woven into these plexuses, which sometimes are so teeming with a limpid liquid which they contain, that by reason of its greater or lesser abundance, every one of them acquires the size of a small pea and the shape of a vesicle or little bladder. This I observed in company with Dr. Chicoyneau in the head of De Cœur de Chesne, whose earthly existence was closed by a bad predisposition of the lungs, which had caused hydrocephalus. The glands, however, which are interspersed in the choroid plexuses, intercommunicate with one another. I opened only one gland of one choroid plexus, and through this the remaining glands upon being slightly pressed with the finger, distilled the pellucid humour which they contained. Besides, a great many shoots of arteries and veins with which they are interwoven, terminate in them; and we conjecture that, as in the case of the infundibulum and the lymphatic vessels, they convey thence a certain aqueous humour which they receive, and which in their turn they empty either into the third ventricle or into the straight sinus. Moreover, certain little veins and arteries emerge out of the choroid plexuses, some of which pass into the anterior processes of the medulla oblongata, and others into the interiors of the thalami optici" (p. 35).

"The choroid plexuses seem to be composed rather of lymphatic vessels than blood-vessels; and the glands in the plexuses contain scarcely any blood, but only an aqueous humour" (p. 109). "The fornix has lateral parts which are thin, very soft, and a little extended; these reach to the anterior parts of its crura, and are called the fimbriæ of the fornix. Some portion of the choroid plexuses is underneath them on both sides, and adheres to them" (p. 60).

504. RIDLEY.[1]—"The choroid plexus is an aggregate body made up of arteries, veins, membranes, and glands, double on each side (which has not heretofore been noticed), and therefore having two origins. The first origin is from the anterior branch of the communicant artery, which running backwards up between the hinder lobes of the cerebrum (in which for some part of the way it is immerged, and to which it gives many large branches) and the medulla oblongata, at length arrives at the lateral ventricles, and makes one part of the plexus on each side. The second origin is from the hindermost branch of that communicant artery, which running in a more backward direction, ascends between the hinder edges of the cerebrum and the cerebellum, till it comes to the corpora quadrigemina, where communicating with the first branch above mentioned, it makes a reticular broad expansion, which covers both the anterior and the posterior tubercles, and the pineal gland, and constitutes the second, or the other part of the choroid plexus. The first branch begins to divide itself into various reticular foldings, interspersed with glands, somewhat before it enters the ventricles, and continues such to its extremity on each side, where both under the fornix wind across the third ventricle into a mutual inosculation. The second branch assumes the same shape or contexture as soon as it begins to enter the region of the corpora quadrigemina, continuing the same throughout its entire expansion mentioned above. These two on each side are joined together by a twofold connection; the first is by an artery running under the descending cornua of the lateral ventricles, intervening between them, which could not be inserted [on plate i.] so as to come to view. The second branch is by a production of the pia mater which is

[1] "Anatomy of the Brain," chaps. vii., xiv.

extended all over these parts of the lateral ventricles, and the third ventricle which lies between the first two parts of the plexus in an anterior direction, and down to the other two parts of the plexus in a posterior direction under the fornix and the septum lucidum; so that whatsoever water is transmitted out of these ventricles, must slip down not only under the fornix, but under that membranous production itself. From this kind of structure and position of this membrane it may probably be understood how there might happen such a hydrocephalus as the learned Tulpius mentions, in which there was found above two pounds of water in one ventricle, without any at all in the other; and such another as Wepfer mentions, where the water causing the hydrocephalus in a heifer was found contained in a cyst, and that only in the left ventricle. For, supposing the membranous production of the pia mater to be double here, as it is certainly in all other places, it is not difficult to conceive that the water which is extravasated must needs insinuate itself between the two laminæ, until by a continual increase it extends them into the shape of a large bladder, such a one as the latter authority found there, and drew out with his fingers. And what settles it beyond controversy that this was so, is that both above towards the corpus callosum and below on the bottom of the ventricle, he found some sort of asperities, as though the bladder filled with water had been covered with some small protuberances, not much unlike white poppy-seed, *i.e.* in those places where it was contiguous to the before-mentioned organs. These protuberances doubtless were the small glands interspersed quite through this plexus. . . . Besides these veins which are very truly described by Willis, I have always found two meeting the anterior extremities of this plexus, from between the two first lobes of the cerebrum, where it seems to end under the anterior part of the corpora striata, by which it is there fixed and as it were kept in its due situation; and from these branches are on each side sent forth many more little ones to the corpora striata, and several other parts adjacent. To this plexus belong also veins, which from the extremities of that part of it which is in the lateral ventricles, begin to enter into two distinct pretty large trunks, running down through the middle of the third ventricle as far as the straight sinus, and there receiving some branches from the other posterior part of the plexus spread over the corpora quadrigemina, discharge the refluent blood into that sinus. But besides this sort of reductory vessels it has also another, namely, lymph-ducts, which I first discovered in the brain of a strangled body, and showed to several then present, running in different ramifications amongst the reticulated vessels and glands of this part. This observation being added to that of the great anatomist Anthony Nuck (who in that curious work called 'Adenographia' says he saw one duct coming from the pineal gland, and that his friend, another anatomist, sent him word he saw another not far from the aforesaid place) may be of sufficient authority to evince the real existence of these vessels. . . . The glands belonging to this plexus are very many, but very small. . . . The choroid plexus is situated upon the middle of the thalami optici, all along them lengthways, and, contrary to what Willis says, is, by virtue of several blood-vessels, joined to that medullary part of the cerebrum so called, lying immediately under it" (pp. 57-63).

"What has been said of the choroid plexuses in the ventricles of one part applies also in part to the plexus of the fourth ventricle. This choroid plexus in the fourth ventricle begins to be glandulous just under the eighth pair of nerves, from whence it runs up on the side of the medullary caudex to the inferior peduncles or the third process of the cerebellum; and thence it enters the fourth ventricle, by Aurantius called cisterna spirituum. This plexus does not lie loose therein, nor at the bottom of it, as the plexus does in the ventricles of the cerebrum, but quite the reverse—which has not heretofore to my knowledge been observed—adhering closely to the top of this ventricle, or the bottom of the superincumbent cerebellum; then running transversely just at the end of the calamus scriptorius, it becomes continuous there with the plexus of the other side. . . . This plexus arises from a ramification of the second or hindermost branch of the basilar artery, as does one part of the other plexus of the cerebrum mentioned above; but another smaller branch of the said artery about the place where it ascends from the vertebrals (which last branch turns into a reticular expansion first, and then a little farther on meets with the others), constitutes this plexus" (pp. 133-135).

505. WINSLOW.[1]—"The choroid plexus is a very fine vascular texture consisting of a great number of arterial and venous ramifications, partly collected in two loose fasciculi, which, one in each lateral ventricle, are partly expanded over the neighbouring parts, covering in a particular manner the thalami optici, the pineal gland, the corpora quadrigemina, and the other adjacent parts both of the cerebrum and the cerebellum, to all of which it adheres. In each lateral portion of this plexus we observe a venous trunk, the ramifications of which are spread through the whole extent of the two portions. Near the pineal gland these two trunks approach each other, and uniting behind the gland, they open into the torcular or the straight sinus. Upon blowing into one of these branches or trunks toward the plexus, the air passes into all its ramifications; and in some subjects these two veins form one trunk which opens into the sinus. The pendulous portions in the ventricles appear to be studded with little corpuscles, like glandular grains, but which in the natural state are extremely small, growing bigger in diseases; if these are immersed in water, and carefully expanded, then by the help of the microscope these corpuscles appear like simple follicles, or little vesicles more or less flattened. The sides of the fornix, of the eminences, ventricles, canals, and infundibulum, are all covered by a very fine membrane, in which by injections or inflammations a great number of very fine vessels is discovered which are very much interwoven. This membrane is in a manner a continuation of the plexiform web, and seems to be a continuation of the pia mater" (section x. nos. 87-90).

[1] "Anatomical Exposition," etc., section x.

506. RUYSCH.[1]—"The choroid plexus is nothing else than juicy little arteries, twisted about in a wonderful manner, and creeping in a serpentine direction, and representing glands, of which it is however destitute (Tabula xv. fig. iii. B, explanation). This author had drawn 'a portion of the choroid plexus replete with hydatids' (*ibid.*, fig. i., explanation); and likewise 'the choroid plexus with a portion of the pia mater attached to it, in which innumerable little arteries appear belonging to the pia mater' (*ibid.*, fig. iii., explanation)."

507. MORGAGNI.[2]—"According to Ruysch the choroid plexus is not furnished with any glands; but that which appeared gland-like to some arises from a contortion of vessels, concerning which the writers in the 'Acta Eruditorum' say that 'on account of their anfractuous little gyres they have the deceptive appearance of glands; for the hydatids which are often met with in the choroid plexus are nothing else than blood-vessels swollen with serum.' I remember, however, that when I exposed to the light a portion of the choroid plexus which I had taken out of a very healthy body, and when I examined it with the aid of the microscope, I saw most elegant little vesicles of various sizes collected in the form of clusters, and sufficiently marked against most slender blood-vessels which crept around them. The same were also seen by some of my friends from Venice. . . . It is also worth considering why the largest of these hydatids very often, and chiefly, according to my observations, are found in that part of the plexuses which is hidden in the hindermost vault of the lateral ventricles" (p. 8).

508. Consult also Vieussens' plates vi. and vii., in the last of which there is a connection by means of blood-vessels with the posterior pillars of the corpus callosum; likewise Ridley's plate v., where these plexuses run in a winding form over the thalami optici, and at last apply themselves in the descending cornu of the lateral ventricle to the farthest extension

1 "Opera Omnia," etc., Amsterdam, 1737. Epistola Anatomica Problematica xii., Amsterdam, 1738.

2 "Adversaria Anatomica," vi.; Animadversio vii.; Lugduni Batavorum, 1740.

of the corpora striata; different from what is shown in Vieussens' plate v.

[Modern Authors.

508*a*. Key and Retzius.[1]—"The authors on anatomy generally agree that the velum interpositum consists of two leaves, which must be regarded as a continuation of the pia mater covering the parts of the cerebrum outside of the velum, and which consequently must be considered as a duplicature of the pia mater. The upper leaf of the velum is an immediate continuation of the pia mater covering the posterior thickened border (splenium) of the corpus callosum, and the surrounding parts of the cerebrum. The lower leaf, on the other hand, is a continuation of the pia mater of the lamina corporum quadrigeminorum, of the crura cerebri, and of the hinder portion of the optic thalami. The pia mater cannot pass directly into the velum interpositum from the upper surface of the cerebellum, as is often stated. The two leaves of the velum interpositum are, indeed, related to the parts of the cerebrum which they cover, in exactly the same way in which the pia mater in any of the sulci of the cerebrum is related to the parts of the cerebrum which it invests" (p. 103).

"In our sub-arachnoidal injections made from the spine we have often obtained a complete impletion of the velum interpositum, as far as the lateral choroid plexuses, which along its edges extend into the lateral ventricles; but the injection has never extended into the projections of the plexuses themselves, as little as into those of the median plexus of the third ventricle" (p. 103).

"There is consequently nothing peculiar in the structure of the velum interpositum by which it is distinguished from any ordinary duplicature of the pia mater; the only peculiarity lies in its position. The question, however, arises, What is the

[1] Axel Key and Gust. Retzius, "Studien in der Anatomie des Nervensystems und des Bindegewebes" (Studies in the Anatomy of the Nervous System and the Connective Tissue), Stockholm, 1875.

relation of the velum interpositum to the choroid plexuses proper? and why is it that the sub-arachnoid spaces do not penetrate into their projections? We shall first direct our attention to the plexuses of the lateral ventricles."

508*b*. "Generally these plexuses, when fully developed, are considered as an immediate continuation of the velum interpositum, from the edge of which along the borders of the fornix they take their origin, floating freely in the contents of the ventricles. We take the liberty of quoting here, as an expression of the commonly-received opinion, the presentation of Henle.[1] 'Laterally, along the edge of the fimbria of the fornix, the velum interpositum is lost in the ependyma of the optic thalamus, and also in an interior direction it is continued along the surfaces of the septum lucidum into the ependyma of this organ; while in the middle where it strikes upon the anterior pillars of the fornix it terminates in a free border, where the choroid plexuses of the cerebrum are joined together.' Concerning the plexus itself he says, 'The lateral plexus runs along the lateral edge of the velum interpositum, and through the foramen of Monro (which it probably fills up completely, when filled with blood) it gets into the lateral ventricle. In the anterior horn of this it lies freely between the septum lucidum and the corpus striatum; afterwards it accompanies the fimbria fornicis into the middle or descending horn. By turning in a median direction its free edge, which is teeming with choroid villi, the lateral plexus covers the fimbria in such a manner that its edge becomes visible only after the plexus is folded back exteriorly. The fimbria of the fornix lies in a fold, the lower wall of which is formed by the velum interpositum proper, while its upper wall is formed by the edge of the velum bearing the choroid villi which is folded back in a median direction.'"

508*c*. "The arrangement of the choroid plexus itself, even in a thoroughly-developed brain, is, nevertheless, not so simple as

[1] Henle (J.), "Handbuch der systematischen Anatomie des Menschen," part iii. section 2 (Nervenlehre), Braunschweig, 1871, p. 319.

appears from descriptions, and from the exhibition which is generally presented to the sight in dissections—this arrangement, indeed, in so far as we have been able to find, has at present thoroughly escaped the attention of the anatomists. The dispositions which we are about to set forth, we have first observed in transverse sections of frozen brains, which in their frozen condition were placed in Müller's fluid and in alcohol. Afterwards we succeeded in corroborating our results by observations made with brains the interior parts of which were well hardened in alcohol" (p. 164).

"In such preparations it becomes apparent that the lateral plexus is not simply furnished with projections, which are thrown out in all directions; and, further, that it is not suspended freely from the edge of the fimbria in the ventricle; but that in reality it consists of two leaves, an upper and a lower one. Either close by, or at a very short distance from, the fimbria, the two leaves are joined into one common, very narrow leaf or ribbon which is attached to the edge proper of the fimbria. The two leaves in the arrangement of their walls bear some similarity to a boat lying on its side, the keel of which represents the common edge by which the leaves are fastened to the border of the fimbria. Or perhaps the relation is still better represented thus, that from the thin, sharpened edge of the fimbria there runs out as it were an immediate continuation of the same, namely, a kind of thin, narrow outgrowth which may be called the root (or keel) of the plexus. This root very soon, sometimes close to its origin, is cleft into two very thin leaves, which bend asunder, each describing the form of an arc. The *upper leaf* turns upwards towards the roof of the ventricle, following the same as far as the lateral edge of the ventricle itself. There it ends in an edge which is mostly free. In this position it is held by blood-vessels which here and there pass into it from the roof of the ventricle. These blood-vessels are lined by the ependyma, whereby the roof as a whole is covered. This upper leaf, therefore, is comparatively free. Both its surfaces are covered with epithelium, which is a continuation of the epithelium lining the ependyma; and from both these surfaces, on either side, choroid projections or villi are shooting out. In the edge of this leaf is the vena choroidea which runs along in loops. With the velum interpositum this upper leaf has no connection whatever."

508*d*. "The *lower leaf* occupies a different relation altogether to the velum interpositum, as well as to the wall of the ventricle. As is shown in the accompanying plates, it extends from the common root, along the edge of the fimbria, towards the bottom of the ventricle; and at some distance from the tænia semicircularis, which is between the corpus striatum and the optic thalamus, it passes over immediately into the ependyma of the optic thalamus. Often the ependyma is a little thickened where the leaf is attached to it. The epithelium of the ependyma is naturally continued only on the upper surface of this leaf. From this surface there shoot out the choroid projections in various, peculiar forms, which cannot be described here, and which are like small, folded leaves and so forth. These projections shoot out either directly, or through the mediation of a trabecular structure which is more or less membranous. Where the lower leaf is fastened to the thalamus long projections or villi are usually thrown out, which are directed outwards, so that with their extremities they cover the thalamus, and reach the border of the corpus striatum. The optic thalamus is thus almost altogether covered with choroid projections. The lower leaf of the choroid plexus now enters into a most intimate conjunction with the edge of the velum interpositum. As may be seen in the illustrations to which reference has been made, this lower leaf covers the intermediate space between the fornix and the optic thalamus, in which the velum interpositum is situated; but by the oblique course of the choroid leaf this intermediate space or tract is prolonged outside the edge of the fimbria in such a manner that it is continued between this leaf and the optic thalamus until the former becomes attached to the latter."

508*e*. "The velum interpositum, with its sub-arachnoidal tissue and its blood-vessels is now continued in this intermediate space as far as the place where it is fastened to the thalamus; and throughout the whole of this space it sends out blood-vessels towards the choroid plexus, and is so intimately conjoined with the lower leaf of the plexus, that wherever the choroid plexus extends itself, it goes attended by the velum interpositum; especially as all its other connections, at the least exertion, are easily broken. Whenever the velum interpositum is injected from the sub-arachnoidal space, the liquid is continued to the place where the lower choroid leaf is fastened to the thalamus; but, as stated above, it never extends into the choroid projections themselves. The arrangements detailed above furnish a clue to this fact."

508*f.* "From the above, indeed, it appears that the pia mater or the duplicature of this membrane—which together with the attendant vessels and the sub-arachnoidal tissue forms the velum interpositum—even in a fully-developed brain, does not penetrate into the lateral ventricles in order to form there the choroid plexuses; but that the velum on either side is separated from the ventricles by the lower choroid leaf, with the lower surface of which, destitute of choroid projections and epithelium, it is most intimately connected."

508*g.* "The fundamental tissue proper of the choroid plexus originates chiefly from the fimbria of the fornix, and with its lower leaf it is fastened to the ependyma of the thalamus, at some distance from the tænia semicircularis. . . . The substance proper of the cerebrum, in the fully-developed brain, seems to terminate abruptly at the edge of the fimbria, and not to be continued into the root of the plexus, or into its two leaves. If we leave out of consideration the choroid projections, the fundamental mass of the two leaves consists of a fibrillary tissue with comparatively large, protoplastic cells. This tissue in the root [of the plexus] is shown to be an immediate continuation of the edge of the fimbria of the fornix, as well as of the ependyma on its upper surface. Besides, both leaves, everywhere on their free surfaces, are covered by an epithelium which is a continuation of the epithelium of the ependyma, and which invests also the choroid projections shooting out from the two leaves."

508*h*. "The relations which have been described here, agree very well with the history of the genesis of the brain, according to which the choroid plexuses are developed in the ventricles independently of the pia mater. Reichert[1] among other things says on this subject, 'The universally-prevailing idea on the subject of the choroid plexuses is no doubt this, that they are to be regarded as excrescences of the pia mater. The *first* genesis and formation of these plexuses, however, has shown that they grow out of the ependyma, and communicate with the pia mater only by means of blood-vessels.' It is now shown that the fully-developed plexuses also bear in themselves the evidence of such a genesis" (pp. 105, 106).

508*i*. "What has been adduced above explains the circumstance why in sub-arachnoidal injections the liquid spreads over the whole velum interpositum, but does not enter into the lateral choroid plexuses. Exactly the same arrangement prevails in respect to the median plexus which enters into the third ventricle from that part of the velum interpositum which is stretched out over it, and forms its roof. Here also the injection does not penetrate into the choroid folds, although the median portion of the velum is usually injected very fully. As well known, the velum interpositum on each side sends down along the declivitous, interior side of the thalamus a fold fastened to the 'tænia thalami optici' [stria pinealis]. Along the interior side of this fold are situated the two strands of the median plexus, which in front are pressed closely together, but in the rear have an open space between them. In the present case it is not from the lower pia-leaf of the velum interpositum that the choroid folds shoot out. . . . But, as in the case of the lateral plexuses the choroid tissues are excrescences of the fimbria of the fornix, so in the present case also, even in the fully-developed brain, these tissues shoot out of the stria

[1] Reichert, "Der Bau des menschlichen Gehirnes," Leipzig, 1861.

pinealis, forming more or less a diminutive vault over the third ventricle; from this vault the choroid folds are cast forth. The lower pia-leaf of the velum interpositum is closely united with this thin medullary wall, and on the outside of, or above, the pia mater there is in the velum interpositum the sub-arachnoidal tissue with its blood-vessels, branches of which pass into the folds. The roof of the third ventricle formed in this manner, and with the choroid tissues attached to it, thus runs along the stria pinealis, and passing along the lateral edges of the pineal gland, its two ends meet on the upper surface of the pineal gland, a little before its pointed extremity" (p. 107).

508*j*. LUSCHKA.[1]—"In claiming for the choroid plexuses a glandular nature, an expression is given of their functional significance, although not of their natural organization. As the choroid plexuses were formerly looked upon as organs of secretion, so we are still justified in regarding them in the same light. But while formerly the secretory agency of the choroid plexuses was attributed to specially-individualized glands, modern investigation acknowledges as the source of this activity a cellular tissue spread out over their surface" (p. 10).

508*k*. "*Blood-vessels.*—In the peduncle of each choroid projection there may be distinguished stems of two kinds of blood-vessels, of which the one has the character of an artery and the other of a vein. In accordance with the number of lobules belonging to each choroid projection these stems are divided into a varying number of little branches. These little branches give rise to very numerous loops folded in many sorts, which rising above the whole choroid projection, determine in a great measure the forms of its little lobules. This resolution into vascular loops sometimes happens directly, so that one little branch, after forming several loops, at once returns into a vein; at another time several little branches combine in forming a net lying in the stroma of a lobule, and enclosing polygonal meshes, out of which net the individual loops are

[1] Luschka (H. von), "Die Adergeflechte des menschlichen Gehirns" (the Choroid Plexuses of the Human Brain), Berlin, 1853, 4to.

projected, and from which the little venous vessels arise which gradually unite into a larger stem. . . .

"In the lobules or villi of the choroid plexuses there are comparatively only a few capillaries, strictly speaking; that is, little vessels with structureless, transparent coatings, and with an average width of 0·004 mm. This is the result partly of careful measurements, and partly of an investigation into their finer structure. The smallest blood-vessels in the choroid plexuses, namely, those which are resolved into loops, have a dimension of 0·008 mm. Most of the finer vessels have a width of 0·012 mm., and the largest among them measure 0·04 mm." (p. 118, etc.)

508*l*. "*Epithelium.*—The epithelial cells of the choroid plexuses, immediately on the structureless lamina of the choroid projections, form a coating which can easily be stripped off, and the ingredients of which are so loosely connected that at the least disturbance they fall apart. The epithelium encompasses throughout their whole width the vascular loops filled with blood, which shine dimly through it; producing thereby the appearance of extraordinary thickness. But after the epithelium has been partly removed, it becomes evident that this appearance is caused by the epithelium resting on a homogeneous border projecting far beyond the blood-vessels, and encompassing it on all sides. The cellular formation meanwhile is considerable, approaching that of the stratified epithelium; since not unfrequently two or three layers of epithelium can be discovered on the top of one another. Besides, this results also from the difference in the phases of the development of the cells themselves.

"A paramount knowledge of the epithelium of the choroid plexuses in all its bearings can be obtained only by an examination of objects which are entirely fresh, and which are taken from persons recently executed, or from animals that have just been killed. The first thing that strikes one in such cases is the great number of bright, roundish cells, spread over the surface of the plexuses, and containing either no nucleus, or one which is quite pale. The next thing is the exudation of numerous circular or oval drops which are homogeneous, vitreous, and clear, and which have a most exquisitely delicate contour. These drops are partly still connected with the epithelial coating, and partly they are already detached from it. . . .

"By far the greater part of the epithelial cells have a polygonal form, and a delicate, granular appearance; their average width is from 0·012 to 0·16 mm. . . . Those cells which rest on the greatest convexity of a choroid lobule, in agreement therewith, present exquisite, concave surfaces, and thus appear curved in one direction. . . . All cells, the contents of which are still granular, have a distinct, roundish nucleus, the dimension of which is from 0·004 to 0·006 mm.; and which usually occupies a central position" (p. 122).

508*m*. "A knowledge of the development and of the metamorphoses of the epithelial cells of the choroid plexuses is very important for an understanding of their presumptive vital significance. By removing the epithelium from fresh choroid plexuses of human beings, I have repeatedly succeeded in obtaining objects which afforded satisfactory information in respect to the genesis of these cells, and the changes which they undergo; inasmuch as these objects exhibit in juxtaposition the various phases in the development of these cells. Their lowest formation seemed to me a very fine molecular mass, which disappeared rapidly under the influence of acetic acid, and through which there were strewn roundish nuclei of a delicate contour, the lateral dimension of which on an average is 0·008 mm., and which besides having turned pale, were not affected by this reagent. Very many of these nuclei contained one, and more rarely two very distinct, sparkling nuclear corpuscles of a dark contour. The next stage in the development of the cells was exhibited by nuclei around which the molecular mass had already formed a delicate rind; and by other bodies of the same kind, around which that mass had already become sharply defined in respect to other bodies, and had thus become increased into a thicker and denser envelope. These last bodies, which were distinguished by a spherical shape, and a finely-granulated appearance, and which were furnished with a roundish nucleus, and nuclear corpuscles, looked very much like finished cells; yet they did not yet possess the genuine attribute of a cell, namely, an independent, structureless coating. . . . Among these unripe elements of the epithelium there are also fully-formed cells, which constitute the greater portion of the same. These cells are produced from the above spherical bodies by the outermost layer of their envelope being blended into a structureless membrane. These cells, which by their continued growth and by pressing against each other become polygonal, in the course of time are changed in a remarkable manner. Their finely-granulated contents, as well as their nuclei, are gradually dissolved into a homogeneous mass, clear as water, which passes through the walls of the cells, and which appears on their surface in the form of bright little drops. During these changes in the interior of a cell, its whole outward appearance changes; it becomes larger, clear as water, and if it has been angular before, it now becomes round. . . . Those epithelial cells which are farthest developed into vitreous, clear vesicles, usually occupy the extreme surface of the epithelium, and they are those of its loosely-connected constituents which seem ready to drop off. Such vitreous, clear cells of the choroid plexuses which have dropped off, are accordingly also found floating in the liquid of the cavities of the cerebrum."

508*n*. "In respect to the final behaviour of these cells, observation justifies us in making the following conclusions. The contents of the cells after becoming homogeneous and liquid, penetrate through the envelope of the cell; while new blastema, on the other hand, is received into the cell from the blood, in order to undergo the same chemical change, and afterwards to pass out of the cell. . . . In favour of this kind of activity in the cells belonging to the choroid plexuses, we may point not only to the fact that there are actually found sometimes cells which look as if they had been emptied, and as if they had collapsed by such a cause, but also to the fact, that during a longer existence of the cells there are formed in them peculiar elements, which are set free by their final dissolution. Very many cells in the choroid plexuses, however, after their contents have become homogeneous, are dissolved forthwith completely; or else they leave behind some small vestiges of their envelopes, which are found sticking to neighbouring cells in the form of pieces of a crescent shape, or describing some other figure. How long a cell of the choroid plexus endures, I am unable to tell, but from their phases of development, which are constantly changing, I think we are justified in concluding that their vitality is but short; this same conclusion also we may draw from the ease with which they are destroyed, and from their great sensitiveness to reagents; and also from the fact that at any time we may find in the liquid of the cerebral cavities epithelial cells, changed into vesicles as clear as water, and in a state of dissolution. At any rate no value can be attributed to the remark made by Virchow, that the duration of the cells can scarcely be assumed as shorter than the life of the individual" (pp. 124-127).

ANALYSIS.

509. There are three choroid plexuses; a large one in the lateral ventricles, a smaller one in the region of the corpora quadrigemina, and the third along the fourth ventricle. The larger runs along the thalami optici, but the lesser over the anterior tubercles of the corpora quadrigemina and the pineal gland. They both originate from one and the same branch, and the shoots of which both are composed, communicate on the way, and likewise at their extremities through veins. They are also at a short distance from each other, having respect to one another from their centres, like partners in the same business. The larger plexus rests near the body of the fornix, the smaller, however, on the pineal gland; for there they terminate, and suspend their reticular webs.

510. The choroid plexuses carry on their systole and diastole in a different manner from the sanguineous plexuses of the body; for the blood-vessels of the body respond to the motion of the heart, while those which enter the cranium, withdraw from the dominion of the heart, and submit themselves entirely to the rule of the brain, and its appendages, members, and parts. Such also is the case with the choroid plexuses, which are blood-vessels woven together, and the texture of which is fastened together in various ways. They suffer themselves to be moved, *i.e.* expanded and constricted, by the thalami optici; wherefore they rest upon these from one end to the other, *i.e.* from the descending cornu of the lateral ventricle to the fornix. The thalami expand and dilate, and again contract and constrict themselves, in alternate times; and they do the same with the sanguineous plexuses which are recumbent on them. The

alternate motion of the plexuses, however, just like that of the remaining vessels of the brain, is in the reverse order of that of the cortical and grey substance, and thus it is in the reverse order of that of the thalami optici; but is in the same order with the alternate motion of the ventricles; that is, the plexuses stretch and contract themselves when the thalami are expanded and dilated. This is the reason why the plexuses float as it were freely over the thalami optici, and are only lightly attached to the thalami and at the same time to the crura of the fornix; and why this attachment is stricter only at their extremities. It would be different, if by the moving agency of these bodies the plexuses, while being elongated, were also extended in their breadth, which would be in opposition to the general rules of motion of the vessels of the brain. The same also is the case with the smaller plexus, or with that near the corpora quadrigemina, which while being specially ruled by the anterior tubercles and the pineal gland, is governed in a general manner by the thalami optici.

511. Blood enters into the choroid plexuses from the body, and spirit from the brain. The blood is conveyed to them by the common branch of the carotid and vertebral arteries, and spirit through fibres from the fornix, and thus from the opposite direction, and each from its extremity; for the blood flows into the plexus in the descending cornu, and the spirit from the other side, namely, from the fornix. There are, indeed, thin, very soft and moist fimbriæ and roots which extend from the body of the fornix and are affixed to the highest coasts of the plexuses; these pour out the pure spirit which by numerous fibres of the corpus callosum is conveyed to its centre of rest, the body of the fornix, which on this account is called the fimbriated appendage of the corpus callosum. The blood is conveyed to meet this spirit; and by coursing through the web of the plexus, it is consociated and mixed with the arriving spirit in every point, and in this wise celebrates as it were a marriage union with its spouse. The whole fabric of the plexus is glandular, or at least glandular in appearance; the blood

circulates in it, as through anfractuous little gyres; and it instils its serum into every least cavity, into every least place, where the fibre also instils its spirit; thence is conceived and born that moisture which the succeeding organs separate, filter, and rectify. The cool temperature of the ventricles favours this marriage union; for if the naked spirit, not confined somewhat within a refined serum, were poured into the cavities of the ventricles, on account of its great volatility it would exhale through the rafters of the sides and the roofs without determination, and would thus be dissipated. This is the first composition of the fluid, and it is accomplished in the plexuses by the alternate expansile and constrictile motion of the whole, and the synchronous motion of the individual parts.

512. The newly-born moisture which by its impregnation with a copious supply of spirit has been made liquid, is discharged from its follicles abroad through an equally great number of little emissary ducts and arteries which are situated in the membrane or meninx which encompasses the plexus. Thus by little mouths it is distilled thence into the cavities of the ventricles, at either side of the thalami optici. Thence by a swift and declivitous course it is conveyed at the very time when the ventricles constrict themselves, towards the two anterior and posterior foramina, which are called "vulva" and "anus."

That the ventricles are constantly moistened by such a dew and perspiration, appears not only from the glandular texture of the plexuses, but also from their pale rather than sanguineous colour—this, especially in dropsical, phlegmatic, and aged persons. It appears also from the continued series of such glandular beginnings, and from the perpetual communication which exists between them, whence arises sometimes by expansion a continuous lymph-duct as it were. That these glandular beginnings have emissary branches cannot be denied, since in the membranous surface there are so many little arteries, and since the membrane itself, which is said to be a production of the pia mater, is thin, and when it is stretched out, constantly sweats forth a certain juice. This moisture and irrigation sometimes does not appear in dead brains; for in the death-struggle the brain with its arteries, plexuses, and members expends its last forces in the recreation of the blood, and thus in the recuperation of the life of the blood by the restoration of the body; and this it does by stimulating its own organical forces into the most violent motion, and by expelling, as long as it is able to do so, the spirit while there is any. Besides, the blood which is unfit for this purpose and which has been deprived of its better essence, is treated as a caput mortuum, a residuous phlegm, and is expelled abroad. This also is shown by the nature of that blood.

513. At the time when the cerebrum, as well as the optic thalami, are expanded, or at the period when the blood-vessels and plexuses are stretched out and elongated, the arterial blood out of the common branch of the carotid and vertebral arteries [the posterior communicating artery], and at the same time the spirit out of the fimbriæ and roots of the fornix are introduced and forced into the innermost recesses of the plexuses. At the same time also the useless and exhausted blood is expelled into the veins, and by the veins into the straight sinus; and likewise the moisture which has already been prepared in the little follicles of the plexuses, or the spirit which has been wedded to, and fixed into, its virgin serum, is expressed into the ventricles. The reverse, however, takes place during the time of the constriction of the cerebrum and the optic thalami, namely, during that of the relaxation of the plexuses.

514. It is to be observed besides, that the brain and the choroid plexuses summon to themselves a better blood out of the kingdom of the heart; for the middle portions and those in the circumference supply quantitatively and qualitatively as much blood and the same kind of blood as the ends or the extremes need. Thus such a dispensation of fluids, and their distribution quantitatively and qualitatively, and such a natural equation, and economical use of fluids, prevails everywhere in the body. In order also that the plexuses may not attract any

other kind of blood than is suitable to their chymical operations and conducive to the [purer] blood which is about to be brought forth, their parent branch arises from the carotid, as well as from the vertebral arteries, and it branches off from them in an acute angle, so that the plexuses may summon a supply accommodated to their uses from both arteries.

515. Lest the laboratory of the brain should remain empty, and lest there should be a want of those essences which are to be supplied to the new blood, a smaller plexus is also associated to the larger one, and both contribute their moisture and their juices to the third ventricle, and finally to the infundibulum. Thus the exudation of the larger plexuses is derived towards that foramen over which the anterior tubercles of the corpora quadrigemina and the pineal gland exercise a superintendence; and together with the exudation of the smaller plexus it is introduced into the common third ventricle; and in this wise they aim towards the same end and goal. The larger plexus is properly that of the cerebrum, and the smaller plexus is that of the cerebellum, or it is common to both; for the smaller plexus is situated in that region over which the cerebellum extends its sphere of activity; *i.e.* where the straight sinus fixes its roots, and where the tentorium and the falx meet. As the sinuses lean against and are recumbent upon the cerebellum, and are moved under its auspices more than under those of the cerebrum, such also is the case with the plexus which is stretched out over the whole of that region which occupies a central position. On this account also the blood of the plexuses is derived more from the arteries of the cerebellum, that is, from the vertebral, than from the arteries of the cerebrum, the carotids. Still those branches which constitute either the one or the other plexus, on their way and in their descent communicate mutually in a wonderful manner, and are interlaced with each other, forming as it were a new common receptacle, so that thence, according as the opportunity is afforded, they may turn towards, and may empty themselves either into the one or into the other plexus. All this is with the purpose, that there may

never be a want of lymph and thus a lack of inpouring upon the operating organs, whether the cerebrum act more gently and quietly, and the cerebellum more forcibly, or whether the cerebellum act more quietly, and the cerebrum more tumultuously; for the cerebrum and the cerebellum agree, indeed, in the times of their motion, but not in the degrees of its intensity, as will be proved hereafter. Thus in both organs accidents and disorders are provided against, and the blood is refreshed in its life. On this account the thalami optici are said to be not only the regulators, but also the common dispensers of the liquids of the laboratory.

[The functions of the choroid plexuses as presented by Swedenborg will be found fully discussed in the light of modern science in Note iii., Sub-section C, which treats of the functions of the Corpus Callosum, the Fornix, and the Choroid Plexuses.—EDITOR.]

CHAPTER XV.

THE CORPORA QUADRIGEMINA AND THE AQUEDUCT OF SYLVIUS.

516. THE corpora quadrigemina, of old called nates and testes, and more lately protuberances, prominences, orbicular, natiform, and testiform processes, are certain gibbous and conical protuberances immediately behind the pineal gland, between the posterior parts of the optic thalami, and almost in the middle between the third and fourth ventricles. They are within that boundary where the isthmus of the ancients is situated, and where the cerebrum and cerebellum meet with the medulla oblongata in the upper part [of the skull]. They are situated under the posterior expanse of the corpus callosum, and near the roots of the straight sinus. The anterior tubercles or nates which arise in front, and which are in the immediate neighbourhood of the pineal gland, and a little higher up than the posterior tubercles or testes, run out as it were from the optic thalami. They are round on the top, have a medullary surface, and are irrigated by plexuses of arterial twigs from the vertebral arteries, and of venous branches which pass close by into the straight sinus. Immediately below this medullary surface the cortex, or rather a little cineritious substance, begins, which sometimes is scarcely conspicuous, but in recently-dissected human subjects is more apparent. By means of interjected fibres and striæ the corpora quadrigemina are thoroughly inosculated into the optic thalami, like apophyses or symphyses; so that their form and constitution is similar to that which is common to the remaining active appendages of the brain; that is, they have a venter or belly, crura or thighs

with tibiæ, which at last are inrooted in a larger body of a similar nature. The posterior tubercles or *testes* arise behind the anterior against which they press. They come out as it were from the optic thalami a little further down, and their origin is near the place where the cerebellum sends out its first process, and where in the form of a bandage it is wound around the medulla in that region; so that these posterior tubercles hold the middle ground between the cerebrum, the cerebellum, and the medulla oblongata. In human brains the "testes" are of the same size as the "nates;" but in those of animals the former tubercles are either very small, or they form together a peculiar epiphysis, over which the "nates" like articulated organs, with cartilage inserted below or between, as in the joints of the bones, seem to be inflected into their motion. These tubercles have a medullary surface, under which the cortex, or a little cineritious substance, is said to begin. They appear of a fair size, but are different in the various species of animals, and in the various subjects of a species. They communicate with the medulla oblongata by striæ sent out from their cineritious bottom, and also from the optic thalami; with the cerebellum by the first process of the cerebellum [the superior peduncles = *crura ad testes*];[1] and by the stria pinealis between the optic thalami and another transverse tract they communicate with the cerebrum. Thus they seem to depend upon all, yet more proximately upon the optic thalami, into which they are inserted by peduncles, and by which they allow themselves to be pulled, and to be drawn into shapes; for according to Vieussens' plates they may be pointed so as to assume the stretched form of a pear, and then again they may be globed together into round forms. Below the corpora quadrigemina and the pineal gland cineritious substance is spread as a basis, but near the bodies themselves, and everywhere around, the substance is medullary. When this basis is removed, or when the tubercles are drawn apart, there is laid

[1] Concerning the connection between the corpora quadrigemina and the cerebellum see Meynert in no. 522*f*.—EDITOR.

open a passage which goes between the third and fourth ventricles. This is called the passage between these two ventricles, by Vieussens the "emissorius aquæ," by Sylvius the aqueduct, and by others the common and intermediate canal; by some of the ancients it has also been called the fourth ventricle. When the two anterior tubercles, the nates, are drawn apart, and the pineal gland is removed or cut through, the passage seems to lead from the third ventricle to the large gland of the cerebrum, in the shape of an inverted little horn. At its sides there is also some medullary substance, in the bottom it is striated, and in the roof there is cineritious substance intermixed with it. At one of its extremities is the pineal gland, and at the other the valve of Vieussens; both of which are in the middle of the longitudinal axis of the brain. Interiorly little veins of the choroid plexus are spread out; for it is a vascular expansion; these veins also attach themselves to the walls by which the third ventricle is connected with the anterior tubercles and the pineal gland. As the optic thalami hold the third ventricle bound, so the nates or the anterior tubercles occupy a similar position in respect to this intermediate passage.

517. WILLIS.[1] – "Behind the optic thalami, other important protuberances, the corpora quadrigemina, which are commonly called 'nates' and 'testes,' are also attached to the upper part of the medullary caudex, and they cover its surface for about the space of an inch; as they are, however, not contiguous to it in the middle, a certain cavity exists underneath the whole of their tract. These corpora are smaller in man than in the dog and the cat. Finally, if we have correctly observed, in the remaining animals, when they are recently born and are yet unable to seek their own food, they are very little developed. In the calf, sheep, pig, and others, they appear larger, in fishes and birds they are wanting altogether. These corpora are four in number, *i.e.* two are attached to each side of the medulla oblongata. The anterior tubercles, which are also called 'nates,' are larger, and

[1] "Cerebri Anatome," cap. ii., xiv.; "Anima Brutorum," cap. iv.

seem to be the chief; to these the posterior tubercles, called 'testes,' are appended, like epiphyses. As to their shape they are orbicular or round, and they are usually regarded as two crura of the cerebrum and cerebellum, lying closely together on each side" (p. 16). "If, however, the situation of these parts, and their uses and relations in respect to the neighbouring bodies are properly considered, it becomes very plain that they constitute a sort of peculiar region of their own, which is altogether distinct from the cerebrum, the cerebellum, and even the medulla oblongata. As to their situation they are sufficiently removed from the forepart of the brain; they are also separated from the medullary caudex by the cavity or ventricle which is underneath them; nay, there seems to be one way or one process which leads from the medulla oblongata into these protuberances, and another which leads away from them, and is thence taken into the cerebellum. . . . Respecting the way which leads from the medulla oblongata into these tubercles, it is manifest that below the origins of the optic nerves a medullary process [the brachia] descends on either side with villi of its own, which terminates in these tubercles. If afterwards you look for an exit from these corpora, it is equally clear that from the posterior tubercles, called 'testes,' a medullary process descends on both sides in an oblique direction, which upon being brought down into the cerebellum, is distributed throughout its whole structure. But in respect to the anterior tubercles being chiefest among the four, and the posterior or testes being their epiphyses, or the heads of the medullary processes which are carried thence into the cerebellum, and by which these processes are attached to the anterior tubercles, this appears manifestly in the sheep, the calf, the horse, and several other animals, where the anterior tubercles or nates are of a very large size, and where the posterior tubercles or testes, which are of very small size, have grown fast to them, and where by them as intermediates the medullary processes exist as processes of the former tubercles" (pp. 17, 18).

"The corpora quadrigemina constitute as it were four little bodies, which, however, are mutually adjoined to certain processes.

Under these little bodies, or rather between their junctures and the caudex of the medulla oblongata which is placed underneath, there is left a cavity, a narrow and long hollow, which by some anatomists is called the fourth ventricle; but according to some other more recent authorities who place the fourth ventricle underneath the cerebellum, this cavity constitutes the passage towards that ventricle. The posterior extremity of this hollow or cavity terminates near the entrance to the fourth ventricle. Its anterior extremity is opened in front of the anterior tubercles called 'nates;' from the middle of this cavity or narrow cave a passage leads directly to the infundibulum. The anatomists differ very much as to the situation, and the dependence of these bodies upon one another, and upon other parts; it is especially noticed that the corpora quadrigemina in some animals, as in the sheep, the calf, the goat, and others like them, are very much larger than in man; also in a healthy, dry, and old brain they are more conspicuous, and their processes, commissures, and connections can more easily be discovered than in a younger, moist, or otherwise unhealthy brain" (pp. 92, 93). "The posterior tubercles, commonly called testes, are attached to the former, and are as it were their epiphyses; . . . wherefore both tubercles, the anterior as well as the posterior, are conjoined together by some processes as by outstretched wings" (p. 94). "That the posterior tubercles or 'testes' are epiphyses of the anterior, or of the 'nates,' appears beyond doubt in the brains of calves, sheep, and certain other animals, where the 'nates' are of very large size, and the 'testes' are very small, and as it were attached to the former. . . . The villi and fibres by which these processes which ascend into the cerebrum are marked, are differently formed and disposed from those which are seen in the neighbouring process which descends from the cerebellum towards the medulla oblongata. . . . Two slender nerves, which continue towards the superior oblique (trochlearis) muscle of the eye, arise from the swelling tops of the corpora quadrigemina, while most others proceed from the sides or the base of the medulla oblongata" (p. 96). "The anterior foramen [of the aqueduct] is opened between the optic thalami, a little in advance of the pineal gland; into this the serous liquid which is deposited near the confines of the medulla oblongata gradually trickles; but the other posterior foramen opens into the fourth ventricle, which is situated under the cerebellum. This foramen is covered by a thin membrane which encircles its own boundary and that of the cerebellum, and acts as a preventive, lest the humours which are derived from the fourth ventricle or the confines of the cerebellum trickle down anywhere else than through that foramen. If this little membrane or skin is ever broken by an inundation of serum, the watery liquid descends into the base of the medulla oblongata, and swamps the origins of the nerves, and causes convulsive affections, and not rarely a deadly failing of the vital spirits, as I have noticed in the bodies of many who died from diseases of the head" (p. 97). "When the corpora quadrigemina are large, or exceedingly large, the pons Varolii is always small, or indeed very small, and *vice versa*" (p. 18).

"When the brain is taken out, and spread out according to our method; if then the dissection of the corpora quadrigemina is carried on so, that while they are left entire, and while the parts of the pineal gland which is cut through in the middle are separated from one another, the cavity which is underneath both is exposed, it appears very plainly that the prominences, called corpora quadrigemina, are but medullary epiphyses of the medulla oblongata, which adhering to the peduncles of the cerebellum, look thence towards the cerebrum, and seem to keep up an intercourse between the two. The last epiphysis from the parts of the cerebrum passes into the nearest, that is, into the natiform epiphysis or process, which is in a certain measure its assistant or helpmate. In the sheep, ox, and most quadrupeds a cineritious substance is attached to this medullary epiphysis. But in man, the dog, fox, and other more sagacious animals it is entirely medullary. This medullary epiphysis [stria pinealis] which separates the 'nates' and 'testes,' or the anterior and posterior tubercles, and pursues its course under the pineal gland, tends towards the optic thalami, and on touching them, it is presently cleft into two nervous branches as it were, one of which is carried towards the cone of the corpus striatum, and the other towards its base; and on its oblique course upwards it sends a shoot into the middle of the corpus striatum; this branch going to the base of the corpus striatum, is inserted behind the root of the fornix in an angle of the corpus striatum" (*Anima Brutorum*, cap. iv.).

518. VIEUSSENS.[1]—"The anterior tubercles of the corpora quadrigemina, commonly called 'nates,' are two roundish bodies, of a whitish colour on the outside, but within of a greyish-white colour; they are prominent in the upper part of the medulla oblongata, and are placed near the thalami optici. On the outside they do not appear thoroughly white, on account of the numerous shoots of blood-vessels by which they are irrigated; but interiorly they are of a greyish-white colour, on account of their being composed partly of cineritious or glandular substance, and partly of white and medullary substance; and, indeed, when their upper, prominent part is a little scraped off, with the aid of the microscope there are easily discovered in them most slender medullary tracts, which pass into the posterior part of the thalami optici" (p. 72). "The posterior tubercles of the corpora quadrigemina, commonly called 'testes,' are styled so, less on account of their shape, which is conically round, than on account of their situation; wherefore we shall describe them as bodies pointed like a boy's top, and white both on their outside and in their interior. These are prominent on the highest part of the medulla oblongata, and are placed near the anterior tubercles or 'nates,' with which they coalesce. When their prominent parts are a little scraped off in a boiled brain, it is seen that all the medullary tracts of which they consist, together with the white tracts of the anterior tubercles, tend towards the posterior region of the optic thalami. . . . Certain little arteries sent out from branches of the basilar artery, and little veins which terminate in the straight sinus, are ingrained in the ex-

[1] "Neurographia," cap. xi.

ternal surface of the 'testes;' and a small and short medullary tract seems interposed in it from the back; this is extracted from the transverse medullary tract which occupies the anterior part of the 'valvula major cerebri' [the valve of Vieussens], and which ascending in a straight line is united with the posterior part of the pons Varolii. This small and short medullary part resembles in a certain measure the membranous band by which the gland and the præputium are connected, wherefore I call it 'frænulum.' When the corpora quadrigemina—the pineal gland having been removed from its proper seat—are drawn apart, a passage is detected under the greyish-white substance by which these parts have heretofore been conjoined. This passage is interposed between the third and fourth ventricles, and is not improperly called 'aquæ emissorius' [the aqueduct of Sylvius], since it receives the aqueous humours which transpire out of the glands with which the choroid plexuses of the lateral ventricles are interspersed. The upper part of the aqueduct of Sylvius, however, the interior surface of which is of a greyish colour, if I am not mistaken, was called 'pons' by Varolius" (p. 73). "All of the very slender medullary tracts which are perceived in the thalami optici are derived from the 'geminum semicirculare centrum,' or from the posterior region of the oval centre; unless you except some which pass off into the optic nerves, are subjected to the corpora quadrigemina, the superior peduncles of the cerebellum (crura ad testes), and likewise to the inferior peduncles (crura ad medullam), and which finally, together with the above-named peduncles, terminate in the hinder part of the spinal marrow, and likewise in the posterior beginnings of the spinal nerves" (p. 68).

519. [RIDLEY.[1]]—"The corpora quadrigemina are oblong and acuminated towards their extremities; but in sheep, calves, and most other creatures, the anterior tubercles or 'nates' are round and large, and the posterior tubercles or 'testes' are oblong, somewhat acuminated, and very small. Before the corpora quadrigemina, under the pineal gland, runs a transverse process

[1] "Anatomy of the Brain," chap. xiii.

[posterior commissure], which upon further inquiry, by drawing the thalami optici still wider, appears to be rather 'nervi' than 'nervuli æmulus' [as Vieussens calls it], and seems to join the thalami optici together. These corpora are not proper appendages either to the cerebrum or the cerebellum, and are divided from the medulla oblongata in some measure by an interstice commonly called 'ductus ad infundibulum' by the moderns, but which by the ancients was signalized as a passage for the animal spirits to the fourth or noble ventricle. They are situated, however, upon that part of the medulla oblongata which is between the cerebrum and cerebellum, which space was before called 'isthmus,' and which is opposite to that part which is called pons Varolii. . . . From this intermediate situation, Dr. Willis thought fit to make them as it were an intelligence office between the cerebrum and cerebellum. . . . After having taken the reticular expansion of blood-vessels off from them, which is very large here, and eminently conspicuous in injected brains, I find them of the very same substance with the pons Varolii and the thalami optici, [partly cineritious] and partly medullary, and in fresh brains somewhat, but very faintly, striated" (pp. 125-127). "Otherwise the medullary tracts in the thalami optici run obliquely down to a part of the subjacent crura and the medullary caudex. Those which belong to the corpora quadrigemina run out after the same manner, and terminate in the same way, only a little lower" (p. 192).

520. "While paring the top part of the cerebrum down to the lateral ventricles with a razor, in a body I lately had, a chance cut gave me an opportunity of showing the pia mater as fairly in those ventricles as the largest membrane of the body, to several who stood by, although Molinetti, who laughs at all who pretend to have found any such thing, affirms the contrary. But this is to be sought for either in recent bodies, or in such as before death, through certain diseases, as dropsy, strangury, some sort of apoplexies, or the like, have been filled with extravasated serum. The way which in want of the other opportunities discovers it best, is by separating the septum lucidum near its

origin, which is just from the fornix, where it arises from its two roots, near which place the medulla of the cerebrum begins to advance into the corpora striata. For from thence, for more than half its passage backwards towards the hinder members of the brain, it continues hollow; and I am apt to think is but a duplicature of this part, though it may be somewhat medullary, and therefore by reason of its transparency has the name of septum lucidum" (chap. ii. pp. 10, 11).

521. WINSLOW.[1]—"The corpora quadrigemina, as their name indicates, are four in number, two anterior and two posterior; they adhere together, as if they formed but one body situated behind the union of the thalami optici. They are transversely oblong, the anterior being a little more rounded, and broader or larger from before backward, than the posterior. Their surface is white, and their inner substance greyish. . . . Directly under the place where the tubercles of one side are united to those of the other side, lies a small middle canal which communicates by its anterior opening with the third ventricle, and by its posterior opening with the fourth ventricle, belonging to the cerebellum. Where the convex part of the two anterior tubercles joins the posterior parts of the thalami optici, an interstice or opening is left between those four convexities, which communicates with the third ventricle, and with the small middle canal. This opening is improperly called 'anus'" (section x. nos. 79-81).

522. Consult also Willis's plates in his "Anatome Cerebri," viz. iii., iv., vii., viii.; and in his "Anima Brutorum" plate v., where two medullary cords [*F*, *F*=the stria pinealis] are seen proceeding from the corpora quadrigemina in a straight direction towards the corpora striata, besides other tracts which are likewise tending towards the corpora striata: and likewise his plate viii. Consult also Vieussens' plates vii., viii., ix., x., xi., xii., xiii., and Ridley's plate vii.

Morgagni mentions besides,[2] that "under that nearest passage which is called the transit to the fourth ventricle [aqueduct of

[1] "Anatomical Exposition," section x.

[2] "Adversaria Anatomica," Lugduni Batavorum, 1740.

Sylvius], he noticed sometimes another passage" (Animadversio vi. p. 12).

[MODERN AUTHORS.

522*a*. QUAIN.[1]—" The corpora or tubercula quadrigemina are four rounded eminences, separated by a crucial depression, and placed on each side of the middle line, one pair before the other. They are connected with the back of the optic thalami, and with the cerebral peduncles at either side; and they are placed above the passage leading from the third to the fourth ventricle. The upper or anterior tubercles (*nates*) are somewhat larger and darker in colour than the posterior (*testes*). In the adult, both pairs are solid, and are composed of white substance on the surface, and of grey matter within. They receive bands of white fibres from below, the majority of which are derived from the fillet [lemniscus]. A white cord also passes up on each side from the cerebellum to the corpora quadrigemina, and is continued onwards to the thalami: these two white cords are the *processus a cerebello ad cerebrum*, or superior peduncles of the cerebellum. At each side of the corpora quadrigemina there proceed outwards two white bands, prominent on the surface, and sometimes named anterior and posterior *brachia*. The fibres of the anterior pass to the thalamus opticus, the inner corpus geniculatum, and the optic tract; those of the posterior to the inner corpus geniculatum and the crus cerebri. According to Meynert, many of their fibres pass directly to the cortical substance of the hemisphere."

522*b*. "In the human brain the quadrigeminal bodies are small in comparison with those of animals. In ruminant, soliped, and rodent animals the anterior tubercles are much larger than the posterior, as may be seen in the sheep, horse, and rabbit; and hence the name *nates*, formerly applied to the anterior, and *testes* to the posterior tubercles. In the brains of carnivora the posterior tubercles are rather the larger. In the fœtus of man and mammals these eminences are at first

1 "Elements of Anatomy," eighth edition, London, 1876.

single on each side, and have an internal cavity communicating with the ventricles. They are constant in the brains of all vertebrate animals; but in fishes, reptiles, and birds, in which animals they receive the name of *optic lobes,* they are only two in number, and hollow: in marsupialia and monotremes they are also two in number, but are solid" (ii. p. 551).

522*c.* "*The aqueduct of Sylvius.*—Beneath the corpora quadrigemina a narrow canal connects the third ventricle in front with the fourth ventricle behind. It varies in shape in different parts, being T-shaped behind, elongated vertically in front. A thick layer of grey substance occupies its floor, beneath which, on each side, is the common nucleus of the third and fourth nerves" (ii. p. 552).

522*d.* MEYNERT.[1]—"The corpora quadrigemina and thalamus opticus, besides being in connection with the crus cerebri, both receive fibres, in common with the corpora geniculata, from the optic tract" (p. 697). "The fibres that thus connect the optic tract with the anterior tubercles of the corpora quadrigemina, pass in diverging rays inferiorly and somewhat posteriorly to the brachium of the anterior tubercles, into the small nerve-cells of the ganglion. . . . Besides this mediate connection between the corpus quadrigeminum and the optic tract, a direct connection is effected by fibres that may be traced from the tract directly into the brachium of the posterior tubercles" (p. 699).

522*e.* "The corpus quadrigeminum is made up of an anterior and a posterior pair of ganglia, which, taken together with their respective brachia—the fasciculi sent to them from the cortex cerebri by way of the corona radiata—have, in general terms, a transverse position in the encephalon. . . . The masses of ganglionic substance of the corpus quadrigeminum are enclosed between a superficial and a deep-seated layer of medullary substance. The superficial layer forms a sort of *stratum zonale,* such as invests the thalamus opticus, made up of fibres of the

[1] "The Brain of Mammals," in Stricker's "Manual of Histology," American edition, New York, 1872.

brachia corporis quadrigemini. . . . The deep-seated layer of medullary substance contains the fibres contributed by the corpus quadrigeminum to the tegmentum. The superficial medullary system of one side is continuous with the deep-seated system of the other, and they are all consequently fused together at the middle line" (p. 699 *et seq.*).

522*f.* "A processus corporis quadrigemini ad cerebellum certainly exists, probably made up of fibres from the brachia after their decussation; although this designation is by no means deserved by the tract to which it is usually given—the processus cerebelli ad cerebrum. It properly belongs to the frænulum of the valve of Vieussens, which consists demonstrably of two similar halves, and which runs, by way of the valve of Vieussens, into the superior vermiform process of the cerebellum" (p. 700).

522*g.* "A cross-section of the medullary substance of the corpus quadrigeminum which passes through the middle line of the ganglion—*i.e.* a median longitudinal section of the ganglion in its natural position—shows the former to be directly continuous with the medullary substance of the *posterior commissure.* This posterior commissure is, however, in connection not only with the thalamus, as has been described above, but also with the ganglionic substance of the pineal gland, and with that of its pedicle, the habenula" (p. 700).

522*h.* "The fibres of the first member of the projection system [see footnote, p. 552] from the cortex cerebri enter the corpus quadrigeminum by way of the brachia of the anterior and posterior tubercles. The brachium of the anterior tubercle traverses the thalamus opticus just above the two corpora geniculata, leaving between itself and them a portion of the substance of the thalamus which, on sections, appears triangular. It has already been stated that the brachium of the posterior tubercle is joined, during its passage through the corpus geniculatum internum, by fibres from the optic tract" (p. 701).

522*i.* "The grey substance lining the inner surface of the corpus quadrigeminum, like that of the inner surface of the thalamus opticus, belongs to the central tubular grey matter. This grey substance surrounds the aqueduct of Sylvius, as a continuation of that which lines the third ventricle. . . . The central tubular grey substance surrounding the aqueduct of Sylvius is limited posteriorly by the decussating medullary fibres of the corpus quadrigeminum; anteriorly by the posterior longitudinal fasciculus (hinteres Längsbündel).

"It is bordered laterally, within the limits of the anterior tubercles, by well-defined fibres, which are on the way to join the tegmentum, while in the region of the posterior tubercles it is not less sharply bordered by a system of fasciculi which run more or less parallel with the aqueduct, and which show on cross-section a chain of cut surfaces; which chain lies externally to the posterior longitudinal fasciculus. These fibres, which constitute the descending root of the *fifth pair of nerves*, become gradually developed from the cells surrounding the aqueduct" (p. 702).

522*j*. "The nerve-cells in the lower half of the aqueduct of Sylvius, . . . in the region of the anterior tubercles, constitute the common nucleus of origin of the oculo-motorius and trochlearis. . . . From the substance of this common nucleus of the oculo-motorius and trochlearis in which the *fibræ rectæ* of the nucleus lenticularis terminate, spring the roots of the *oculomotorius* nerve, being fibrous bundles of considerable thickness. . . . From the same nucleus spring the roots of the *nervus trochlearis*. . . . The roots of the trochlearis spring principally from the compact portion of the common nucleus, and especially from that part of it which lies below the rest, in an excavation in the posterior longitudinal fasciculus, and their fibres converge in the form of a pencil. . . . The nucleus of origin of the trochlearis lies anterior to the aqueduct and in the region of the anterior tubercles, while its final point of exit lies behind the aqueduct and below the posterior tubercles. . . . Misapprehending their real character, Stilling and Deiters have described certain descending roots of the fifth nerve, which certainly lie very near the trochlearis at the point of exit of the latter, as a so-called inferior division of the roots of the latter nerve" (pp. 703, 704).

"Even within the limits of the anterior tubercles, the central tubular grey matter encloses nuclei that give rise to the motor-nerve roots referred to, which lie more or less near the *median* line; also to a *laterally*-disposed sensory-nerve track, the roots of the fifth cerebral nerve. The fibres composing these roots originate at the outermost border of the grey matter that surrounds the aqueduct of Sylvius. . . . They form themselves by degrees into a series of bundles whose transversely-cut surfaces, succeeding each other like the links of a chain (as seen in cross-sections made in this region), lie in a curved line around the outer edge of the thick wall of grey substance which surrounds the aqueduct" (pp. 704, 705).

522*k*. "When the deep-seated layer of medullary substance that separates the ganglionic substance [of the corpora quadrigemina] from the central tubular grey matter [of the aqueduct], is examined on cross-section under high magnifying powers, it is seen to be traversed by a number of fine, straight fibrillæ. In the course of these fibrillæ are inserted long, spindle-shaped cells, 45 μ by 10 μ, and the two establish a nervous connection between the grey matter of the corpora quadrigemina and the grey matter around the aqueduct, in which latter the nuclei which give rise to the motor nerves of the eye are embedded. Thus connected, the two sets of ganglia form a single nervous centre as it were, and this anatomical union is in keeping with the physiological fact that an influence is exercised by the retina, when brought into a condition of excitement, upon the muscular system of the globe of the eye" (p. 706).

522*l*. "The crus cerebri springs in a similar manner from the anterior and posterior tubercles of the corpora quadrigemina. From the same ganglionic masses that receive the brachia of the corpora quadrigemina emerge bundles of fibres that, in decussating at the median line with those of the opposite side, form the dense nervous substance of the raphë, which is the continuation backwards of the medullary substance of the posterior commissure. The fibres that form the indirect prolongation of the brachia of the anterior tubercles pass, after their decussation, forwards and upwards, in delicate fasciculi, in which small, elongated cells, 18 and 25 μ by 5 μ, lie scattered obliquely and outwards. They collect themselves finally into a fibrous layer, which on cross-sections presents a crescent-shaped surface. This layer of fibres, which is at first covered in by the brachium of the posterior tubercle, forms *the superior lamina of the lemniscus.* The fact that nerve-cells are scattered among the fibres of this formation, even after it has become a part of the 'tegmentum,' indicates that the number of these same fibres is continually on the increase.

"The fibres contributed by the posterior tubercles to the 'tegmentum,' run forward in fasciculi that, under the form of *the inferior lamina of the lemniscus,* are in part covered over by a sickle-shaped segment of the superior lamina of the lemniscus, but they form to a great extent the exposed outer surface of the 'tegmentum.' This layer of fibres covers immediately the processus cerebelli ad cerebrum of the same side, which at the level of the origin of the former in the posterior tubercles of the corpora quadrigemina, has already completed its decussation, and is on its way towards the outer surface of the 'tegmentum'" (pp. 706, 707).

522*m.* "Above the level of the region where the fibres of the processus cerebelli ad cerebrum intertwine themselves among those of the 'tegmentum,' the latter is traversed, within the region of the anterior tubercles of the corpora quadrigemina, by a tract that terminates peripherally in the *larger root* of the *fifth cerebral nerve.* . . . The large cells that give rise to the descending root of the fifth pair, described in 522*j*, which lie in clusters embedded at the external border of the central tubular grey matter around the aqueduct of Sylvius, give rise also to a striking system of fibres that encircle the latter. They may be designated collectively as *the communicating quintus-strands* (Quintusstränge). These strands are made up of fasciculi which, disposed one above the other, form a continuous delicate (about

150 μ thick) medullary wall, which surrounds the aqueduct throughout almost the entire region of the anterior tubercles of the corpora quadrigemina" (p. 708).

522*n*. "The valve of Vieussens, the prolongation of the frænulum veli medullaris, is the part that, as Arnold has shown, really deserves the designation of processus cerebelli ad corpus quadrigeminum, which has been wrongly applied to the processus cerebelli ad cerebrum.

"In the valve of Vieussens three different systems of medullary fibres lie woven together. 1. The great mass of its substance is composed of the fasciculi of the frænulum. 2. At its anterior extremity the decussating fasciculi of the nervus trochlearis, which are of great thickness, intertwine themselves transversely among those of the frænulum. 3. The velum medullare further contains longitudinal fibres from the superior vermiform process of the cerebellum; they decussate before quitting the limits of the latter, and after traversing the valve of Vieussens almost to the lower border of the corpora quadrigemina, they turn on themselves, describing curves with their convexity looking upwards, join the inferior lamina of the lemniscus as its hindermost fasciculus, and pass onward with the latter, in the posterior division of the pons Varolii, to the spinal cord" (p. 713).

522*o*. "Whether the innervation of the *sixth or abducent nerve* by certain special centres of co-ordination (corpus quadrigeminum) takes place directly, or whether by means of fibres that cross the median line from the opposite side, must be determined by studying the history, in other parts of their course, of the tracts by which that nerve is connected with the centre in question. Certainly the interesting fact discovered by Gudden[1] is worthy of mention in connection with the influence exercised upon the sixth nerve by a distant nervous centre in the neighbourhood of the origin of the third or oculo-motor nerve [*i.e.* the

[1] Gudden, "Ueber einen bisher nicht beschriebenen Nervenfaserstrang im Gehirne des Menschen und der Säugethiere." Archiv für Psychiatrie, Berlin, 1870, vol. ii. p. 364.

corpora quadrigemina], namely, that a flattened bundle of fibres passes transversely from the anterior tubercles of the corpora quadrigemina into the crus cerebri (tractus transversus pedunculi), which Gudden found to attain only to an imperfect degree of development when, in new-born animals, he rendered the retina incapable of performing its functions, and which therefore may be supposed to bear a certain functional relation to that organ. The fasciculus itself had been already noticed and correctly figured by Inzani and Lemoigne"[1] (p. 737).

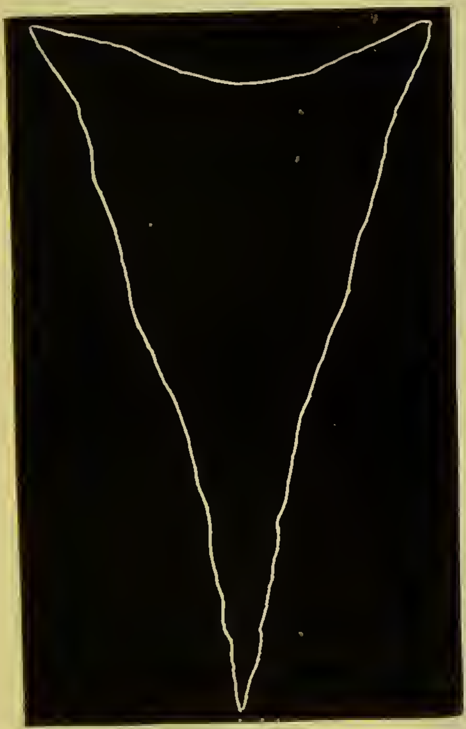


Fig. 1.

Fig. 3.

Fig. 5.

522*p*. GERLACH.[2]—"On making cross-sections of the *aqueduct of Sylvius* it appears that during its course it does not preserve the same shape, but alters it continually. . . . Where the third ventricle passes over into the aqueduct of Sylvius, its ceiling is

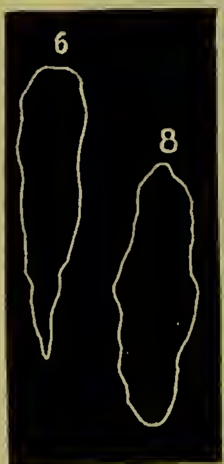
[1] G. Inzani e A. Lemoigne, "Sulle origini e sull' andamento di vari fasci nervosi del cervello," Parma, 1861.

[2] Gerlach (J.), "Mikroscopische Studien aus dem Gebiete der menschlichen Morphologie," second article, entitled "Von der Sylvi 'schen Wasserleitung und iherer Auskleidung," Erlangen, 1858.

formed proximately by the white posterior commissure; and there the shape of the aqueduct is exquisitely triangular, and indeed in such a manner that the two basal angles of the triangle are turned upwards; while the third angle is turned downwards. This triangular shape is preserved as long as the ceiling of the aqueduct is formed by the posterior commissure (figs. 1-5[1]). The dimensions of the triangle, however, become considerably smaller further back in the aqueduct.

"Exactly in harmony with that place where the anterior tubercles of the corpora quadrigemina begin, the aqueduct alters the shape of its cross-section. The former triangle is changed into a mere fissure, which above as well as below is bounded by an acute angle (figs. 6-8).

"Towards the middle of the anterior tubercles the superior angle is again divided, and between the two superior angles obtained in this manner there juts out a little protrusion directed downwards, the carina of Krause. This change results also in an increase in the diameter of the canal from right to left (figs. 9-12). In the middle of the anterior tubercles the shape of the aqueduct approaches that of a heart in playing-cards (figs. 13, 14).



Figs. 6 and 8.

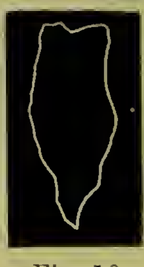


Fig. 10.

Fig. 14.

"Henceforth the carina disappears, and the two superior angles also are lost. The diameter from right to left increases still more, and both on the top and at the sides the canal appears rounded; one angle only remaining below (figs. 15-17).

[1] Gerlach represents thirty-eight cross-sections of the aqueduct; of these we reproduce a number of the most characteristic.—Editor.

"Towards the end of the anterior tubercles the diameter from right to left diminishes, and the upper half of the canal from having been circular becomes oval (figs. 18, 19). While the diameter of the aqueduct from right to left is thus becoming continually smaller, at the end of the anterior tubercles the roundness on the top also is becoming lost, and between the anterior and the posterior tubercles the canal presents again a broad fissure which above and below is closed by two acute angles (figs. 20-23).

Fig. 16.

Fig. 20.

Fig. 22.

"Under the posterior tubercles the diameter from above downwards increases more and more, in consequence of the considerable drawing out of the lower angle. The angle in the upper extremity, however, together with the diameter from right to left, remains pretty much the same (figs. 24-27).

"Towards the end of the posterior tubercles the diameter from above downwards diminishes again, while the diameter

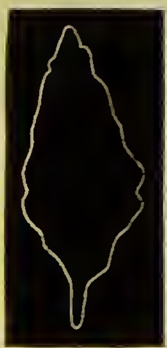


Fig. 25.

Fig. 28.

from right to left gradually increases, and the upper angle becomes round again (figs. 28, 29).

"Still farther back the cross-section of the canal, with a rapid increase in the diameter from right to left, has a triangular appearance, surmounted by the segment of a circle (figs. 30-33).

Fig. 30.

Fig. 32.

"While the circular segment becomes flattened out more and more, and the diameter from right to left, in consequence of a drawing out of the lateral angles, increases considerably (figs. 34-36), the canal presents the appearance of a triangle with two lateral horns, and while the lower angle becomes more and more obtuse, it passes over into the fourth ventricle (figs. 37, 38).

Fig. 35.

Fig. 38.

"The length of the aqueduct with adults, as I find with Luschka, amounts to 1·5 cm. With children it is not much shorter; with newly-born infants it has a length of 1·2 cm., and with children one year old it is 1·3 cm. long.

"The parietes of the aqueduct are not even, but sinuous in a high degree. . .

"Those parts of the brain which are in the immediate neighbourhood of the aqueduct, belong to the grey brain substance. The white or medullary substance in some places, indeed, is very near the canal, yet it does not anywhere form the parietes itself; but in the direction of the aqueduct is always covered with grey substance" (pp. 23-25).

522*q*. FERRIER.[1]—"The optic lobes of frogs, fishes, and birds are structurally homologous with the corpora quadrigemina of mammals.

"The superficial origin of the optic tracts from the optic lobes in frogs, fishes, and birds, and from the anterior tubercles of the corpora quadrigemina in the lower orders of mammals, and the similar, though less apparent, connection of the optic tracts in the monkey and man with the corpora quadrigemina, through the medium of the corpora geniculata and their brachia or arms, would almost, without experimental proof, indicate that these ganglia have an important relation to vision. But it would by no means follow that these ganglia are the centres of vision, even though it should be found that destruction of them produces blindness. . . . The facts of anatomy and those of physiological experiment mutually support the view that the corpora quadrigemina, though not the centres of conscious vision, are centres of co-ordination of retinal impressions with special motor reactions.

"Flourens first experimentally demonstrated that the optic lobes were the centres of co-ordination between retinal impressions and movements of the iris. When the optic lobes on both sides were destroyed, vision was completely abolished, and the pupils ceased to contract when light was thrown on the retina. This is a proof that in the optic lobes there is an organic connection between the optic and the oculo-motor nerve which supplies the circular or constringent muscle of the iris. This connection has an anatomical basis in the fact that the central nucleus of the oculo-motor, or third nerve, is situated in the corpora quadrigemina beneath the aqueduct of Sylvius, a canal which as it were tunnels these ganglia" (pp. 70, 71).]

[1] Ferrier (D.), M.D., F.R.S., "The Functions of the Brain," London, 1876.

ANALYSIS.

523. Everywhere in the chemical laboratory of the organs of the brain occur cavities, foramina, and clefts or rimæ; eminences, also, or tubercular bodies are found there keeping watch. These organic cavities are the lateral ventricles, the aqueduct of Sylvius, the third ventricle, the infundibulum; the two foramina are those of which the anterior is called "vulva," and the posterior "anus." Over each of these preside their active little bodies, such as are interspersed with grey substance. Over the lateral ventricles are placed the corpora striata, and the thalami optici; the same also preside over the third ventricle which is hollowed out between the heads or cones of the optic thalami. Over the anterior foramen are placed two little crura [the stria pinealis] which are attached to the larger crura or the thalami optici; over the posterior foramen preside the anterior tubercles of the corpora quadrigemina. Over the passage [aqueduct of Sylvius] which is common to the [posterior] foramina are placed the anterior and posterior tubercles of the corpora quadrigemina. The foramen which leads thence into the third ventricle is governed by the pineal gland; and the infundibulum in like manner is superintended by the tuber cinereum (*prominentiæ pone infundibulum*). The fourth ventricle even is presided over by the whole of the cerebellum, and its calamus scriptorius by the corpora pyramidalia and olivaria. As the cavities and tubercles have mutual respect to one another, the latter are called upon, whenever the exigencies of the universal kingdom require, that the passage should either be opened or closed; on this account also they diminish in size and almost

disappear when their use ceases, and they increase in proportion as their activity increases.

524. The larger and smaller cavities themselves are as it were so many bottles and receivers destined to hold the liquids which flow towards them; the foramina open a passage for them, from the large ventricles to the glandula vitæ, the pituitary gland. These cavities are the very organs of the laboratory, so disposed as to have respect to the axis, into which they despatch their liquids, and from which they draw those which are despatched to them. The very fate of the life and the condition of the kingdom depends upon each of these cavities or each of these organs performing justly the accurate number of its duties; for the question concerns the blood, that is, the life of the body. Wherefore it is necessary that there should be active bodies which exercise supervision, and that there should be passive bodies which yield obedience to the active bodies; and that there should be at the same time a regulating force which descends from the common fountain of all the forces. The tubera or tubercles are so many active forces, and as it were so many assistant wheels, and sheaves with pulleys, in the machine, which while acting from their own power, are at the same time acted upon by more general powers. The medullary strata, however, are so many passive members subject to the active. The whole mass of the brain is a general fountain of forces.

525. The posterior foramen called "anus" leads into the aqueduct of Sylvius, *i.e.* into the passage under the "testes," in a twofold way, that is, from both lateral ventricles. Hence it is of a twofold nature, although terminating in a single sinus or bosom. Thence through the foramen under the pineal gland a passage is afforded into the third ventricle. This posterior foramen is opened on either side as often as the lateral ventricles and the third or middle ventricle are closed, for then it offers itself with an open mouth, and draws in the lymph with full lips. The reverse happens when the ventricles by the action of the corpora striata, the optic thalami, and the fibres of the ventricular roofs allow themselves to be

expanded. In order that this twofold foramen may fulfil its duties properly, two tubercles, namely, the anterior ones of the corpora quadrigemina, are placed near it. These at the time when the foramen is to be opened, expand themselves along with the optic thalami, and thus relax the fibres, and stretch open the aperture of its mouth down to the bottom. In this wise they afford to the moisture which is expressed then from both choroid plexuses an opportunity of passing in. The little transverse tract [the posterior commissure] also which emanates from the medullary tract [stria pinealis] interposed between the thalami optici, is then stretched out, and draws apart the edges of the sphincter. In this wise there conspire together for the production of the same effect, the optic thalami as the general motors, regulators, and dispensers, the anterior tubercles or nates as the particular motors, regulators, and dispensers, and at the same time the cerebrum with its fibres. The anterior tubercles therefore lean proximately against the optic thalami, and derive thence a goodly number of fibres; for both, namely, the "nates" and the optic thalami, as colleagues in the same work, mutually attach themselves to each other by fibres and medullary bands.

526. The passage under the corpora quadrigemina, or under the "testes," and under a part of the "nates," is likewise drawn apart at the same time when the foramina are opened, and it absorbs the pure wave which approaches; and indeed by the same powers, that is, by the general powers of the optic thalami, and the particular powers of the "testes," which are also assisted in their work by the "nates;" and therefore the "testes" appear as epiphyses of the nates. Thus the medullary cords between the two testes, the two posterior tubercles, and again between them and the anterior tubercles or "nates," pass over into the optic thalami; thus nothing is carried distinctly to its ends without particular assistants under a general regulator. Besides, the grey substance which is interspersed in the sides of this aqueduct, and in the medulla by which it is enclosed, lends a helping hand, so that the fibres may be elongated, and that the connection in every direction may be relaxed.

527. The greatest help, however, in the dilatation of the aqueduct is afforded by the third and fourth ventricles, between which it is situated; for when each of these ventricles is compressed into a mere fissure, and stretched out towards the extremity of each, the intermediate space is necessarily increased and transformed into a wider sinus or bosom, especially at its bottom, which is raised up higher, when the third ventricle in its state of compression is swollen with lymph; and *vice versa.*

528. This intercalary passage is a receptacle of the lymph of the lateral ventricles, and a storeroom of the same for the third ventricle. In its shape it is not unlike a retort furnished with two beaks, and it does not pour more liquid into its ventricle than is required for the infundibulum and pituitary gland. For there is no violent intrusion, but rather a spontaneous influx, and as it were an invitation from the extreme parts which demand both the quantity and quality of their fluid. The forces of constriction of this cavity are indeed very small, and they do not correspond, nor are they equivalent to its forces of expansion; for otherwise, as in the cases of diseased and dropsical persons, a sharp liquid and yellow serosity would corrode, cut off, and stuff up the pipes and filters.

529. In respect to that flood of infected serum with which the ventricles are sometimes surcharged, as in the case of hydrocephali, and which does not come from the choroid plexuses, but is caused by an inroad through the folds of the pia mater covering the lateral ventricles, which are raised up and broken through, it is very probable that it is discharged in another direction, through some apertures and passages which are not yet discovered; for wherever there is a liquid, there also are ducts and asylums for the evacuations. Through the narrow beak of the infundibulum it cannot be discharged; for in this case it would destroy the entire organical laboratory. Morgagni, indeed, mentions another passage which runs underneath the aqueduct; and Ridley speaks of the duplicature of the pia mater around the anterior foramen, and also of an interstice which is continued towards the umbones or bosses of the cere-

brum. Willis, however, mentions medullary tracts and fissures in the direction of the olfactory bulbs, and ancient anatomists, a communication with the fourth ventricle. In looking for such a duct, it would have to be done either in this very passage, or near the septum lucidum, or, finally, in the septum itself, because it is bifidous. Such an interstice would be opened when the ventricles were flooded by an inundation of the kind, and were violently labouring during their times of constriction. It is better, however, to keep silence on such a subject than to indulge in conjectures under the appearance of truth, before a sharper use of the anatomical knife has laid open these hidden pipes, a task which has to be left to posterity.[1]

530. Thus far we have spoken of the chemical use of the corpora quadrigemina; but as the cerebrum and its parts serve also for the purpose of exciting voluntary motions in the body, and for propagating sensation into every cineritious and cortical substance, therefore also the corpora quadrigemina, as has been stated and maintained above in respect to the corpora striata and the optic thalami, cannot but contribute their share, and afford some particular help to the brain in this respect also.

531.[2] Nor are we mistaken in our surmises; for experience furnishes to us the following information: Are there not some fibres of the cerebellum which are inserted into both tubercles of the "testes" as well as of the "nates"? By this way these fibres tend upwards into the surface or into the delicate membrane of the optic thalami [stratum zonale], and at the same time more deeply into them, and thence, in conjunction with the fibres of the cerebrum, they direct their way towards the bulb, the coatings, the humours, the iris, and the pupil of the eye; that is, chiefly towards those parts of the eye which are being adjusted to the state of the objects at the time, and indeed spontaneously, and without any previous will of the

[1] On this subject see Sub-section D in Note iii.—EDITOR.

[2] Two paragraphs are here crossed out by the author, and the following *N.B.* is put in the margin: "The parts flow into the thalami optici, for the peduncles tend thither."

cerebrum: this is the office of the cerebellum. Thus the first of its processes or peduncles [*i.e.* of the cerebellum] enters into the caudex of the medulla oblongata and encircles it immediately below the "testes." Thence a way is prepared for it in company with the fibres of the rounded tops of the corpora quadrigemina, of entering into the surface and structure of the optic thalami. A greater harmony still is produced, because the choroid plexus of this region is subjected to the rule of the cerebellum, as well as to that of the cerebrum; and there is thus established an irresolvable knot, and the isthmus, *i.e.* the region of the corpora quadrigemina, is subjected both to the cerebrum and the cerebellum.

531*a.*[1] *At the same time the aqueduct of Sylvius seems to afford space for the roots of the nerves tending towards the muscles of the eye, so that they are able to act by a living force. Its grey substance also seems to concur with the cerebrum in causing these nerves to move;* namely, the third [or oculo-motor] nerve, the fourth [or trochlear] nerve, the sixth [or abducent] nerve, with the ophthalmic part of the fifth nerve. All these derive their fibres of origin from that neighbourhood, and in a certain measure depend upon the optic thalami by which the above passage is enclosed, and thus they concur with the sight of the eye itself in the production of a similar effect. That the roots of the nerves which are sent out into the muscles require for themselves a space for expansion either within or at the outside of their place of origin, and thus the power of influencing muscles, has been repeatedly pointed out above; and that this open or free space is obtained just as well in cavities as on certain external surfaces, as in the case of the cortical tori in the brains of the more perfect animals—this we may conclude from the ventricles of birds and fishes, and likewise from the cavities wrought into the medulla oblongata and spinal cord, which organs are also furnished with grey matter, as is the case pre-eminently with the aqueduct of Sylvius. Through the mediation of this grey substance they are

[1] From Codex 65, vol. iv. of Photolithographed MSS., p. 346 *et seq.*—EDITOR.

able to concur or to make common cause with the voluntary action of the cerebrum; and there arises hence such an involuntary principle of action as is noticed in the diversified motion of the eye, which is scarcely ever caused by a command of the cerebrum, but spontaneously determines itself in accordance with the objects, and according to the state of the cerebrum itself. . . . Near the aqueduct of Sylvius also the two processes of the cerebellum descend into the medulla oblongata.

EDITOR'S NOTES.

NOTE I.

THE MOTION OF THE BRAIN.

1. *Reality of this Motion.*

1. A knowledge of the motion of the brain Swedenborg regards as absolutely indispensable for a proper understanding of the functions of the brain. On this subject he expresses himself above in no. 59 as follows: "Without this knowledge we are not able to perceive anything in the anatomy of the brain; for unless we behold it as it were set in motion, all things appear, so to say, closed and dead; if then we look for the brain in the brain, we examine simply its dead body. But the uses of all the parts begin to lie open before us, as in the light of the rising sun, as soon as we represent to ourselves that the brain in general, and also each of its members and parts, is expanded and moved, and thus as it were lives. Without a knowledge of the motion of the brain we inquire in vain for the principles, the causes, and origins of the motions of the senses, and also for those of the remaining effects and phenomena in the body; for the universal body, with its powers, forces, and actions, lives entirely or chiefly under the motion or the auspices of the brain. . . . Without this knowledge we should remain in doubt as to the various diseases, especially of the head, and we should not know how to point out their causes, and on seeing and observing the changes in the opened brain, we should stand agape and wondering, as a donkey before a machine set in motion by wind or water. Without this knowledge also we should know nothing whatever in psychology; we should not know what the soul is, what the mind, the understanding, the will, and what the exercises of each are; for in order that the soul may live corporeally or by a body, the brain or everything organized must be moved or animated in alternate periods; but in order that the soul may live spiritually or in its spirit, the brain, or that which is an organism, must be quiescent."

2. If struck with these remarks we turn to the modern text-books on physiology for further light on this subject, we look in vain for any notice of the motion of the brain in the following works: (1) in Todd and Bowman's "Physiological Anatomy and Physiology of Man," 1845; (2) Todd's "Descriptive and Physiological Anatomy of the Brain, Spinal Cord, and Ganglions," 1845; (3) Carpenter's "Manual of Physiology," 1868; (4) Carpenter's "Principles of Human Physiology," ninth edition, 1881; (5) Foster's "Text-book of Physiology," third edition, 1879; (6) Draper's "Human Physiology," second English edition, 1861; (7) Flint's "Physiology of Man," second edition, New York, 1875; (8) Hermann's "Elements of Human Physiology," second English edition, 1878; (9) Ferrier's "Functions of the Brain," 1876.

3. If surprised at this result we inquire for the reason, why in our standard works on physiology there is absolutely no mention made of the motion of the brain, which up to Swedenborg's time had been acknowledged by most of the leading anatomists and physiologists—viz. Realdo Colombo, Bartholin, Ridley, Vieussens, Wepfer, Baglivi, Pacchioni, Fantoni, Bellini—we obtain the following answers from the Faculty.

Richet[1] says, "If you examine the head of a newly-born child, or of an adult the cranial walls of whose head have suffered loss of substance so that the dura mater is exposed, you will see that the membranes which replace the osseous walls are agitated by a double rising motion, of which one which is weaker is synchronous with the arterial pulsations, while the other, which is more marked, corresponds to expiration. Either of these elevations is succeeded by a subsidence, a kind of retreat. . . . If now it is incontestable that the encephalic nervous centres when they are in the anatomical conditions detailed above, that is, when they are enclosed in a cavity with osseous and membranous walls, are agitated by a double movement of elevation and subsidence, the question may, nevertheless, be asked whether in an adult cranium which is completely ossified, matters are circumstanced alike. The surgeons of all times, reasoning no doubt by analogy, and unmindful of the objections which might possibly be raised, admitted the fact [of these motions] as constant [*i.e.* as applicable to the adult as well as to the infant]; when all at once Pelletan,[2] a professor of physics to the Faculty, basing himself on the impossibility of the walls of the cranium lending themselves to the least extension; also on the state of repleteness in which the cranial cavity is at all times, and

[1] "Traité pratique d'Anatomie Médico-Chirurgicale," seconde édition, Paris 1860.

[2] "Traité de Physique," t. i., Paris, 1829, p. 448.

on the incompressibility of the liquids and the cerebral substance, laid down *a priori* this proposition, that *in the normal state with the adult these movements are an impossibility.* It is doubtful whether this assertion, which was diametrically opposed to all received ideas when it was first put forth, was deemed worthy of a refutation; and it required the experimental demonstration of Dr. Bourgougnon[1] a few years later to secure its admission into science, where, however, by the favour of the eminent men who have taken it under their patronage, it may now be said to have universal sway" (p. 284).

Dr. Carpenter seems to entertain a similar idea in respect to the movements of the brain, for he says, "In the experiments performed by Kussmaul and Tenner,[2] it was found on trephining the skull and compressing the carotids, that the brain, especially after removal of the dura mater, became very pale, and retreated from the opening to so great an extent as to form a cup $2\frac{1}{2}$ mm. in depth; whilst on releasing the pressure, it assumed a deep rose colour and became convex. When, however, they luted a piece of glass air-tight into the hole made by the trephine, as suggested by Donders, the phenomena were no longer the same, for no movement of any kind could then be perceived in the brain, which remained in all cases immovably in contact with the glass plate" ("Principles of Human Physiology," seventh edition, p. 310).

Luschka, in referring to Donders' experiment, says, "This observer succeeded in establishing the fact that when the skull is closed and unyielding, there is no motion whatever in the brain, the motion being rendered impossible, because the whole space of the cranium and the vertebral canal is constantly filled, and the changes in the pressure of the blood by respiration must be regarded as the same in measure and in time in all arteries and veins" ("Anatomie des Menschen," Bd. iii. Abtheil. ii. 1867, p. 158).

The reason, therefore, why the subject of the motion of the brain is excluded from the leading text-books on physiology in England and America seems to be that the authors admit indeed a motion of the brain in infants, and in cases where adult persons have lost a portion of the cranial substance; while in the normal state of adults, they believe this motion to be impossible, and therefore of too little practical importance to be treated in text-books.

4. This theory of a want of motion in the normal brain of adults, as we have seen, rests mostly on the experiments of Bourgougnon and Donders. In either of these cases an opening was effected in the skull

[1] "Recherches sur les mouvements du cerveau." Thèse de Paris, 1839.

[2] "Nature and Origin of Epileptical Convulsions." *New Sydenham Society*, London, 1859, p. 39 *et seq.*

of animals by trephining, and as long as the brain was exposed to the action of the atmosphere it moved; but when the opening was made air-tight, the motion of the brain ceased. Donders,[1] as we have seen, luted a piece of glass into the hole made by the trephine, while Bourgougnon, as Dr. Vaillard[2] informs us, screwed a ferrule to which a glass tube had been fastened into the hole. In the interior of the tube there was a little metallic plate resting on the brain, which communicated the motion of the brain to a little lever with an elbow, answering for an indicator. This motion was seen to agree nicely with the beating of the heart so long as the tube containing the lever was open. But as soon as it was filled with water (previously boiled in order to exclude all air-particles) beyond a little tap fixed so as to intercept all communication with the atmosphere,—on the tap being turned off, the movements of the little lever at once stopped. This gave rise to the conclusion that the motion of the brain exists only so long as there is an artificial communication with the atmosphere.

Richet repeated Bourgougnon's experiment with a view of testing its accuracy, and found it correct. "But," says he, "the inductions that have been drawn from it are false, and the experiment does not by any means prove what it is intended to prove. What, indeed, has Bourgougnon done? . . . He superadded to the cranial cavity a kind of appended cavity placed under exactly the same conditions as the cranium itself; that is, it was formed of incompressible walls and filled with a liquid which in its turn had been rendered incompressible by having been purified of air. In order that a liquid may oscillate in a tube presenting these physical conditions, a vacuum is required in the cranial cavity, which is a physical impossibility. This is all that the very ingenious experiment of Bourgougnon is capable of proving, and nothing beyond; and to infer from his experiment that in the cranium itself no displacement of liquids takes place, and that the brain is perfectly motionless in its osseous box, is drawing thence utterly unwarrantable conclusions. Let us suppose, for instance, that the sub-arachnoidal fluid contained in the cranium, and retreating under the pressure caused in the cranium by the arrival of the arterial blood, and the reflux of the venous blood, should for a short fraction of time take refuge in the vertebral canal, which amounts simply to one liquid replacing another. Let us suppose further that this substitution is effected without any vacuum being produced in the glass tube, the walls of which are just as inflexible as those of the cranium, and

[1] The principle involved in Donders' experiment is also discussed below in no. 15 of Note i.

[2] Dr. Vaillard, "Revue Critique: Des Mouvements du Cerveau." (Revue mensuelle de Médecine et Chirurgie, t. iv., Paris, 1880.)

resist just as much every attempt at expansion and elevation. Suppose all this is admitted, should we not then be able to understand that the twofold movement which is then being accomplished in the encephalic cavity—namely, (1) the expansion of the brain swollen by the pressure of a greater amount of blood, and (2) the displacement of a proportionate quantity of the cerebro-spinal liquid—may take place without the instrument revealing it to the eyes of the observer? It follows thence that the theory of Pelletan, in spite of the researches of Bourgougnon, is still in the condition of a hypothesis resting on the impossibility of explaining how in a cavity with inflexible walls which is exactly filled with an incompressible liquid or substance, any kind of motion may take place" (*loc. cit.* p. 284 *et seq.*).

In order to prove the capacity of the vertebral tube of expanding, Richet points to the condition of the dura mater in the vertebral cavity, and to the existence in its cervical portion of various venous plexuses, which are backed by a compressible layer of a fatty liquid. Still, if according to Swedenborg's theory, as confirmed by the researches of Key and Retzius,[1] the cerebro-spinal fluid at each expiratory movement of the brain is propelled through the interstices between the fascicles and fibres of each departing cranial and spinal nerve; if, therefore, each foramen affording an exit to a nerve is at the same time a place of departure for the cerebro-spinal liquid, then each of these foramina also is a goal towards which the expansile motion of the brain is directed, away from the trephined opening made air-tight either according to Donders' or Bourgougnon's method.

5. Richet, however, was not the only one who disputed the correctness of the deductions drawn from the experiments of Donders and Bourgougnon. François-Franck[2] relates the following experiment instituted by Mosso and himself, whereby Richet's course of argumentation is confirmed in every particular. He says, "Put your hand into a jar [through a lid made air-tight] furnished with two mouthpieces. One of these mouthpieces is closed with a very elastic membrane; the other supports a tube with a tap, the tube being filled with water beyond the tap. It is easy to see that as long as the communication with the external air is kept up, the oscillations of the water consequent upon the increase and decrease in the volume of the hand are considerable in the tube where the tap is kept open, while there are scarcely any vibrations in the mouthpiece covered with an

[1] See our note on the "Cerebro-spinal Liquid" in vol. ii. of the present work.—EDITOR.

[2] "Recherches critiques et expérimentales sur les mouvements alternatifs d'expansion et de reserrement du cerveau." (Journal d'Anatomie et Physiologie, Paris, 1877, xiii. pp. 267-307.)

elastic membrane. Why is this? Evidently because the changes in the level are produced at that point where there is the least resistance, and because there is nothing to oppose itself to the manifestation of these changes in the tube which is in communication with the open air. On the other hand, the elasticity of the membrane of indiarubber covering the other membrane, however weak it may seem, nevertheless opposes a serious obstacle to the movements of the column of water, all of which, in this case, are conveyed towards the open tube. This corresponds to the first part of Bourgougnon's experiment; to that part where the movements of the brain are conspicuous.

"Let us now close the tap of the tube in which the oscillations had been so manifest. All motion now disappears, and it cannot be otherwise, since the column of water is not compressible. But has your hand on that account ceased to change in volume, and to swell each time when there is an afflux of blood? All you have to do is to examine the elastic membrane, which has hitherto remained motionless, and which now begins to heave and to subside in turns, in order to convince yourself of the fact that the oscillations still continue, and again manifest themselves where they meet with the feeblest resistance. The case is the same in the second part of Bourgougnon's experiment: if the lever which rests on the brain ceases to indicate any motion after the tap is closed, the reason is that the movements are conveyed towards those parts of the vertebral canal which are compressible. This experiment, which seems very convincing, is due to Mosso."

6. Vaillard[1] in summing up these cases says, "The reality of the motion of the brain in the ossified cranium [*i.e.* in the normal adult brain] is henceforth established, and the following is a fundamental fact belonging definitely to science: namely, that this motion takes place through the medium of the cerebro-spinal fluid, which is capable of displacement in exactly the same way as the changes in the volume of the hand, or of any other part of the body, are produced in an apparatus filled with water."

The existence of the motion of the brain is hence not only a rational, but also a scientific fact.

2. *The Respiratory Motion of the Brain.*

7. As the heart and the lungs have each their peculiar motion, so also the brain, according to Swedenborg, has its own specific motion which it imparts to the whole of the nervous system; and that motion,

[1] "Revue mensuelle de Médecine et Chirurgie," iv. 1880, pp. 632-654.

he declares, is synchronous with that of the lungs. To the demonstration of this thesis, namely, that "the motion of the brain, *i.e.* its animation, is coincident with the respiration of the lungs," he devotes an entire section in Part II. of his "Œconomia Regni Animalis," published at Amsterdam in 1741, pp. 103-158. A categorical statement of this thesis he makes in our present work in these words, "The times of the animatory motion of the cerebrum, cerebellum, of the medulla oblongata and the spinal marrow, coincide with those of the respiration of the lungs in adults; but with the times of the pulsation of the arteries and of the heart in embryos, and in persons not breathing" (i. no. 53). A synopsis of his entire theory, however, on this subject, he published in his "Regnum Animale," vol. ii., which appeared in Amsterdam in 1744. He says there, "The respiration of the lungs flows not only into the trunk of the body, but also into the head, and into the organs of motion and sensation; and in fact to the brain, the very fountain of its motion, to which it rises in infinite streams, as it were in meanders and circles, and associates itself with the periods of its respiration, which we term the animation of the brain. Thus the lungs and the brains with the medulla oblongata and the spinal cord are synchronous in their respective animations and respirations; and this in order that causes may act harmoniously, and conspire in operation, with effects; things prior with things posterior; and the spirit of the soul with the spirit of the body; and in order that there may be an influx and reflux of the one into the other. On these accounts the pulmonic engines or bellows rise precisely at the same moments that the cerebrum inspires its costal, and the cerebellum its sympathetic nerves" (ii. no. 398, English edition).

Swedenborg is well aware that a second motion is usually attributed to the brain, namely, one that is pulsatile, and which is synchronous with the motion of the heart. That motion, however, he maintains, belongs to the dura mater, and not to the brain itself, and is erroneously attributed to the brain. He says on this subject, "If we do not reach the brain itself, we perceive either by sight or touch the motion of the dura mater alone, and conclude from it to that of the brain. But here we are deceived by first appearance; for there is a mixed or compound motion in the dura mater—one motion owing to its arteries, which communicate immediately with the arteries on the outside of the head, and another motion received from the brain through the medium of the three great sinuses. This is the reason, as I think, why Baglivi, Pacchioni, and all other anatomists so far as I know, founding their assertions upon what appears to them to be experimental fact and evidence, assert that the moments or pulses of the brain and heart are synchronous" (i. no. 106).

8. According to Swedenborg, there is therefore in the dura mater one motion which is peculiar to that membrane, and which is imparted to it by the network of arterial shoots extending into it from the external carotids; and another motion which is communicated to it by the brain underneath through the medium of the three large venous sinuses. The former of these motions, which is pulsatile, seems more persistent, and on account of the great number of arterial shoots disseminated through the texture of the dura mater, is diffused over its whole substance. The other motion, which coincides with the movements of respiration, is more limited and variable. It is strongest in the neighbourhood of the sinuses, and diminishes in force as the dura mater retreats to a greater distance from the sinuses. Again, the respiratory motion of the dura mater is naturally most apparent where that membrane is laid bare; while the feebler and more delicate moments of that motion are necessarily lost to the observer, when the dura mater is fortified by an outside membrane and other soft parts, as in the fontanelle of infants, and in such cases in adults where cranial wounds are healed over. Still, when the dura mater is covered simply by a thin periosteum and a delicate skin, as in infants, only the feebler respiratory movements would be withdrawn from observation; while in analogous cases in adults, where these membranes are thicker and denser, more of these movements would be obliterated.

These positions which flow from Swedenborg's theory of the double or mixed motion of the dura mater, are fully borne out by the self-registering observations of the movements of the brain which have recently been made by Prof. François-Franck and Dr. Salathé in Paris, and Prof. A. Mosso in Turin, by means of the various apparatuses (pneumograph, sphygmograph, etc.) introduced at the laboratory of Prof. Marey of the Collége de France, and described in Marey's text-book entitled "La Méthode Graphique," etc., Paris, 1878.

The following is a graphic representation, taken by François-Franck in conjunction with Dr. Brissaud,[1] of the movements of the dura mater in the case of a woman who by necrosis had lost the greater part of the left parietal bone. The necrosed bone had spontaneously detached itself, leaving a large surface of the dura mater exposed, the oscillations of which could easily be communicated to a receiver (tambour) in connection with a registering lever. The movements of the dura mater were recorded simultaneously with the respiratory motion of the thorax.

[1] Brissaud et François-Franck, "Inscription des mouvements d'expansion et de retrait du cerveau chez un femme présentant une vaste perte de substance du pariétal gauche." (Travaux du Laboratoire de M. Marey, Professeur au Collége de France, iii. année, 1877. École Pratique des Hautes Études.)

Description of Fig. 1.[1]—" *R*, respiratory curves of the thorax (expiration corresponds to the ascending portion of each curve). *Ce*, change of volume of the brain in correspondence with the respiratory movements."

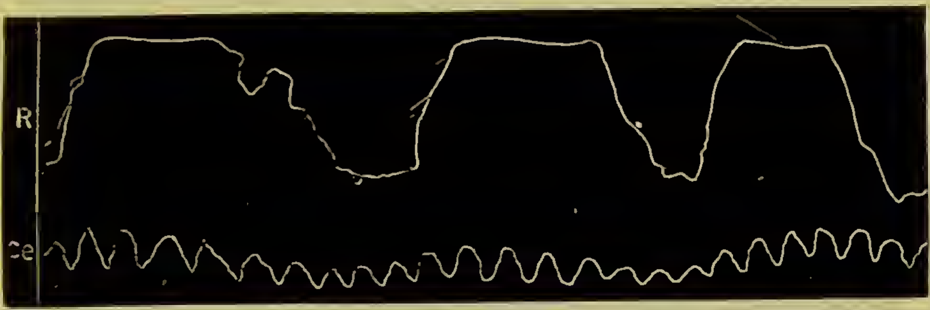


Fig. 1.

The little curves or angles jutting out in the line *Ce* represent the arterial pulsations of the dura mater, which are synchronous with the pulsation of the heart; while the larger undulating line formed by the little arterial curves describes a movement in the dura mater in harmony with the respiration of the lungs. Strictly speaking, therefore, fig. 1 exhibits the motions of the dura mater, and not, as the authors represent it, "the alternations in the increase and decrease in the mass of the brain during expiration and inspiration."

"The above figure," they further say, "shows the respiratory oscillations of the changes in the volume of the brain, while the respiration of the lungs is full, and the entrance of the air is a little obstructed. . . . Fig. 71 [our fig. 2] has been obtained from the same patient while she was breathing gently" (p. 138 *et seq.*).

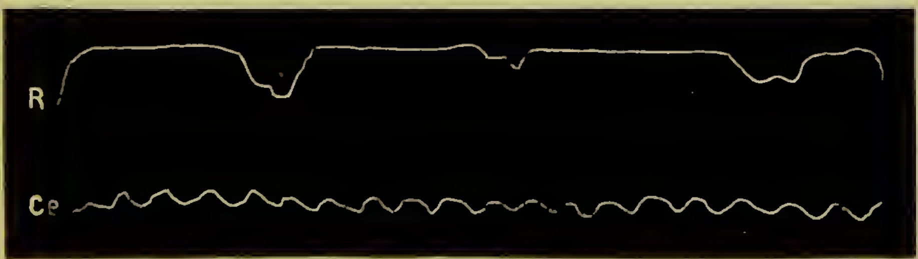


Fig. 2.

"In the following example, fig. 75 [our fig. 3], an effort made by the patient, although moderated in respect to energy, has nevertheless produced a very considerable increase in the volume of the brain; and, indeed, for this reason, because the effort was made while the body of the patient was in a condition of greatest efficacy; namely, on account

[1] The figures introduced from François-Franck, Salathé, and Mosso are obtained by tracings from their printed works.—EDITOR.

of a large amount of air having previously been introduced into the chest by a deep inspiration."

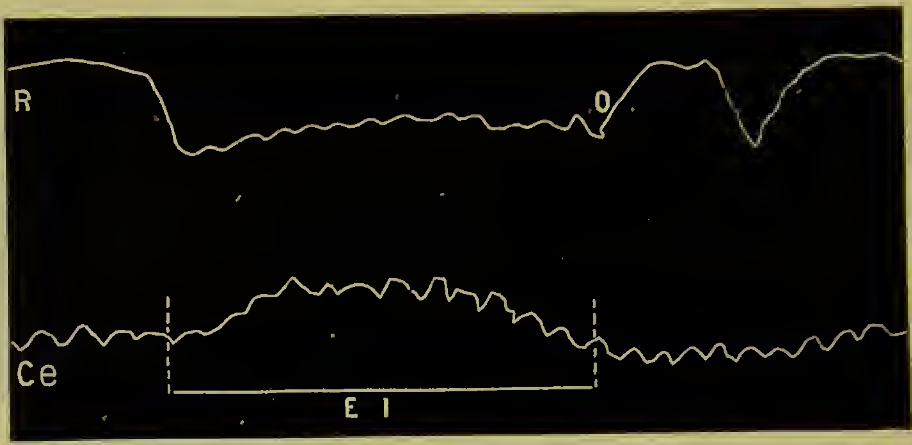


Fig. 3.

Description of Fig. 3.—"Considerable increase in the brain (*Ce*) during a moderate effort (*E* 1) made after a deep inspiration. *R*, respiratory curves obtained by means of the pneumograph" (p. 143).

9. Results analogous to those published by Brissaud and François-Franck were obtained by Dr. Salathé,[1] who experimented on the fontanelle of an infant six weeks old, and also on the head of a man who had lost a piece of his skull of the size of a five-franc piece.

In the case of the child we notice an absence of respiratory curves 'while it was asleep," and in the case of the man while he was "in his ordinary state, breathing calmly and regularly." This absence of respiratory curves, in both these cases, seems to be due partly to the fact of the dura mater having been covered by an additional extraneous membrane, by which the respiratory movements of the brain were deadened. In a state of forcible respiration, however, or during a state of effort, the respiratory curves, in either case, are most decidedly marked.

The following figure is Salathé's tracing of the movements of the fontanelle in a sleeping child.

Description of Fig. 4.—"Beating of the anterior fontanelle of a child six weeks old (line *F*) during sleep, with the respiration of the thorax registered simultaneously."

Salathé says, "This figure exhibits in the first place a lower line, that of respiration, which consists of a series of undulations of which each corresponds to an act of respiration. These undulations are very even, a sign of the equality and regularity of respiration in the sleep of an infant.

[1] Salathé (A.), "Recherches sur le Mécanisme de la Circulation dans la cavité céphalo-rachidienne." (Travaux du Laboratoire de M. Marey, Professeur au Collége de France, ii. année, 1876. École Pratique des Hautes Études.)

"The upper line is that of the beating of the fontanelle. A punctuated line gives the general level of these beatings. Here again we have undulations which are even and regular, but much smaller and

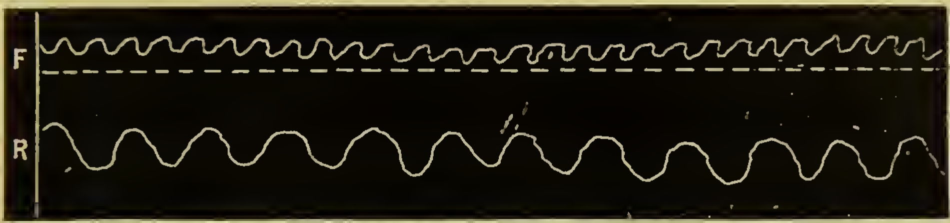


Fig. 4.

more numerous. They correspond to the pulsations of the arteries, and represent especially those rhythmical swellings of the encephalon [of the dura mater !] which are in harmony with the cardiac movements.

"The respiratory motion, as is easy to see, in the present case does not exercise any special influence on the beating of the fontanelle.

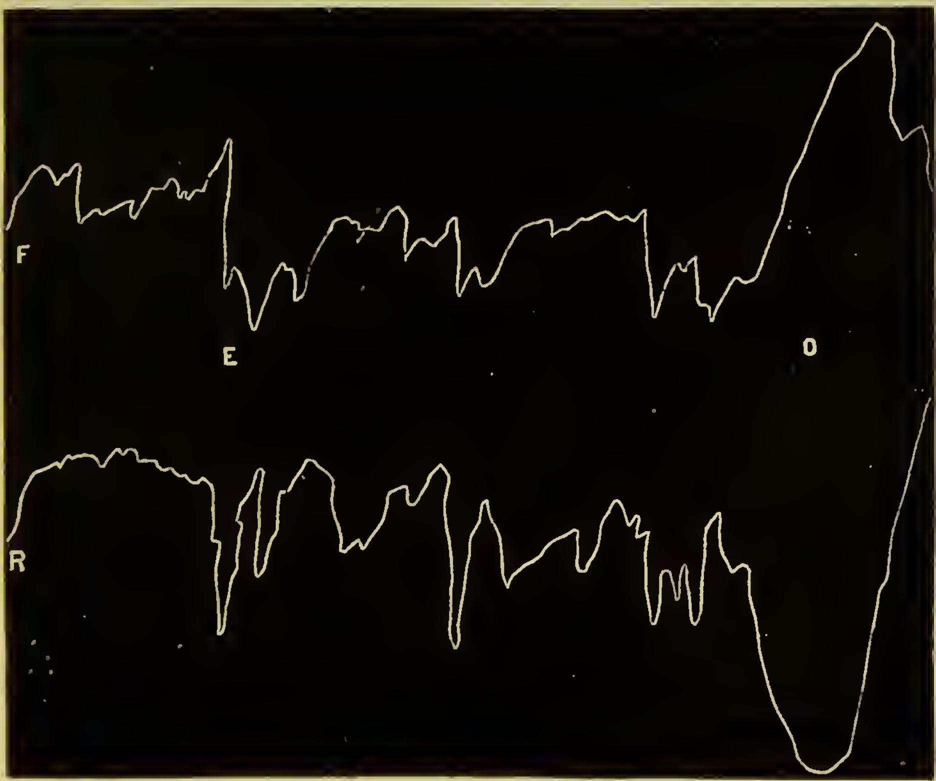


Fig. 5.

"After this period of calm our infant awakes. He cries, and you can scarcely believe that fig. 172 [our fig. 5] represents the same elements as the preceding figure [fig. 4].

"Here, however, as in the previous case, the upper line corresponds to the movements of the fontanelle, and the lower to the respiration of the thorax.

"The former of these lines recalls scarcely in any particular the preceding line; in short, the influence exerted by respiration predominates to such a point that the cardiac influence is entirely covered up and disguised, or at least rendered incapable of being deciphered.

"But are we able at least to discover any similarity between the tracings furnished by the fontanelle and the respiratory movements? At first it seems difficult to trace any likeness between them. Nevertheless, you are soon able to find some correspondence between the most marked of the undulations of each line. But while some of them are almost parallel, others appear inverted: a depression of the respiration on the one hand corresponding to a rise in the tracing of the fontanelle on the other. This contradiction, nevertheless, is only apparent. The reason lies in the new type of respiration adopted by the child who from a tranquil sleep passed into the excitement of waking up, and whose respiration has become altogether abdominal: whence the inversion of the curves.

"This inversion is most noticeable in the point marked *O*, which corresponds to a prolonged cry, which caused an extreme ascension in the line of the fontanelle."

Salathé, referring to Dr. Mocquot's[1] essay on this subject, explains the abdominal inversion of the respiratory curve thus: "The abdominal muscles contract themselves violently, pushing the diaphragm suddenly and forcibly into the thorax. Thence there results a considerable increase in the thoracic pressure. This increase in pressure produces two simultaneous effects: a dilatation of the thorax, and an expulsion of a certain amount of air; causing a descent of the respiratory curve during expiration. The ascent of the curve during inspiration, however, is explained by an inverse mechanism. The diaphragm having been violently pushed into the thorax, contracts itself energetically, and in doing so carries the lungs with it, while the chest, distended by the preceding act, subsides; the inspiration being caused exclusively by a contraction of the diaphragm" (p. 351 *et seq.*).

10. The following tracings Dr. Salathé took from a man who had lost a piece of his skull of the size of a five-franc piece. His description of his experiment is as follows:—

"We employed the new *explorateur à tambour* of Prof. Marey, the button of which we applied to the region corresponding to the loss of the osseous substance. At the same time we also took a tracing of the radial pulse by means of the sphygmograph *à transmission*; while

[1] Mocquot, "Essai de pneumographie, pour servir à l'étude de maladies des enfants." Thèse de Paris, 1875.

the pneumograph which was applied to the chest gave us the respiratory curves. The tracings were taken while the patient sat in an upright position, his head being slightly inclined forwards.

"Under ordinary conditions, the patient being tranquil and his respiration calm and regular, we noticed that only the systaltic motions of the heart produced an effect on the frontal curve reproduced in the upper line of fig. 175 [our fig. 6]."

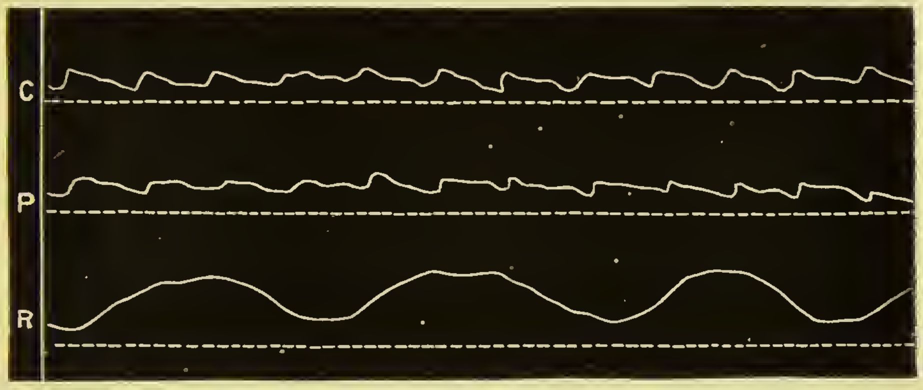


Fig. 6.

Description of Fig. 6.—"Graphic representation of the movements communicated to the soft parts covering a loss of cranial substance. *C*, tracing taken from the forehead; a punctuated line showing the general level. *P*, the radial pulse with a punctuated line. *R*, respiration.

"No modifications, the results of respiration represented in the lowest line, can be discovered here, that is, in the frontal tracing. . . .

"The first portion of fig. 176 [our fig. 7] reproduces the same effects; but the patient is making an effort, and as soon as we tell him to do so, the scene changes."

Description of Fig. 7.—"The same as fig. 6, while the patient is making an effort. *C*, frontal curve. *P*, radial pulse. *R*, respiration. The descent in the undulation corresponds to inspiration, its ascent to expiration.]

"To the second wave in the respiratory curve," says Dr. Salathé, "succeeds a line almost horizontal, which marks the duration of the effort.

"The corresponding portion in the tracing of the radial pulse shows us a series of pulsations ascending in stair fashion, which indicate in an unmistakable manner that increase in the arterial pressure, of which we find the effects again in the ascent of the frontal tracing which is so very remarkable, and which still allows us to distinguish some projections in harmony with the cardiac pulsation.

"As soon as the effort ceases we find that at the very time when the respiration is taken up again, the cerebral elevation effects quite an abrupt descent, while the arterial tension in the radial pulse abates. The two lines lapse even a little below their first level.

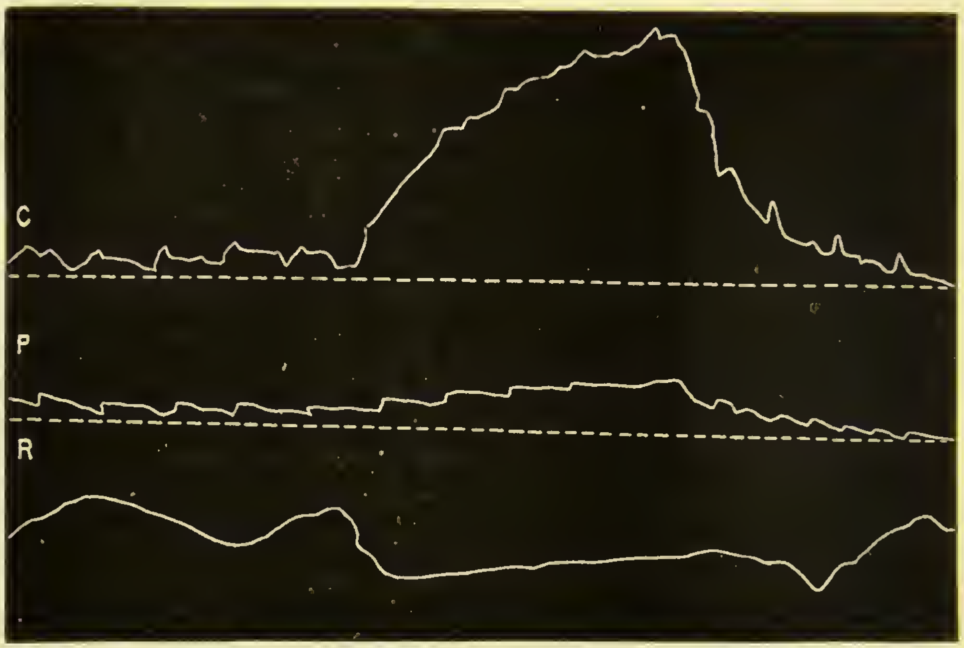


Fig. 7.

"A continuation of the tracing, after the cessation of the effort, would have shown that after the respiration had become calm, the instrument which recorded the encephalic motions would have indicated only a cardiac influence.

"In summing up these observations we may state that the respiratory influence manifested itself on the cerebral tracing only in the case of an exaggerated respiration, during effort, etc. The cardiac influence, which is alone noticeable in a state of normal respiration, expresses itself in that case by a series of oscillations parallel with those of the pulse, of which they reproduce the peculiar elevations" (*ibid.*, p. 358 *et seq.*).

11. On studying the bearing which the facts brought before us by François-Franck and Salathé have on Swedenborg's theory of the mixed motion of the dura mater, we find that they fully bear out and confirm every one of his positions. Thus in the first place they prove that the respiratory motion observed in the dura mater is not inherent in it, and therefore must be communicated to it by a force extraneous to it; for in what the observers call a "normal state," only arterial motions synchronous with the pulsation of the heart are noticed in the dura mater; compare figs. 2, 4, and 6. The alternate movements in the dura mater synchronous with respiration are noticed only in fig. 1; that is, in the case where a large piece of the dura mater was exposed,

and the observation could be taken *immediately from the dura mater.* But when the dura mater is covered by additional membranous layers and other soft parts, as in Salathé's second case, these continuous respiratory motions can no longer be discerned. From this, however, it does not follow that these motions in that case did not exist; but that they were deadened by the additional soft parts through which they were observed. Still, when François-Franck's patient breathed very gently, as in fig. 2, the respiratory motions in the dura mater ceased even in her case, thus showing that the motion of the brain underneath was so light that it did not make any impression on the dura mater. The same would also seem to be the case during sleep; for all that Salathé noticed in the fontanelle of a sleeping child were arterial movements synchronous with the beating of the heart. When persons, however, make an effort; when thus the will-force in the brain is set to work, as in figs. 5 and 7, the effect of the brain upon the dura mater is so powerful that it causes in it exaggerated motions which are reflected in, and assisted by, the respiratory movements of the lungs.

12. Upon the question whether the respiratory movements in the dura mater are really produced by the brain independently of the lungs, the following experiment made by Prof. Mosso[1] in Turin settles this question in favour of the brain.

The case which he observed was that of a peasant of the name of Bertino, who had lost a part of the anterior portion of his skull by a brick falling upon it. The following figure contains a tracing from Bertino's forehead taken while his brain was undergoing a distinct mental operation.

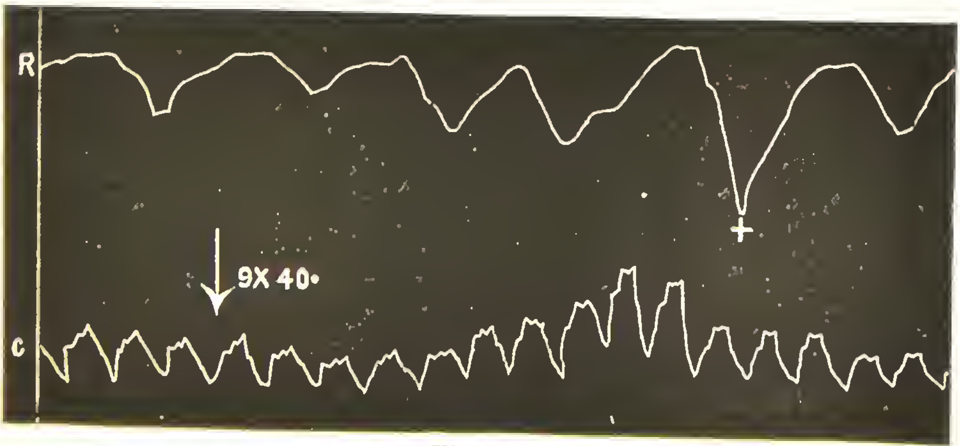


Fig. 8.

Description of Fig. 8.—"The increase in the volume of the brain

[1] Mosso (A.), Professor of Physiology in the University of Turin, "Ueber den Kreislauf des Blutes im menschlichen Gehirne," Leipzig, 1881.

during an intellectual operation does not correspond to a change in the respiration. *C*, the pulsation of the brain [*i.e.* of the dura mater]. *R*, respiratory motion of the thorax registered by means of one of Marey's pneumographs.

"Fig. 20 [our fig. 8] shows us that the change in the pulse of the brain [observed in the dura mater] does not depend by any means upon a change in the movements of respiration. Thus while I put Bertino through a process of multiplying 9 by 40, there was caused an increase in the elevation of his [animatory] cerebral pulse, while the increase in the motion of respiration ensued only after the increase in the volume of the brain had been accomplished" (p. 71).

The mind, therefore, by its influx into the brain, is the cause of the motion of that organ, and not the subordinate motion of the lungs.

13. Another point flowing from Swedenborg's theory of the motion of the brain, namely, that it is synchronous with respiration, is this, that the blood-vessels of the brain, which are continuations of the internal carotids and the vertebrals, on entering the cranium are emancipated from the motion of the heart, and move in the stream of the animatory motion of the brain, which is synchronous with respiration. His statement in brief on this subject is as follows: "As soon as the arteries of the body reach the first threshold of the head, the cranium, they renounce the government of the heart and subject themselves to the cerebrum and cerebellum. There are two arteries which ascend from the kingdom of the heart, that is, from the body; they are the [internal] carotids and the vertebral arteries. As soon as these touch the bony threshold itself, they twist and bend themselves in a wonderful manner, and untwist again; they also lay aside their motory coating beyond which the heart of the blood cannot act; moreover, they are dilated contrary to customary usage, and at last after repeated decussations they insert themselves into the pia mater, and after being ramified into least threads, they enter into the cerebrum and cerebellum without blood, and submit themselves entirely to their orders" (i. no. 55).

What does science say to this? Swedenborg's statement about a change in the coatings of the arteries at their entrance into the cranium, Burdach confirms in these words, "After gaining an entrance they [the arteries] give up their fibrous sheath which passes over into the dura mater; and in correspondence with the sphere to which they henceforth belong, they acquire a peculiar character: for in accordance with the great sensitiveness prevailing everywhere within the cranium, they, together with their annular, muscular fibres, lose every vestige of a proper or independent irritability, by becoming thin-coated

Placed under the immediate influence of the brain, they also cease to be attended by their own nerves" (see above, no. 383*a*). This statement is confirmed by Quain in these words: "Some arteries have much thinner coats than the rest, in proportion to their calibre. This is strikingly the case with those contained within the cranium and in the vertebral canal; the difference depends on the external and middle [muscular] coats, which in the vessels referred to are thinner than elsewhere" (see above, no. 383*c*).

From this, however, it follows that the arteries in the cranium having "lost every vestige of a proper or independent irritability," have acquired a passive character, and are ready to accommodate themselves to, and to become imbued with, the animatory motion of the brain.

In Dr. Carpenter's "Principles of Human Physiology" we meet with the following statement, which has a bearing on the present subject: "The movement of the blood through the veins is, without doubt, chiefly effected by the *vis à tergo* or propulsive force which results from the action of the heart and arteries" (7th edit., p. 306). From this principle, which we find repeated in most treatises on physiology, it follows that if we know the character of the motion which prevails in a set of veins, we are able to conclude back from them as to the character of the arteries by which they are acted upon *à tergo.* Now in no. 328*p* of the present volume we detail an experiment made by Key and Retzius, by which they show that the increase and decrease of the pressure in the longitudinal sinus is mainly in accordance with the movements of inspiration and expiration. Thus, while the rise and fall of the blood in the longitudinal sinus during the intervals of respiration, as measured by the manometer, amounts to from 2 to 4 mm., the arterial pulsation, which could also be observed simultaneously in the manometer, they describe as being "small." If, therefore, the prevailing motion in the longitudinal sinus is in accordance with the intervals of respiration, and if the arterial pulsation in them is only "small," it follows from the principle laid down by Dr. Carpenter in relation to venous circulation, that the prevailing motion in the arteries within the cranium is also in accordance with the intervals of respiration, and that their arterial pulsation is weak.

Here then we have another confirmation of Swedenborg's doctrine in respect to the motion of the brain; namely, that the motion of the brain itself is synchronous with respiration, while the pulsatile motion, which is usually attributed to the brain, belongs to the dura mater. The experiment of Key and Retzius, to which we have referred above, confirms also a statement made by Swedenborg to this effect, that the dura mater receives the animatory motion of the brain "through the medium of the three great sinuses," *i.e.* the longitudinal and the two lateral sinuses.

To the fact that the arterial as well as the venous blood of the encephalon is emancipated from the jurisdiction of the heart, and is placed under the immediate government of the brain, which imbues it with its own motion, we also attribute a peculiarity noticed by physiologists in connection with the circulation of the blood within the cranium, namely, a tendency in the blood of remaining within the cranium, and a disinclination to being forced thence.

14. The next point which concerns us is the motion observed in the liquid between the dura mater and the brain; namely, in the sub-arachnoid or cerebro-spinal liquid which circulates between the arachnoid membrane and the pia mater. This involves the relation which the dura mater and the brain occupy in respect to one another. On this subject Swedenborg says, "*The dura mater grants the brain space, bounds, measure, mode, and ability of swelling in alternate times; nay, as a common or general bond it permits it even to reciprocate the times of its animation; and to this it also contributes its own share.* It grants it space, because the dura mater is removed from the pia mater of the brain, except in the points mentioned above. It grants it bounds and measure; for the brain is able to swell so far, and no farther. It grants it mode according to the bounds or limitations which it prescribes; and consequently ability; for without the dura mater, or when its bands are loosened—when, therefore, the brain is not embraced by the dura mater—the brain raises itself only with great difficulty; as has been observed by experience in some diseased persons. It is therefore also smoothed and polished on the side which is turned towards the brain, and anointed by a proper fluid. On this account also its vessels are imprinted on some of the tables of the cranium. Hence arises the expansile motion of the dura mater; for it has a double motion, namely, one which is expansile, and another which is pulsatile. The former it derives from the brain, and the latter from its own arteries. Reaction and elasticity are required of the dura mater, in order that it may concur in a general manner with the motion of the brain; for when it has reached the extreme bounds of its expansion, then the dura mater urges it to enter upon the reciprocal period of its contraction. . . . The dura mater, therefore, ministers to the brain in the capacity of a tendon" (i. no. 261).

The property of the dura mater by which it is enabled to reciprocate the motion of the brain—its elasticity, in fact, which is denied by a number of the leading anatomists—is fully discussed in the light of modern science in Note ii. on "The Structure and Use of the Dura

Mater," nos. 4 to 11. But as to its structure, so far as it is enabled thereby to have a twofold or mixed motion, Swedenborg distinguishes in it a "duplication or a triplication of strata or laminæ" (i. no. 163); and he says, "the internal lamina of the dura mater belongs to the brain, the external to the heart, and the middle where the arteries run, to both" (*ibid.*).[1] From this, however, it follows that the external lamina, which is turned towards the cranium, has a pulsatile motion, and the internal, which is turned towards the brain, is imbued with the respiratory motion of the brain. Now we learn from the tracings of François-Franck, Salathé, and Mosso, that whenever the breathing is tranquil, or when the brain retreats from the dura mater, the pulsatile motion prevails in the dura mater; but when the brain makes a voluntary effort, or goes through a mental operation, the respiratory motion of the brain prevails over the pulsatile motion. From this again it follows that the liquid which occupies a middle ground between the dura mater and the brain, is a recipient both of the pulsatile motion of the dura mater, and of the respiratory motion of the brain. This also is the result of experience in the case of animals where a part of the cranium has been removed by a trephine, and the dura mater under it has been excised, thus enabling the observer by a suitable apparatus to record the oscillations of the cerebro-spinal liquid. These movements are exhibited in fig. 9, which is a tracing, taken by Salathé,[2] of the oscillations of the cerebro-spinal liquid in a trephined dog, with a simultaneous registration of the respiratory motion of the dog's chest.

Fig. 9.

Description of Fig. 9.—"A tracing of the cerebral oscillations (*C*) and the respiration (*R*) taken simultaneously in a dog; *I*, inspiration; *E*, expiration."

[1] Concerning the distinction of the dura mater into laminæ, see Note ii. nos. 1-3.

[2] "Recherches," etc. (Travaux du Laboratoire de M. Marey, ii. année, 1876).

Salathé continues: "The tracings furnished by the dog are much more satisfactory than those obtained from the rabbit. Fig. 178 [our fig. 9] is a good example.

"The upper line shows oscillations which for convenience' sake we shall call 'cerebral oscillations.' Oscillations are noticed there harmonizing with the pulse, to which large respiratory undulations are superadded. That these undulations are in harmony with the respiratory motion can very easily be seen by a comparison of the two lines placed one above the other. The volume of the brain is seen diminishing during inspiration (*I*), and increasing during expiration (*E*).

"In the above example the respiration is very calm" (p. 365).

Very little difference is noticed between fig. 9, which represents the oscillations of the cerebro-spinal liquid, and fig. 1, which represents the motions of the dura mater taken from that membrane itself. The influence from the brain in either case seems to be as marked as that exerted by the dura mater.

15. In Salathé's description of his experience in measuring the oscillation of the cerebro-spinal fluid in trephined dogs, a circumstance is alluded to which, no doubt, had a considerable share in determining the result of Donders' experiment adverted to above (p. 647) by Dr. Carpenter and Prof. Luschka. Salathé[1] says, "The brain on coming into contact with the orifice [produced by the trephine] in the cranium, applies itself to the same so closely as to shut it up completely in the manner of a cork-stopper, which no longer allows the cerebro-spinal liquid, which had been drawn away by the expansile motion of the brain, to flow back into the tube [attached to the opening in the cranium]. Under such conditions it was, indeed, still possible to perceive some very feeble oscillations in the tube, which oscillations became especially visible by the play of the light on the surface of the liquid contained in it; yet these exceedingly small displacements arose only from the small portion of the encephalic surface engaged in the orifice and forming the hernia, and which could be the seat of very feeble movements occasioned by the increase and decrease in the swelling of the encephalon. The production of such herniæ in the roof of the cranium can be easily understood when it is borne in mind that in a normal condition the cerebral hemispheres are in contact with the roof of the cranium, from which they are separated simply by a thin stratum of the sub-arachnoid liquid.

"In one of our last experiments we were able to ascertain very positively the part of an obstructor which a cerebral hernia may play in an operation with the trephine.

[1] Salathé (A.), "Recherches sur les mouvements du cerveau." Thèse de Paris, 1877.

"After applying our apparatus to the opening obtained, we were able to register some fine movements from a trephined dog. These movements, which at first were very marked, gradually became weaker, until at last they became nearly equal to zero. After unscrewing the tube fixed to the cranium of the animal, we perceived a hernia which extended considerably into the osseous space. By pressing it gently with the finger we caused it to return into the cranial cavity. At the same time, as the brain no longer pressed against the edges of the opening in the cranium, we saw how the cerebro-spinal liquid made its way impetuously between the cerebrum and the cranium, all around the opening which had been made by the trephine. After the tube had been screwed on again the movements reappeared, but disappeared in proportion as the hernia was produced anew" (p. 74).

Such herniæ are no doubt formed in all those cases where, as in Donders'[1] experiment, a piece of glass is luted air-tight into the hole formed by the trephine. Thus, suppose the space between the brain and the glass is first filled up by water which has been boiled, yet that water is sure to be absorbed by-and-by, when the substance of the brain is necessarily pushed into its place, thus forming a hernia of the kind described by Salathé, which is the subject merely of very diminutive cerebral movements.

16. The facts concerning the motions of the brain and of the dura mater which have recently been published by the "Graphic School," as represented by Professors Marey, François-Franck, Mosso, and Dr. Salathé, are so positive, and as being self-registered are established so firmly beyond all reasonable doubt, that it seems unnecessary to dwell on the results obtained by previous observers. And yet it is necessary to regard the results and the conclusions at which previous explorers have arrived in the new light gained on the subject.

Up to Swedenborg's time, *i.e.* 1740, the motion of the brain was universally supposed to be synchronous with the systole and diastole of the heart. And although Oribasius, as far back as the fourth century after Christ, is said to have spoken of a motion of the brain in harmony with respiration, and although Slevogt, who published, 1690, at Jena, a disputation on the dura mater, is said to have given utterance to similar ideas; still attention to the labours of these men has been called only after Swedenborg, in 1741, had published at Amsterdam vol. ii. of his "Œconomia Regni Animalis," which contains a most important section bearing this title: *De Motu Cerebri: quod*

[1] Donders, "Die Bewegungen des Hirns und die Veränderungen in der Gefässfüllung der Pia Mater auch bei geschlossenem unausdehnbarem Schädel unmittelbar beobachtet." (Nederl. Lancet, 1850. Schmidt's Jahrbücher, Bd. 69, 1851.)

ejus animatio cum respiratione pulmonum coincidat. It seems strange that in speaking of the above volume where the running title of the section in question is to this effect, "the coincidence of the motion of the brain and the lungs," Haller[1] should have stated that, according to Swedenborg, "the motion of the brain is voluntary, and *originates from the heart.*" The fact, however, is that Swedenborg was not only the first author who discussed in full, and defended most successfully, the thesis of "the coincidence of the motion of the brain with that of the lungs," but the theory which he set forth on this subject is also so complete that the facts recently established by the "Graphic School" confirm it in every particular.

Ecker[2] describes the discovery of the respiratory character of the motion of the brain as follows: "Fantoni (17)[3] had observed a relation between the respiratory motion and the movements of the brain; his observations, however, remained unnoticed; Slevogt (12) also had remarked an elevation of the dura mater during expiration; yet J. Daniel Schlichting, a physician of Amsterdam, was the first [Swedenborg published his first work on this subject in 1741, Schlichting in 1750] who directed again attention to the connection between the respiratory motion and the movements of the brain. Based on experiments and observations he declared that at each expiration the whole brain becomes elevated or expanded, while during inspiration it subsides and collapses. Never before him [?] had this view been laid down so distinctly; and therefore this discovery is one of great importance. Schlichting's observations appeared in the year 1750 in the 'Mémoires de mathématique et physique présentés à l'Académie Royale des Sciences. Savants étrangers,' tom. i. p. 113. He showed that this motion is due neither to the contraction of the dura mater, nor to a pulsation of the sinuses or of the arteries, but is an intrinsic motion of the entire mass of the brain; that this motion continues during the whole existence of life, and that it is rendered possible by an empty space between the cranium and the brain. The real cause of this motion was not recognised by Schlichting with certainty; and he leaves it undecided whether it is a kind of systaltic and diastaltic motion peculiar to the brain itself, or whether its expansion is caused by a greater afflux of blood or of air towards the brain during expiration than during inspiration. Schlichting's observations were the cause of many investigations which led to important results. Haller

[1] "Bibliotheca Anatomica," ii. p. 328.

[2] Ecker (Prof. A.), "Physiologische Untersuchungen über die Bewegungen des Gehirns und Rückenmarks, etc.," Stuttgart, 1843.

[3] The figures in parentheses which throughout the remaining part of Note i. are put after the names of observers or authors, refer to the titles of their publications, which are given in full in a bibliographical list at the end of Note i.

and his pupil Walsdorf (24) in Germany, and Lamure (25) in France, entered almost simultaneously on their investigations. . . . Towards the end of 1751, and in the beginning of 1752, Haller communicated his results in letters to Sauvages and Réaumur, wherein he stated that the movements of the brain are due to the circulation of the venous blood, which during expiration flows back towards the brain. . . . Lamure made his first experiments in 1751, where he observed a swelling of the brain during expiration, and its subsidence during inspiration. . . . In 1752 he made additional experiments whereby he obtained results similar to these of Haller, and learned that a mere compression of the thorax, even in the dead animal, produces the same effects as expiration. Lorry (29) did not add much that was new to the observations of these gentlemen, but by his experiments confirmed the double motion of the brain. Portal (33) in 1771 repeated the experiments of Haller and Lamure in the Collége de France, arriving at the same results. Ravina (40), with a view of exploring these motions, experimented on twenty cats, a number of dogs, on foxes, otters, martens, donkeys, horses, sheep, calves, hares, rabbits; he recognised the double motion of the brain, and attributed it to the same causes as Haller. Treviranus (43) and Burdach (46), who also treat of this motion, have contributed nothing new to the subject, although the latter furnished some theoretical explanations; the same is the case with Lucæ (39). The most recent investigations into this subject were made by Flourens (55), in the new edition of his 'Experimental Researches into the Properties and Functions of the Nervous System'" (pp. 27-31).

17. Althann,[1] who wrote nearly thirty years after Ecker, continues the history of our subject as follows: "Flourens (63) at first experimented with rabbits, the arteries of which in his estimation were too small to communicate to the brain a sensible motion by their intumescence; on which account he at first denied altogether the arterial motions of the brain. Experiments made with dogs caused him to change his opinion, so that he afterwards was able to trace the arterial motions even in rabbits, and in two persons wounded in the forehead. Valentin (64) and Donders (65), who by the reflected light thrown on the surface of the brain by a mirror discriminated arterial elevations even in rabbits, together with Virchow (70), Bruns (71), Kubel (69), Budge (78), Hyrtl (68), and all modern authors in general, without

[1] Althann (Georg), Beiträge zur Physiologie und Pathologie der Circulation, i. "Der Kreislauf in der Schädelhöhle," Dorpat, 1871. Chapter iv., "Die Gehirnbewegungen am geöffneten oder nicht vollkommen verknöcherten Schädel." (The motions of the brain in an opened skull, or in one which is not perfectly osseous.)

any exception, declared in favour of both kinds of motion in the brain. According to Burdach (46), Bruns (71), and Kubel (69), however, only arterial motions take place in the brain while the lungs are breathing calmly, the respiratory motion being added by laboured breathing. In a patient suffering from a considerable loss of substance in her cranial bones, Bruns could discover only pulsatile motions, as long as she was breathing very quietly. Under the same circumstances, and in the same patient, Kubel could distinguish only indistinct respiratory motions, while both observers noticed them clearly whenever she breathed with a greater effort; feeble respiratory motions manifested themselves as soon as she commenced talking. Haller (26) already (t. iv. p. 176) considers the pulsatile motions as more constant. Leny (32) witnessed during screams only a kind of respiratory movement, which at other times he could not see; that is, at one time the brain pressed through an opening in the skull, and at another time it sank to its usual level."

The following authors, according to Althann, acknowledge only such motions of the brain as are synchronous with the pulsation of the heart; the names in brackets are quoted also by Swedenborg: [Realdo Colombo (3)], Riolanus (7), [Bartholin (8)], Diemerbroek (10), [Vieussens (9), Ridley (11, 15), Baglivi (14), Pacchioni (16), Bellini (18)], Gambs (8), Walther (9), Richerand (35, 47), Klein (36), Walther (41), Rudolphi (45), Velten (52), Zartmann (53), Kaehler (51), Mayer (54). Their observations, he states, were made both in animals and in human beings.

The following authors, on the other hand, he says, recognised only respiratory, and no pulsatile motions in the brain; namely, Lamure (25), Portal (33, 34), Lucæ (39), Treviranus (26), Weidmann and Wenzel (38).

The following additional authors, not mentioned above by Ecker in this connection, have expressed themselves in favour of a double motion in the brain; namely, Vicq d'Azyr (31), Bichat (44), Magendie (56), Longet (57).

18. Between the time when Donders in 1850 and 1851 published the results of his investigation into the movements of the brain, and the rise of the graphic method of physiology which was successfully applied to the registration of the motion of the brain in 1875, a kind of obscuration coupled with indifference seems to have come over the physiologists which induced them to deny the existence of all motion in a normally-constituted brain, and to exclude the consideration of this important subject altogether from their text-books. In vain physiologists like Richet (see above, p. 646) protested against the arguments by which science had fortified itself in this negative position;

he preached to deaf ears, until at last the respiring brain itself declared the reality of its motion by those tracings which it furnished by means of the graphic method.

Preparations for the graphic method were made as early as 1813 by Ravina (40), who was the first observer by whom a glass tube was fastened to an opening in the skull with a view of ascertaining the motion of the brain by the rise and fall of a liquid in the tube. Bourgougnon (50) in 1839 followed up Ravina's experiment, and he in his turn was succeeded by Prof. Bruns in Tübingen, who constructed an instrument by which an indicator exhibited the movements in an exposed dura mater. Kubel (69) experimented with Bruns' instrument, and published his results in an inaugural dissertation in 1853. Leyden (75) in 1866 was the next who measured the motion and pressure in the brain by an instrument, and he also was the first who tried to obtain a tracing by means of his instrument. He did not, however, succeed very well in his attempt, as little as Langlet, who took up this subject after him in France. Mosso in Turin and François-Franck in Paris were the first who applied successfully Prof. Marey's sphygmograph and his pneumograph to the registration of the movements of the brain. Their results were made known in 1875.

19. Another factor which stimulated them in their researches was a discovery made by Dr. Piégu (60) as far back as 1846, and which promised to explain satisfactorily the twofold motion of the brain. Piégu showed by his experiments that movements analogous to those of the brain exist in the arms and legs; in short, in every part of the body.

According to Vaillard,[1] "Piégu enclosed his leg, or a portion of one of his limbs, in a metallic boot filled with tepid water. This boot communicated with a horizontal tube furnished with a scale which was graduated in millimetres. With the aid of this simple apparatus he realized what Chelius afterwards termed volumetric sphygmography, that is, the measurement of the sanguineous wave in the extremities. Piégu noticed that the liquid column in the tube presented the alternate movements of a rise and a fall; the liquid reached its maximum of depression during inspiration, while its highest elevation coincided with expiration. The passage from the state of depression to that of elevation was marked by a series of little starts which were exactly synchronous with the contractions of the heart. By this experiment Dr. Piégu established precisely the double nature of the movements which he had been observing. The more rapid of these movements, which kept time with the heart, corresponded to the arterial pulsations;

[1] "Revue mensuelle de Médecine et Chirurgie," iv. 1880.

while the other, which were slower, and interfered with the former, were due to the influence of respiration. . . . Impelled by the logic of circumstances, Piégu extended the results which he had observed to the brain, and acknowledged in that organ the double movements which he had studied in the extremities" (p. 644).

Like most new discoveries destined to interfere with the commonly-received scientific ideas, Piégu's discovery remained unnoticed for nearly thirty years, when at last, as Vaillard informs us, the Doctor took up the subject again in the "Journal de l'Anatomie" of 1872, insisting that the movements of the brain, far from constituting a phenomenon peculiar to that organ, are but the expression of a law common to the whole body. "The movements of the brain, those of the cerebro-spinal fluid, and those of the limbs of the body," says he, "are all identical in their manifestation. They all acknowledge the same cause, that double expansion which the entire organism of circulation undergoes, and whereby all vascular pressure is represented under the general form of the double influence of the heart and the lungs."

20. The fact discovered by Piégu in 1846 was well known to Swedenborg, as appears from the following passage in his "Regnum Animale," vol. ii., published in 1744: "Not only do the lungs themselves respire, but they also cause the whole of the organic system to respire along with them; namely, both the middle region, in which they themselves are situated; the superior region, which is that of the head and the brain; and the inferior region, or that of the abdomen; and in fact, even the appendages of the trunk,—*the arms and hands, the legs and feet, down to the tips of the fingers in the one case, and to the ends of the toes in the other;* so that there is not a corner in any province of the kingdom whither the pulmonic breath does not penetrate with active power; and this, by the mediation and instrumentality of a number of general appliances,—for instance, of the mediastinum, the pleura, the diaphragm, the peritonæum, the ribs, and the vertebræ; speaking generally, by the mediation of the nerves, vessels, membranes, muscles, tendons, ligaments, cartilages, and bones; that is to say, of all the constituents that make up the compages of the whole. We shall clearly perceive this to be the case, if we consider the continuity, relation, and circling course of the above substances; nay, we may have sensible experience of it in our own persons, in the respective acts of sneezing, coughing, shouting, vociferating, evacuating the fæces, wrestling, and other similar operations, during which we distend the lungs and augment the breathing to the greatest degree; that is to say, provided we fix our mental vision attentively upon all the circumstances of the case. And again, the fact is brought completely home to our senses, and placed in clear light, in the simpler

and less elaborate forms of the animal creation,—in worms, nymphs, caterpillars, butterflies, flies, and other little living machines of a similar kind; in which the pulmonic breath flows in, not as in animals of larger size, through so many mediations, and instrumental appliances, of ligaments, membranes, and muscles, and through so many cartilaginous and osseous balances, but immediately, by air-vessels or bronchial pipes, dividing and ramifying in the form of fibres, through all the organic powers of the body; and this flowing in, by manifest co-operation expands their chain of uses" (English edition, no. 395).

Swedenborg also agrees with Piégu in extending the sphere of operation of the lungs into the head, and even into the brain; but he differs from him in this respect, that he derives the respiration of the lungs from the animatory motion of the brain, and not *vice versa;* and that he regards the lungs as the vicegerent of the brain in the body, co-operating with the brain in carrying out its behests in the body. This Swedenborg declares in the following passage: "The respiration of the lungs flows not only into the trunk of the body, but also into the head, and into the organs of motion and sensation; and in fact to the brain, the very fountain of its motion, to which it rises in infinite streams, as it were in meanders and circles, and associates itself with the periods of respiration, or as we term them, the animations of the brain. Thus the lungs and the brains with the medulla oblongata and the spinal cord are synchronous in their respective animations and respirations; and this in order that causes may act harmoniously, and conspire in operation, with effects; things prior with things posterior; and the spirit of the soul with the spirit of the body; and in order that there may be an influx and reflux of the one into the other. On these accounts the pulmonic engines or bellows rise precisely at the same moments that the cerebrum inspires its costal, and the cerebellum its sympathetic nerves" (*Regnum Animale,* English edition, vol. ii. no. 398).

In explanatory notes Swedenborg enters more fully into this subject. Concerning the necessity of the motion of the lungs coinciding with the animation of the brain, he says, "The animations, or elevations and constrictions, of the cerebrum and cerebellum, cannot fail to be synchronous with the respiration of the lungs; otherwise the lungs could not conspire to the same effect as the brains. Putting aside the arguments and inductions derivable from the anatomy and connection of substances, this statement is confirmed by the subordinations and mediations of all the causes that enter and constitute each particular effect; as in the present case by the fact that the lungs concur in the most absolute manner to every action originating from and ordered by the brains. The complete concordance is perfectly manifest from all actions. Thus when the mind is thinking very intently, and breathing tacitly and slowly, then the lungs, elevated to a certain degree, appear in like manner to keep silence, and to send out and draw in the air almost imperceptibly, so as not to disturb the analyses of the rational mind by any motion on their part. On the other hand, when the mind is heated with passion, and the cerebrum acts tumultuously, and as it were swells and surges, then the lungs likewise boil up. The same is the case in all the other affections of the rational and animal minds. . . . Hence it is that the lungs communicate their respiratory actions so extensively; in short, to all points in the body; for whithersoever the fibres of the cerebrum and cerebellum, and their modifications, penetrate, thither also goes the breathing motion or action of the lungs" (*ibid.*, note *y*).

The method again by which the brain through its animatory motion produces the respiratory motion of the lungs, Swedenborg describes thus, "It is a truth constantly presented to us as the result of all our analytic investigations, that every action of the cerebrum and cerebellum is determined through the fibres; and that the fibres cannot be determined into act except by their beginnings or principles; in short, by the organs that are prefixed to those fibres. The latter must certainly be excited to motion by their principles, and commence and describe their motion in this way. It is absurd to suppose that any action can begin in the middle of a fibre, and not in its first terminus. If then it begins in the first organs, it must inevitably begin in the cortical glands [or nerve-cells], for the fibres commence, and are conceived and produced, in those glands, and the arterial vessels of the brain terminate also in them. Hence if the principles of motion exist in them, according to all physical and philosophical laws, as mutually confirmed by, and confirming each other, those principles must necessarily commence by a kind of active, living, or locomotive, reciprocal force, that is, by a kind of expansion and constriction, or systole and diastole, such as we observe in a gross form in the lungs and heart; for the same conditions are involved, whether the spirit is to be driven through the fibres, or the blood through the vessels. The blood cannot be driven through its arteries without the reciprocal expansion and constriction of the heart; nor can the spirit be driven through the fibres, which are little canals and vessels analogous to the arteries, only more pure, without the reciprocal expansion and constriction of the cortical glands of the brain, which on this account deserve the appellation of pure corcula or little hearts. Assuming or granting these points, the necessary consequence is, that every time the cortical and cineritious substance of the cerebrum, cerebellum, medulla oblongata, and spinal cord contracts, or constringes itself, the whole mass of these parts sinks down, and undergoes systole; but, on the other hand, undergoes diastole, when the same substance, I mean the whole congeries, expands. This is the animation of the brain—using the term brain in its widest acceptation—that corresponds to the respiration of the lungs. We must now proceed a step farther. If the animal or nervous spirit, at the intervals of the constriction of these organic substances—of the little hearts of the cerebrum—is expressed by the cerebrum through the nerves and nervous fibres, of course it is expressed by the cerebellum into its grand sympathetic nerves, the pneumo-gastric nerve, and the great sympathetic cords: and granting this, it follows that these nerves act during the same intervals upon the fibres of the pulmonary plexus, and upon the fibres of the costal nerves; which cannot fail on the instant to act upon their muscles and membranes; nor the latter to act upon the ribs, and thus upon the internal structure of the lungs. Hence it follows that the animations of the brain (using the term here again in its widest sense) must necessarily be coincident with the respirations of the lungs: and the fact is still more plainly declared by the influx of the fibres of the above-mentioned cerebellar nerves, the pneumo-gastric, and the great sympathetic, into all the viscera of the abdomen; and by the motions of those viscera agreeing exactly, and keeping perfect time, with the respiratory motions of the lungs" (*ibid.* note *z*).

From this universal theory of Swedenborg concerning the relations which exist between the motion of the brain and the respiration of the lungs, it follows that when the brain expresses the spirit or nervous fluid from its grey substance into the nerves of the body, when therefore the brain has its expiratory motion, the lungs go through the process of inspiration, and *vice versa.*

What has science to say to this?

21. Ecker (58) says: "The brain swells, becomes turgescent, and elevates itself during the moment of expiration [*i.e.* of the lungs], but collapses, is diminished in its volume, and becomes flattened in the moment of inspiration [*i.e.* of the lungs]. The brain manifestly swells during the moment of expiration, as I have observed, most distinctly. After the brain during inspiration has lain flattened out, far below the level of the aperture in the cranium, so that a large empty space is left between the cranium and the brain; at the beginning of expiration it commences to swell, so as at last to fill up the whole cranium; nay, frequently it is forced into the aperture made into the cranium" (p. 31).

In support of this statement Ecker refers to the experiments made on the exposed brains of animals by Schlichting, Haller, Walsdorf, Lamure, Lorry, Portal, Ravina, Flourens, adding the results of six experiments of his own on pp. 33-38. Besides, he communicates the following cases where the animatory motion of the brain was observed in human beings whose brains had been exposed by wounds, or by the operations of the trephine. He says : "In a boy whose dura mater had been considerably exposed by a wound, Slevogt (12) saw that the membrane during several days was forced out by every violent expiration, by a cough, screaming, etc. Schlichting (23) describes a case which he had observed in 1742 where a piece of the parietal bone of the size of a thaler was broken out of the cranium of a boy by a wound which he had received, and where the brain, together with its membranes, distinctly raised itself at each expiration, and subsided during inspiration. These same motions he not only saw, but also felt in the scar of a man, forty years old, who was injured by a fall from the mast of a ship in India, so that nearly the whole of one of the parietal bones had to be removed. This case Schlichting imitated in a dog by experiment, obtaining thereby the same results. Ravina (40), in the year 1810, observed these motions in two cases; once in that of an infant two months old, the frontal and parietal bones of which had been injured by a hog, and indeed to such an extent, that the parietal bone was entirely torn off, and the brain with its membranes for a considerable space was laid bare. Ravina saw distinctly that the brain was raised by the beats of the arteries, and that in addition it swelled during expiration, *e.g.* during screaming; and that it subsided during inspiration. The same he witnessed in the same year in the case of a man who had fallen from a high tree, and whose skull on the left side near the crown was broken and pressed in, and on the eleventh day after the removal of the suppurating bones the brain was exposed to the extent of two inches. The brain very plainly moved synchronically with respiration. As soon as the patient stopped breathing, the brain also ceased its motion; when he breathed more quickly, the brain accelerated its motion; during a long and deep inspiration the brain sank more deeply, and during a forcible expiration it raised itself proportionably higher. Klein (36) noticed a complete cessation of the motion of the brain during a long inspiration, during which the pulse also became very feeble" (pp. 38-40).

22. Since, according to Swedenborg, the motion of the brain through its nerves is communicated not only to the lungs, but also to all the remaining parts of the body, and hence to the arms and legs; and since these parts besides, by ligaments, membranes, arterial vessels, tendons, cartilages and bones, are connected with the lungs and the thorax, it follows that the respiratory movements in all these parts agree with the inspiration and expiration of the lungs; that is, the parts subside when the lungs subside, and the parts rise when the lungs rise.

That such is actually the case Mosso proves by the graphic method. The following tracing represents the cardiac and respiratory movements in the lower thigh :—

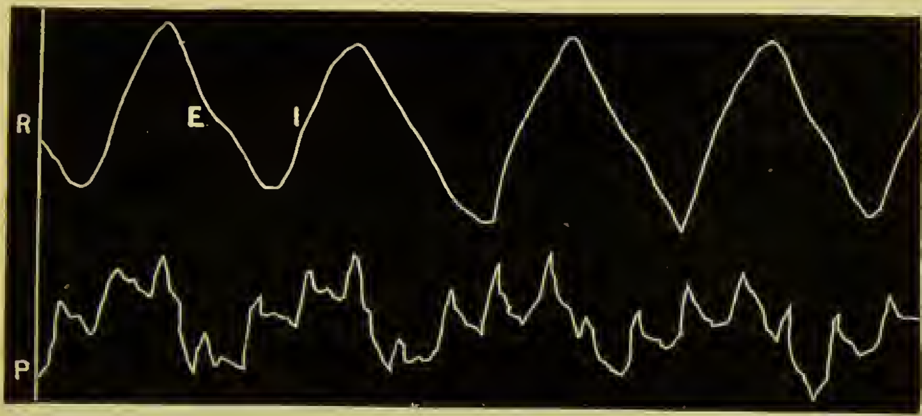


Fig. 10.

Description of Fig. 10.—"*P*, changes in the volume of the lower thigh during a normal state of respiration *R* [*E*, expiration; *I*, inspiration]."

Mosso[1] says: "The following tracing was obtained from Mr. Caudana, while he occupied a sitting posture. The movements of respiration were registered by means of one of Marey's cardiographs simultaneously with the oscillations in the volume of the lower extremity. The curve *R*, which marks the movements of respiration, sinks during expiration, and rises during inspiration.

"A characteristic appearance by which we are struck in this tracing is the rapid decrease in volume in the beginning of the expiration of the lungs. Immediately afterwards, and indeed while the expiration still continues, but especially towards the end of the same, the volume of the leg begins to increase again. This increase lasts during the whole period of the inspiration. At the close of the inspiration the curve [taken from the leg] reaches its highest point, and at the beginning of the expiration it suddenly lapses down again" (p. 134).

In summing up his experience as to the increase and decrease of the brain and the fore-arm during the inspiration and expiration, Mosso says: "In the majority of cases I found that the brain during the inspiration of the lungs experiences a decrease in volume;[2] the fore-

[1] "Ueber den Kreislauf," etc., Leipzig, 1881.

[2] That the brain decreases, or has its expiration while the lungs inspire, is shown also above by François-Frauck's and Salathé's tracings in figs. 1 and 9; where the brain, that is, the dura mater and the cerebro-spinal liquid respectively, indicate a rise or an increase in volume during the expiration of the lungs, and a decrease during their inspiration.

arm, on the other hand, begins to increase in volume already before the end of inspiration, and it shows a decrease in its volume before the end of the expiration. Still there are a number of exceptions to this rule" (*ibid.* p. 187).

The following tracing exhibits the increase in volume in the fore-arm compared with the motion of the lungs. It will be observed that the curve of respiration, on comparing it with fig. 10, appears inverted, inspiration going down, and expiration up :—

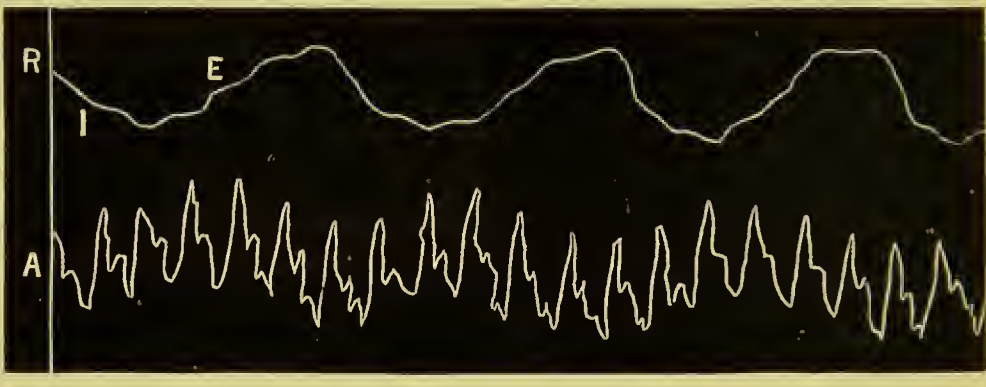


Fig. 11.

Description of Fig. 11.—*R*, respiration; *A*, increase in volume in the fore-arm ; *I*, inspiration ; *E*, expiration.

Mosso says in reference to his fig. 74 (our fig. 11): "The undulation showing the change in the volume of the forearm, it will be noticed, begins before the end of the expiration, and continues during inspiration. Yet before the act of inspiration is accomplished, a considerable increase in volume may be observed, which increase continues during the first period of expiration. This I found to be the case in most of the observations which I took of the forearm with the plethysmograph, comparing the same with the motions of respiration. I should be inclined to regard this as the normal type, if I had not come across two subjects, who in a state of perfect rest, and otherwise under the same circumstances, furnished different results" (*ibid.* p. 184).

23. On comparing the actual results obtained by the graphic method with Piégu's theory in reference to the movements of the brain, namely, that they are "identical in their manifestation" with the movements observed in the limbs, we find that experience declares in favour of Swedenborg's theory, and against that set forth by Piégu and Vaillard. This latter author (101), in pointing to the labours of Piégu, Mosso, and Franck, says : "Their labours . . . demonstrate that the mechanism of the oscillations of the brain reduces itself to a phenomenon common to all the peripheral organs, that is, to the entrance of a sanguineous wave into a vascular tissue, and the turgescence produced by the alternate impletion of the vessels. Mosso, who registered in

parallel lines, from the same subject, the movements of the brain, and the modifications in the volume of his hand plunged into an apparatus of displacement, obtained in the two cases identical tracings, thus demonstrating their common origin" (p. 641).

The latest tracings which we have quoted from Mosso not only show a difference between the movements which he observed in the forearm and in the lower thigh, but he also declares that "in the majority of cases he found that the brain during the inspiration of the lungs decreases in volume;" which means that the motion of the lungs in respect to the motion of the brain is inverted; that the brain in fact goes through its motion of expiration, while the lungs are drawing in their breath. The same inversion in respect to the motion of the brain, as shown in fig. 10, is exhibited also by the movements in the lower thigh, and in a lesser extent by the movements in the forearm.

3. *Extent of the Motion of the Brain.*

24. That the motion of the brain is not limited to the cerebrum, but extends to the cerebellum, the medulla oblongata, and the spinal cord, Swedenborg declares in the following passage: "By the observations made by the most celebrated men, we have been convinced that the cerebrum is stirred to its very base by alternate motions; and if such is the case with the cerebrum, it follows of necessity that such must also be the case with the cerebellum, the medulla oblongata, and the spinal marrow; for the connection of the parts, the continuation of membranes, the consociation of fibres, and the passage of the arteries among them, is such that it is impossible for one to be moved without the other" (Part i. no. 42).

Concerning the motion of the cerebellum, Ecker (58) makes the following remarks: "*The cerebellum moves in the same way as the cerebrum.* Schlichting (23) did not observe this motion distinctly in the cerebellum; but he pronounces it as his firm conviction that the same motion which he noticed in the cerebrum takes place also in the cerebellum. Walsdorf and Haller (24) saw the motion of the cerebellum in a mole and in an old dog. Ravina (40) also observed this motion in cats, rabbits, dogs; likewise Magendie.[1] . . . I myself saw the motion of the cerebellum, *e.g.* in my tenth experiment, and especially in my sixteenth" (p. 40).

25. In respect to the motion of the spinal cord and the medulla oblongata Ecker says: "Portal (33, 34) first proved by direct observations and experiments that the spinal cord also, as this had long since been

[1] Magendie (F.), "Précis élémentaire de Physiologie," 3me édit., Paris, 1833.

proved in relation to the brain, moves synchronously with respiration. . . . On theoretical grounds Peter Frank (42) deemed it probable that respiration exerts a similar effect on the spinal cord as on the brain, since a long retention of the breath causes congestion in the spinal marrow, and is also able to produce apoplexy of the same. Yet Portal first proved this by direct observations and experiments. He does not speak of its pulsatile motion as little as of that of the brain. Portal noticed in a child with a spina bifida, situated in the upper part of the vertebral column, not far from the cranium, that at each expiration there was a distinct intumescence in the swelling, which intumescence increased in volume with the force of the expiration. On opening cautiously in recently born puppies or cats the upper vertebral column, he saw an alternate expansion and subsidence of the spinal marrow. . . . According to his observations this motion probably is constant, since the cavity of the vertebral column is much wider than the spinal cord, and therefore there is abundant room in it . . . Magendie[1] also has confirmed the existence of these motions of the spinal cord. He noticed them in several experiments; that is, an elevation of the spinal cord during expiration, and its collapse during inspiration. In one experiment which was made with a strong dog, the air at each inspiration entered noisily into the vertebral column, and was forced out when the animal exhaled. Magendie considered this motion as a swelling, and also in part as an elevation, consequent upon the swelling of the large veins in the posterior surface of the vertebral bodies. The *whole* of the spinal marrow moved, and not only its upper part. Ollivier d'Angers (49) also observed these motions in young animals. He saw that the motion of the spinal marrow consists of a local motion and a swelling. Seubert (48) in his experiments on the functions of the anterior and posterior roots of the spinal marrow, saw that the spinal marrow during expiration raises itself, and during inspiration subsides. So likewise Tiedemann. No one, however, speaks of a pulsatile motion of the spinal marrow; only Cruveilhier[2] mentions such a motion in the lumbar tumours of the spina bifida; and Ollivier says that on making experiments on living animals you notice that the sub-arachnoid liquid is agitated by a double motion, of which one is synchronous with the pulse, and the other with the movements of respiration. Something similar, I think, I have noticed in my eighteenth experiment. There also I noticed a weak pulsatile motion in the spinal marrow, but in other cases I did not observe it. If, therefore, there exists such a

[1] "Sur un mouvement de la moëlle épinière isochrone à la respiration." (Journ. de physiol. expérim. i. 1821, p. 200.)

[2] Cruveilhier, "Essai sur l'anatomie et les vices de conformation de la moëlle épinière," Paris, 1823.

motion in the spinal cord, it is very weak. My own investigations in respect to these motions led me to the following results: in the experiments which I made in order to test the influence of the cerebro-spinal liquid on the motion of the brain. When I opened the beginning of the vertebral canal opposite the medulla oblongata, and the beginning of the spinal cord, I constantly saw that the medulla oblongata and the upper part of the spinal cord rose at each expiration, and subsided during inspiration; compare my eleventh, twelfth, and thirteenth experiments. At each expiration the spinal cord rose, while at the same time it was completely submerged by the cerebro-spinal liquid which ascended from the vertebral cavity. At each inspiration, however, it was laid dry, it sank down more deeply, and seemed to be flattened. The same I also noticed in my seventeenth and eighteenth experiments" (*loc. cit.* pp. 102-107).

26. The fact that observers generally have been able to notice only a respiratory, and no pulsatile motion in the spinal cord, finds its explanation in this consideration, that the pulsatile motion which is usually attributed to the brain belongs in reality to the dura mater and not to the brain, and is caused by the great abundance of blood-vessels in the cranial dura mater, especially around the longitudinal sinus; as has been proved by Boehm, Paschkewitz, and especially by Key and Retzius (see chapter on the Dura Mater, nos. 244*e*, 244*f*, and 244*g*, and also note ii. no. 6). The spinal dura mater, however, lacks this abundant supply of blood-vessels, since it is not adherent to the bone, and therefore is not called upon to afford nutriment to it, as is the case with the cranial dura mater. "In the dura spinalis," as Key and Retzius observe, "the finer arrangement of the blood-vessels does not offer anything in particular, while in the dura cerebralis their arrangement is peculiar." From this it follows that in the case of the cranial dura mater there is a marked pulsatile motion which it communicates to the sub-arachnoid liquid which is intermediate between the dura mater and the cerebrum; while in the spinal dura mater the pulsatile motion is so small that it scarcely makes any impression on the cerebro-spinal fluid, and therefore has escaped the eyes of most observers.

On the other hand, however, as all observers have noticed in the spinal cord a marked movement of expansion and contraction synchronous with respiration, and no pulsatile motion, it follows that such also must be the case with the cerebrum and cerebellum; that, therefore, these organs also have intrinsically only one motion, namely, a motion which is synchronous with respiration.

27. The following is a tracing obtained by Dr. Salathé of the oscillations of the cerebro-spinal fluid in the cranial cavity and in the vertebral canal. These oscillations were taken simultaneously, thus show-

ing that the same motion prevails in either cavity; only in the cerebral line there are noticed inequalities arising from the pulsatile motion of the dura mater, which are totally wanting in the spinal line:—

Fig. 12.

In explanation of this figure Salathé says, "On trephining the cranium and the spinal column at the same time, we have always been able to demonstrate a synchronism in the motions prevailing in them. . . . It cannot therefore be maintained that there is an antagonism between the phenomena which take place in the cranial cavity and those that occur in the vertebral canal."

He continues: "In the above figure the trephine had been placed on the axis of the column; therefore the line marked *A* represents the oscillations of the cerebro-spinal liquid on the level of the axis, and the line *C* the same in the cranium" (Travaux du Laboratoire de Prof. Marey, ii. Année, 1876, p. 385).

4. *Origin of the Motion of the Brain.*

28. The origin of the motion of the brain has been treated incidentally throughout the whole of our present discussion, and hence also Swedenborg's theory on the subject, which in our estimation is the only one that meets successfully the difficulties and contradictions with which all other theories respecting the origin of the motion of the brain are beset.

The problem of the origin of the motion of the brain, regarding it from Swedenborg's standpoint, is unnecessarily involved, at the hands of the authors generally, since they consider themselves obliged to account not only for the respiratory, but also for the pulsatile motion of the brain.

Now Swedenborg, in declaring that the pulsatile motion noticed in the brain belongs to the dura mater, and not to the brain, and that the brain, like the heart and the lungs, has only one motion, namely, its animatory motion, which is synchronous with respiration, and which it imparts also to the blood-vessels within its own organism, has simplified the subject very much.

The affirmative arguments in favour of the position that what is usually called the pulsatile motion of the brain belongs to the dura mater, and not to the brain, we believe have been sufficiently set forth in chap. ii. of our present note, pp. 658-664, and in chap. iii. p. 679; wherefore we shall limit ourselves here to an examination of the methods by which it is supposed that a pulsatile motion is imparted to the whole of the brain.

Althann (82) says: "The authors have not yet agreed whether this motion is produced by a lifting of the brain on the part of the large arteries at the base of the skull, or by a swelling of the brain-substance on the arrival of the systaltic increase in blood; or whether it is effected by both methods, and how much is due to either" (p. 85).

The first of these views is entertained by Senac (30), p. 239; Bichat (44), p. 262; Richerand (35), p. 203, and (47), p. 164; Rudolphi (45); Burdach (46), p. 33; Chelius,[1] p. 38; Bardeleben (76); Vierordt (81).

Althann says that "on account of holding the above view Richerand denied altogether the respiratory motion of the brain, because the veins are so situated in the brain and cranium that they are unable to lift the brain during their turgescence; the greater part of them, at least of the larger ones, being placed on the top so that they would actually have to press the brain towards the base of the cranium; and therefore he holds that an impletion of the veins can cause only a turgescence, but no motion of the brains" (*loc. cit.* p. 85).

Ecker (58) says: "The pulsatile, arterial motion is due to the pulsation of the arteries in the base of the cerebrum, whereby the whole brain is lifted, and also to the pulsation of the finer arteries distributed through the brain" (p. 123).

"Bruns,"[2] continues Althann, "in accounting for the lifting of the brain has recourse to the cerebro-spinal liquid which accumulates at the base of the cranium during pulsation. Whenever the arteries at the base are dilated, their increased pressure, he says, is communicated to the cerebro-spinal liquid, which thereby presses against the brain from below, and lifts it. An increase in the volume of the brain by an increase in the arterial wave he declares to be impossible; since there is no analogy for such a proceeding in other organs, where the smaller vessels are always filled evenly. The main support for his view he finds in a cessation of the arterial movements when the cerebro-spinal liquid is drawn off" (*loc. cit.* p. 94).

[1] "Zur Lehre von den schwammigen Auswüchsen der harten Hirnhaut," Heidelberg, 1831.

[2] "Handbuch der praktischen Chirurgie," Abth. i., Tübingen, 1854, pp. 590, 600.

Kubel (69) also believes that the motion of the brain consists in a mere lifting and lowering of the brain, and thus in a locomotion of the whole organ, caused by the systaltic and diastaltic motion in the arteries at the base of the cranium, without any increase and decrease in the volume of the brain by a change in its supply of blood.

Walther (22), on the other hand, declares that the mass of the brain is too great to be raised by the impetus of the arterial blood. Portal (34) also denies these arterial motions in the brain, and adduces the testimony of Vicq d'Azyr to the effect that a dilatation of the arteries takes place much more frequently than an elevation of the brain; and that this dilatation can never be powerful enough to raise the brain.

Ravina (40) attributes the pulsatile motions of the fontanelle not to the brain, but to the arteries of the dura mater; while Ecker declares that in the fontanelle he has hitherto been able to discover only the respiratory, but not the pulsatile motion of the brain. Compare here Salathé's tracings of the motions in the fontanelle in no. 9 of our present note.

29. If we turn to the manner in which the authors endeavour to explain the respiratory motion of the brain, we meet with the same lack of unanimity. But while they all differ more or less in their explanations, they seem to agree in this, that the motion of the brain must be explained only by mechanical means, and that on no account must the brain be credited with the inherent power of moving itself. And yet the facts themselves collected by modern science all tend to prove that the origin of the motion of the brain is in the brain itself, and that that motion is not conveyed to it by any mechanical agency from the body below. That such is the case it will be our next purpose to show.

Althann gives us the following sketch of the various methods which have been suggested to account for the respiratory motion of the brain. He says: "The realization of movements in the brain by respiration has been explained in many ways. Some attribute it to an obstruction in the venous circulation during expiration, by which the venous blood is prevented from leaving the skull; while others even speak of a forcing back of the venous blood into the cranium, and a consequent forcible impletion of the vessels of the brain. Others again think that an increase in the arterial afflux during expiration has a share in the production of the movements, although the forcing back of the venous blood is the chief cause. Others, again, as in the explanation of the pulsatile movements of the brain, have recourse to the cerebro-spinal fluid, and deduce the movements of the brain from the motion of that liquid.

"This last explanation," he continues, "was first started by Magendie (56). . . . Flourens (55, 63) sides with Magendie so far as his explanation concerns the forcing back of the blood into the vertebral sinuses. Ecker (58) holds that the dilatation and evacuation of the cerebral veins contributes only in a very subordinate manner to the rise of respiratory movements in the brain, while the swelling of the vertebral sinuses during expiration causes the dura mater to draw near to the spinal cord, whereby a pressure is exerted on the cerebro-spinal liquid, which is urged thereby into the cranium, or rather into the ventricles and the sub-arachnoid spaces (p. 123). Magendie's explanation has also been adopted by Longet (57), p. 183 *et seq.*, (80), vol. ii. p. 256, vol. iii. pp. 303, 309; Valentin (64), p. 451; Bruns (71); Kubel (69), pp. 30, 31; Luschka (77).

"The other view attributing the respiratory movements of the brain to an obstruction in the venous circulation, is older in time, and counts more adherents, namely, Lamure (25), p. 545 *et seq.*, Haller (26), vol. ii. pp. 333-335, vol. iv. pp. 171, 172; Walsdorf (24); Lorry (29), p. 308; Ravina (40); Rudolphi (45); Burdach (46), p. 38; Berlin (66); Bardeleben (76); Budge (78), and many others; in fact, most authors are in favour of the theory which assumes such an obstruction of the venous circulation, and partly also they are in favour of a forcing back of the venous blood into the cranium.

"Many adherents of this theory, for instance Lorry, Portal, Burdach, Hamernik (62), Donders (65), Hyrtl (68), Valentin, Kubel, have pointed out that an increase in the volume of the arterial wave during expiration assists the veins in the production of the respiratory movements of the brain; but with the exception of Burdach they assign the chief part to the veins" (*loc. cit.* pp. 94, 95).

The new attempt at explaining the respiratory movements of the brain on the basis of Piégu's experiment has been discussed above, pp. 669-677. That theory, starting with the fact that in every part of the body there is a pulsatile and a respiratory movement, reasons from this fact that the same force which causes these movements in the arm and in the leg produces them also in the brain. This theory, as we have seen, has completely broken down, by a comparison of the tracings exhibiting the double motion of the dura mater and the cerebro-spinal liquid, and those representing the double motion in the extremities of the body.

30. According to the dynamic or autocratic theory of the motion of the brain, as stated by Swedenborg, the origin of the motion of that organ is contained in its own bosom, and therefore is independent of the arterial and venous circulation of the body, and of the circulation of the cerebro-spinal liquid. These points we shall take up seriatim.

FIRST: *The respiratory motion of the brain is independent of the arterial circulation.*

We first quote Ecker's proof of that position. He says: "*Tying the two carotids does not stop the motion of the brain.* . . .

Lamure (25)[1] tied both carotids, and severed them between the ligature; when the movements of the brain continued unabated . . . Flourens (55)[2] tied both carotides communes and one of the vertebral arteries in a rabbit. After this operation the brain subsided more and more, and became flattened out. But in respect to *the motion of the brain,* he says that it not only existed as heretofore, but became even *much more distinct;* and it manifested itself in an extraordinary degree, as soon as he rendered the respiration difficult, and thereby caused the animal to take deep inspirations; the movements of the brain, indeed, became visibly more distinct, even without impeding respiration. Flourens repeated these experiments several times with the same result. As soon as he tied also the second vertebral artery the animal died at once. In my ninth and fourteenth experiments I tied both carotids in rabbits without noticing the least decrease in the motion of the brain; yet I am unable to maintain that this motion thereby became more forcible. In my tenth experiment, however, *I tied both carotids and both vertebral arteries in a dog, without stopping thereby the motion of the brain.*"

His account of this last experiment is as follows: "In order to enable myself to operate with greater ease, the dog was narcotized by the injection of tincture of opium into one of the venæ crurales. The effects of the tincture became visible after thirteen seconds, when the animal breathed very deeply and slowly, while the pulsations of the heart were very frequent; the breathings numbered thirty in a minute, and the pulsations one hundred and thirty to one hundred and forty. The right carotid was first exposed, and the ligature thrown temporarily around it. Most distinctly we could notice here how at every deep inspiration the vena jugularis externa emptied itself, and thereby became flattened and looked pale, and how at each expiration it was closely filled up, assuming a dark blue colour. From the carotid I now penetrated downwards with my finger and the handle of the scalpel, behind the upper edge of the musculus pectoralis major, into which I made an incision at its origin. Far down in the depth I felt a pulsating string running along the vertebral column, which could not be anything else than the vertebral artery. After several vain attempts I finally succeeded in throwing a ligature around it, and in closing it up. Professor Bischoff, who had previously succeeded in tying the vertebral artery of a dog for a different purpose, kindly assisted me in this very difficult operation. Afterwards the left carotid was tied, and finally the left vertebral artery. The best guides in the latter operation are the transverse process of the sixth vertebra, the first rib, and the trachea, between which parts the artery ascends. How Sir A. Cooper succeeded in compressing it, I find it difficult to comprehend. The subsequent dissection showed that both vertebral arteries had been

[1] *loc. cit.* p. 543. [2] *loc. cit.* p. 351.

completely tied, the right artery together with the subclavian, the left alone. During the operation the animal had gradually awakened out of its narcotic sleep, giving manifest expressions of pain, moving itself vigorously, breathing freely, and in the end in a sobbing manner. After tying firmly the last three arteries, no change whatever was noticed. We now tightened the ligature around the right carotid. At the same moment the animal dropped its head backwards, and no longer stirred, after having previously moved about vigorously during the whole time. The respiration now became stertorous and very slow. The heart beat very quickly, irregularly, and tremulously. I now quickly trephined the skull of the animal, when at each of the rare, deep inspirations I saw the dura mater subside, and again elevate itself convexly whenever the animal exhaled its breath, or was pressed upon the thorax. I did not see a trace of a pulsatile motion. An incision was now made into the trachea, and respiration was maintained in an artificial manner; yet scarcely a motion could be noticed in the dura mater. After opening the dura mater there was at once a discharge of the cerebro-spinal liquid, whereupon the opening in the dura mater was enlarged. From time to time the animal of its own accord drew again a deep inspiration, which was succeeded by a stertorous expiration. At each artificial or natural expiration it could plainly be noticed, (1) that *the brain rose;* (2) that a liquid was discharged out of the opening in the dura mater; (3) that a liquid collected under the arachnoid membrane, which first issued out of an opening in that membrane, and afterwards poured out of the aperture which had been made in the dura mater. At each inspiration the brain subsided, and no more liquid was discharged. On raising the animal by its hind legs an additional flow of the liquid was produced; by a severance of the obturator ligament a little additional liquid was obtained. During the discharge of this liquid the brain gradually collapsed completely, and no longer moved; the rare inspirations of the animal also became discontinued; but the heart continued to beat for some time, and died only gradually" (*loc. cit.* pp. 75-77).

This proof seems perfect, and it evidently shows on the basis of experiment that the motion of the brain continues after every supply of arterial blood is cut off from it; only Salathé by an experiment which seems equally fair and successful (see his "Thèse de Paris," p. 85) arrived at the very opposite result, for on tying the fourth artery leading into the brain he says "all cerebral oscillations were absolutely suppressed in an instant." Vivisection thus is unable to settle this point, wherefore we must fall back on the common-sense argument, that inasmuch as the arteries are vessels conveying the systaltic and diastaltic motion of the heart, these vessels from their own energy can introduce into the brain only the pulsatile motion of the heart, and not

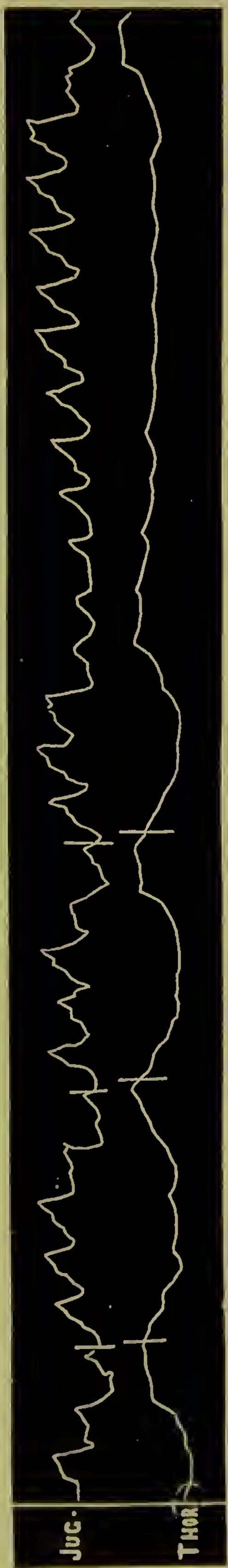


Fig. 13.

a motion synchronous with that of the lungs. It follows therefore that if there is a motion in the brain synchronous with that of respiration, it cannot be conveyed there by the arteries, because they do not convey that motion.

31. SECONDLY: *The respiratory motion of the brain is not caused by the venous circulation.*

Dr. Carpenter says, "The movement of the blood through the veins is, without doubt, chiefly effected by the *vis à tergo* or propulsive force, which results from the action of the heart and arteries; this is very greatly diminished by the time that it acts on the blood in the veins; but the resistance to the onward movement of the blood is now so slight, that a very feeble power is adequate to overcome it" ("Principles of Physiology," seventh edit. § 271). The venous wave thus starts from the arterial system, whence it receives arterial pulsations, and it terminates in the heart, the focus of arterial motion. The veins, therefore, move between two sources of arterial movements; and as they have no inherent motion of their own, being destitute of the muscular rings which characterize the middle coating of the arteries, their essential motion must be the arterial, which, as Dr. Carpenter says, they receive *à tergo*, and which is supported by their discharge into the heart in cardiac periods. During their course, especially in the thorax, being of a passive nature, they would naturally be influenced by the motion of the lungs; expiration causing an accumulation in the veins, and inspiration contracting them, and thus urging them to discharge their contents, which, nevertheless, in the end has to be done in cardiac periods. Hence Swedenborg says "the familiar and natural mode of fluxion of the jugular veins is the pulmonic" ("Economy," etc., ii. no. 29). Still the pulmonic movement in this case would only be superadded to the arterial movements, and would by no means supersede, or even diminish, their essentially arterial motion; as is clearly shown in fig. 13, which is a tracing of the right external jugular vein obtained by Mosso, and compared with the movements of the thorax. Dr. Carpenter also is decidedly of the opinion that the respiratory movements noticed in the veins are of a subordinate nature; for, says he, "several considerations agree in pointing to the conclusion that no great efficacy can be rightly attributed to the respiratory movements as exerting any *general* influence over venous circulation" (*ibid.*).

Mosso's[1] description of fig. 13.—"*Jug.*, pulse of the right vena jugularis externa, taken simultaneously with the pulse of the thorax, *Thor.*, in which the undulations of respiration are also visible." The thorax curve, it will be noticed, is inverted, a depression marking the expansion of the thorax, and *vice versa.*

Such being the elements of venous circulation, and of the motion of the veins, let us see whether that motion is able to impart a respiratory motion to the brain. The brain, in this case, must be assumed as void of motion, with arteries and capillaries penetrating its body in every direction. "The brain itself," as Burdach observes, "is purely arterial, and only in its membranes are veins visibly present. On this account also the venous branches have their places assigned to them rather on the external surface; they are fastened to the dura mater, and [in the form of sinuses] approach near to the bones of the cranium; while the arteries, on the other hand, draw nearer to the brain, and remain confined to the pia mater. . . . The veins also, from their most delicate beginnings to their trunks, pursue a way which is quite different from that of the arteries" (see above, no. 383 *b*). The veins, in fact, begin where the capillaries end; and from the capillaries, according to Dr. Carpenter, they derive a *vis à tergo* or propulsive force, and that force partakes, and it must partake, of an exclusively arterial character, since the brain itself is assumed as motionless; and besides the dura mater there is no substance or texture within the encephalic cavity which could possibly communicate a respiratory motion to the veins. The veins after leaving the cranium may have a respiratory motion superadded to them, so as to present in a tracing a motion like that of the external jugular in fig. 13; but that motion is entirely swallowed up by the arterial motion, as the cranial veins in the body of the vena cava approach the heart. From this it follows that as the veins have no respiratory motion inherent in them, they cannot communicate any motion of that kind to the brain.

Again, it may be supposed that after the veins on leaving the cranium

[1] Mosso (A.), "Die Diagnostik des Pulses in Bezug auf die localen Veränderungen desselben," Leipzig, 1879, p. 60, fig. 12.

are connected with parts permeated by the respiratory motion of the lungs, and are thereby initiated into a motion of dilatation and contraction synchronous with that of the lungs, they are able to communicate that motion backwards to the veins in the brain, and by that means may introduce a respiratory motion into the cranium, and impart it to the brain.

To this we reply that if the respiratory motion of the brain were caused by a reflux of venous blood into the brain, that motion would be stopped by a ligature or a severance of the veins leading into it. This, however, is by no means the case, as shown by Ecker; for he declares, "Severance of the venæ jugulares weakens the movements of the brain, it is true; yet it does not stop them, as has been observed by myself, as well as by Flourens and Lamure. Nay, it is not even stopped by cutting the venæ jugulares and vertebrales" (*loc. cit.* p. 81).

Others, again, may suggest that during inspiration the lungs open themselves for the reception of a large amount of blood from the whole body, which they discharge again during expiration; that therefore when the lungs are filled with venous blood, the sinuses and veins within the cranium, along with the rest of the veins all over the body, are relieved of pressure, which pressure becomes intensified again, when the lungs during expiration return their blood to the heart. If the brain received its blood directly from the lungs, there would be perhaps some force in this argument; but as the pulmonic blood before rising into the cranium has first to pass through the heart, where all its respiratory motion is converted into arterial pulsation, the action of the lungs may perhaps increase and decrease somewhat the pressure of the arterial blood in the carotids and vertebral arteries, but it does not impart the least respiratory movement to them.

The only other channel through which the motion of the lungs may ascend into the cranium is that whereby that motion is conveyed to all the parts of the body, namely, by "membranes, muscles, tendons, ligaments, cartilages, bones." Through such channels, indeed, the respiration of the lungs is communicated to the spinal dura mater, and by continuity is extended to the cranial dura mater, assisting the same in reciprocating the surging motion of the brain, when it impinges against the dura mater. The dura mater thus predisposes its sinuses for the reception of the animatory motion of the brain; yet the dura mater by itself alone can never impart a respiratory motion to the veins of the brain, and thereby to the brain itself. In fact, under those circumstances which are detailed in the description of figs. 2, 4, 6, the arterial pulsation is so predominant in the dura mater that in the tracings obtained from the dura mater under these conditions not a vestige of a respiratory motion can be noticed in it.

From all this it follows that the venous circulation in the brain is utterly incompetent to cause in that organ a motion synchronous with the motion of the lungs.

32. THIRDLY: *As the cerebro-spinal liquid has no inherent motion of its own, therefore it may, indeed, be of assistance to the brain in going visibly through its animatory motion, but it cannot be the cause and origin of that motion.*

As this liquid has no inherent motion of its own, Ecker endeavours to account for its motion by the alternate swelling and collapse of the vertebral sinuses, thus making the motion of the brain still dependent on the circulation of the blood. He says, "During the moment of expiration these sinuses must necessarily swell—as I succeeded in establishing in my eighteenth experiment by direct observation. . . . This swelling of the sinuses must manifestly cause the dura mater to draw nearer to the spinal cord, and this motion must exert an effect on the enclosed liquid; that is, it must compress the same. Urged in this manner it seeks to find an exit, which it finds nowhere else more easily than into the cranium. . . . There it penetrates into the ventricles, and some of it perhaps also under the arachnoid membrane spreads over the surface of the brain. The introduction of this liquid must cause an expansion of the cerebrum and an elevation of the cerebellum. At each inspiration of the lungs the vertebral sinuses discharge their contents, the liquid returns into the vertebral canal and fills up its cavity. Therefore this liquid is in a constant state of commotion, ascending and descending continually." That the cerebro-spinal liquid ascends and descends in this manner during the expiration and inspiration of the lungs, Dr. Ecker proves by a number of his experiments from the eleventh to the eighteenth.

In investigating the motion of the cerebro-spinal liquid, it must be borne in mind that during the inspiration of the lungs the brain has its expiration, and *vice versa;* and, further, that according to Ecker's experiments (11 to 18) both the medulla oblongata and the spinal marrow are expanded during the expiration of the lungs, and contracted during inspiration.

It must also be remembered that the dura mater reacts upon, and thus draws nearer to, the brain and the spinal marrow during their period of contraction, and thus during the inspiration of the lungs; while it retreats from the brain and the spinal marrow during their expansile movement, and hence during the expiration of the lungs.

From this, however, it follows that during the periodical repletion of the vertebral sinuses, which, according to Dr. Ecker, takes place during the expiration of the lungs [?], the dura mater, so far from "drawing nearer to the spinal cord," as maintained by him, is actually in the endeavour of retreating from it as far as possible. The inevitable conclusion of this is, that during the expiration of the lungs the cerebro-spinal liquid is forced from the spinal cavity, not by the pressure of the dura mater caused by the swelling of the vertebral sinuses, but by the expansile movement of the spinal cord itself, which arises from the swelling of each of the grey particles of which its central axis is composed.

33. Richet (74) explains the motion of the cerebro-spinal liquid differently from Ecker, who follows Magendie. According to Richet the cerebro-spinal liquid does not during inspiration descend into the spinal cavity, but is pumped up into the cranial cavity; while during expiration it descends into the spinal cavity. Instead of making its motion depend on the vertebral sinuses, Richet connects it with the arterial and venous circulation in the cranial cavity. The veins in the brain, he says, are not able to return the blood at the same rate at which, at each expiration of the lungs, it pours into the cranium through the arteries. By this excess of arterial blood in the cranium during expiration, he says, the cerebro-spinal liquid is made to descend into the spinal cavity, where it presses against the dura mater, and displaces the blood in the venous plexuses in the cervical part of the cavity. At the inspiration of the lungs the blood returns into the venous plexuses and forces the cerebro-spinal liquid into the cranial cavity, where meanwhile the ultra-pressure of the arterial blood has diminished, and the cerebro-spinal liquid has taken the place of the displaced blood, until at every successive expiration of the lungs it is sent back into the spinal cavity. In this wise, he says, a locomotion is established in the liquids of the cranium, and the cerebral motion is accounted for.

In reviewing Richet's position, attention must be called to the fact that the arterial afflux takes place at the same rate into the vertebral and cranial cavities; that, therefore, when there is an ultra-pressure of blood in the cranium there is also an ultra-pressure of the same kind in the vertebral cavity, while the displacement of blood in the venous plexuses of the cervix is quantitatively so small that it does not, and cannot account for the considerable displacement and motion in the cerebro-spinal liquid which is noticed in experiments at each expiration and inspiration of the lungs.

According to the dynamic theory of Swedenborg, on the other hand, the arterial pulsation in the blood is reduced materially, as soon as it enters the cranial cavity, and places itself at the disposal of the brain. In fact the numerous curves which the carotids and the vertebral arteries are compelled to make before they are allowed to enter the substance of the brain, and the fact of their losing the muscular rings in their middle coat by which the arteries are alone enabled to continue the cardiac motion, shows that in a normal state of the brain there is never an ultra-pressure of arterial blood, and that when there is, it is a sign that the brain is in a diseased, and hence in a disordered state. The dynamic theory of the motion of the brain declares further, that at each contraction of the brain the fourth ventricle, which furnishes the main supply of cerebro-spinal liquid, discharges its contents into the sub-arachnoid spaces both within the cranium and the vertebral column, but chiefly into the latter. At each expansion of the brain, however, the cerebro-spinal liquid, which is now called the nervous juice, is directed by the arachnoid membrane into the sub-arachnoid spaces of the departing spinal and cranial nerves, and thus is propelled into the lymph-tracks of the peripheral nervous system, as is beautifully shown in Key and Retzius' great work entitled "Studien in der Anatomie des Nervensystems und Bindegewebes." But that portion of the cerebro-spinal liquid which is not required for this purpose, during the same period of inspiration is conveyed from the vertebral cavity into the larger sub-arachnoid spaces of the cranium for further use. At each contraction of the brain, however, a new supply of cerebro-spinal fluid is conveyed from the fourth ventricle into the spinal column, chiefly through the central canal of the spinal cord.

34. By our review, we may fairly say, of the entire literature on the motion of the brain and its collateral issues, we have proved in the first place the reality of that motion. Our next step was to point out that the brain in reality has only one motion, namely, that which is synchronous with respiration; and that what is usually called the pulsatile motion of the brain is a motion peculiar to the dura mater. Afterwards we have shown that the motion of the brain is not analogous to that which Piégu has discovered in the remaining parts of the body; and, further, that the motion of the brain is not derived from that of the lungs, but is anterior to it in time. After that it was shown that the motion of the brain extends throughout the whole encephalon, including the spinal cord. Lastly, also, we proved the utter insufficiency of all explanations by which physiologists of every shade and colour have endeavoured to explain the origin of the motion of the brain by mechanical means. Every one of these attempts has been examined on its own merits, and found to be wanting, because at variance either with fact or sound reason; so that at last the dynamic theory of Swedenborg alone remains, having stood the test of all known facts in connection with the brain, and combining into one grand rational whole all these facts, from the time of Swedenborg in 1740 to the most recent facts of our own times.

The dynamic theory of the motion of the brain in Swedenborg's own words is as follows: "It is the cortical or grey substance which is expanded and constricted, or from which the cerebrum has its animatory motion; for its parts are globules of a roundish shape approaching the oval; they are engirded by a thin or most delicate meninx or membrane; they are distinctly separated from those parts to which they are related, and which are in their confines; so that each single globule is movable, or capable of expansion and compression, within its own space. The impression given by their form is, that they are least hearts—*corcula*—and least brains—*cerebellula*—of a purer nature. Little arteries flow into them with their ultimate and least ramifications, and fibres proceed from them, as many as ever appear in the brain, in the nerves, and finally in the body. These grey particles constitute the circumference of the cerebrum; they penetrate into the cerebellum in the form of a little tree; they interline the medulla oblongata in the form of striæ, and they constitute the entire axis of the spinal marrow; so great is their number. Moreover, they also occupy, here and there, in various forms the interiors of the cerebrum, that is, its [fibrillary] texture, its glands, and corpora. We must not look for the origin of the motion of the brain anywhere else than in these its organic parts; for only in these does the brain begin to be a brain; from these it takes cognizance of the arteries about to enter into it from the body, and likewise of the fibres that are about to depart into the body; and thus as it were from so many centres it contemplates whatever is done in the rays and circumferences of its kingdom. Their number also is so great that while each single particle expands itself, the whole mass of the brain is expanded from its bottom and from all its depths. Their connection also is such, that all are able to have their systole and diastole in the brain in conjunction, or some separately; and that they are thus able to inspire their fibres, and to excite the motion of their fibres, almost as is the case with the arteries which depart from the large heart. There are thus myriads of origins of motion in the brains which cannot in any way be derived from the one only source of motion in the body, namely, from the heart; this, on the contrary, is compelled to live under the auspices of the motion of the brain" (nos. 56, 57).

35. One among the many authors who have written on the motion of the brain, declares that that motion is not due to mechanical causes flowing in from the lower parts of the body, but has the cause of its motion within itself. Of Dorigny, who wrote on the motion of the brain in 1809, and whose article on this subject is contained in the "Journal de Médecine," edited by Corvisart, Leroux, Boyer (vol. xvii. 1809), Althann says, "Dorigny rose against the explanation of the motion of the brain by mechanical means, namely, by the movements

of the blood, and maintains that its origin has as little to do with those movements as with the respiration of the lungs. The intumescence of the brain, he says, always increases whenever the spinal cord or the nervous system in general is stimulated or excited, even after the carotids and the trachea have been tied" (*loc. cit.* p. 92).

In conclusion, however, we must not forget the many additions to a precise knowledge of the motion of the brain which we owe to the school of François-Franck, Mosso, and Salathé; for they all have graphically exhibited the effect which mental efforts and operations exert on the motion of the brain. Especially valuable are the tracings contained in the latest work of Mosso entitled "Ueber den Kreislauf des Blutes im menschlichen Gehirne" (The Circulation of the Blood in the Human Brain), from which we have borrowed fig. 8, on p. 659, where Mosso exhibits the effect which a mental operation consisting in multiplying 9 by 40 exerted on the brain and on the respiration of the lungs of a simple peasant; and where he shows that the increase in volume takes place first in the brain, and afterwards is succeeded by an increase in the volume of respiration. In the following tracing (fig. 14) he gives us another instance of the effect which the mental act of multiplying 8 by 12 exercised on the motion of the brain in the same person, comparing it with the effect which the same mental act exerted upon the circulation and the volume of his forearm.

Fig. 14.

In explanation of this tracing he

says, "Fig. 19 [our fig. 14] gives an example of the modifications which the circulation of the blood in the brain experiences during a mental operation." [Mosso ought to have said here, "which the circulation *in the dura mater* experiences during a mental operation;" for his tracing is from the head of a patient whose dura mater was covered with soft parts.] He continues, "Where the sign *a* ' is placed in the tracing, I told Bertino to multiply mentally 8 by 12. Here it is shown clearly that the elevation of the pulsations [we should say that 'the pressure of the brain upon the arteries in the dura mater'] and the volume of the brain (*C*) increase in the beginning of the mental operation. The form of the pulse in the forearm and the volume of the forearm (*A*) are relatively little affected. . . . The psychical effect is marked most in the beginning when I told Bertino to do the sum, as well as at the close when he told me the result, which place is marked *ω* " ("Kreislauf," etc., p. 67).

36. We conclude our extensive Note on the Motion of the Brain with a complete list of those works where that subject is treated of. In compiling that list we based ourselves chiefly on the works of Ecker (58) and Althann (82), as well as on Mosso (85, 104), Vaillard (101), Abadie (96), Salathé (90); but we are also much indebted to the remarkable "Index Medicus; a Monthly Classified Record of the current Medical Literature of the World," compiled by Dr. J. S. Billings of the U. S. Army, and Dr. R. Fletcher, M.R.C.S. Engl., published in New York since 1879. Nearly the whole of the works mentioned in our list we were able to consult in the British Museum.

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5. Ambr. Paré. Opera omnia. Paris, 1582. Edidit Guillemeux. P. 300.

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96. Abadie. Recherches historiques et critiques sur les mouvements du cerveau. Thèse de Paris, 1878.

97. Suc. Recherches historiques et critiques sur les changes de volume des organes périphériques. Thèse de Paris, 1878.

98. Bochefontaine. Sur la pression du liquide céphalo-rachidien. (Comptes Rendus, Acad. d. Sc., Paris, 1878, lxxxvi. pp. 1555-1557.)

99. Mosso (A.). Die Diagnostik des Pulses in Bezug auf die localen Veränderungen desselben. Leipzig, 1879.

100. Ragosin und Mendelsohn. Graphische Untersuchungen

über die Bewegungen des Gehirns beim lebenden Menschen. (St. Petersburg Med. Wochenschrift, 1880, iv. pp. 765-772.)

101. VAILLARD. Des Mouvements du Cerveau, Revue critique. (Revue mensuelle de Médecine et Chirurgie, Paris, 1880, iv. pp. 632-654.)

102. MAYS. Ueber die Bewegungen des menschlichen Gehirns. (Verhandlungen des naturhist.-medic. Vereins zu Heidelberg, 1881, Folge, iii. p. 73-78.)

103. MOSSO (A.). Sulla circolazione del sangue nel cervello dell uomo; ricerche sfigmografiche. (Archivio per le scienze mediche, Torino, 1881, v. pp. 44-72.)

104. MOSSO (A.). Ueber den Kreislauf des Blutes im menschlichen Gehirn. Leipzig, 1881.

105. NAUNYN (B.) und SCHREIBER (J.). Ueber Gehirndruck. Leipzig, 1881.

106. MOXON (W.). On the Influence of the Circulation upon the Nervous System. Croonian Lecture. (British Medical Journal, 1881, i. p. 491 *et seq.*)

107. FRANÇOIS-FRANCK. Étude des travaux récents sur les rapports entre les modifications de la circulation cérébrale et l'état de repos ou d'activité du cerveau. (Gazette hebd. de Médecine, Paris, 1881. Seconde Série, xviii. pp. 455-457 and 492-494.)

NOTE II.

The Structure and Use of the Dura Mater.

1. Swedenborg says: "Because the dura mater can be divided, it is supposed to consist of two laminæ which cohere most closely. The external of these is rough, the interior is as it were polished and free, and the fibres of both laminæ cohere most closely, and also intersect one another, according to Vieussens and Heister" (i. no. 202).

2. Modern science seems divided on the subject of the existence of two laminæ in the dura mater. Sappey [1] says on this subject: "In the fronto-parietal region the greater part of the superficial bundles of fibres form an antero-posterior layer, and those which lie deeper a layer which is directed transversely. This arrangement induced Massa in 1560 to admit in the dura mater the existence of two leaves; one of which is external or periosteal, and the superficial extent of which corresponds exactly with that of the walls of the cranium; and the other of which is internal, which is supposed to separate from the former on the level of the sinuses on the one hand, and on the level of each of the various prolongations by which the cranial cavity is partitioned off on the other. . . . The distinction into two leaves was ingenious, and, besides, had the advantage of facilitating the understanding of the principal details which are embraced in a description of the dura mater. This division also has been generally adopted. . . . Nevertheless there is nothing in it; since nowhere can there be observed two leaves simply placed on the top of one another. Everywhere, where two or more layers are met with, a certain number of fibres are seen to pass from the superficial to the deeper plane, and *vice versa;* so that you can never succeed in separating the dura mater into two laminæ to any great extent without dividing in a certain measure a greater or lesser number of fibres" (iii. pp. 18, 19).

3. Swedenborg does not deny that the fibres of both laminæ cohere closely and even intersect one another, and therefore he is not opposed to Sappey's grounds, on which he holds that there is nothing in the distinction of the dura mater into two laminæ. That the fibres of the

[1] Sappey (Ph. C.), "Traité d'Anatomie Déscriptive," third edition, Paris, 1877.

dura mater are, nevertheless, concentrated into two layers, is confirmed by the following authorities:—

Cruveilhier[1] says: "The dura mater may be regarded as consisting of two very distinct fibrous layers: of an *external* or *periosteal* layer, which forms the internal periosteum of the bones of the cranium; and of an *internal* or *proper cerebral layer*, which though blended with the preceding throughout the greatest part of its extent, is separated from it at certain points, in order to form the fibrous canals which are called the *sinuses*, and also the several productions which are projected from the dura mater" (see above, i. no. 244 *a*).

Solly[2] fully bears out Cruveilhier's views in the following passage: "The dura mater consists of two layers united by cellular tissue, the external of which forms the internal periosteum of the bones of the skull. The separation between these two portions is perfect in the vertebral canal, though at the internal surface of the atlas the spinal dura mater and periosteum of the vertebral canal meet together and adhere so as to exhibit in the skull the appearance of one membrane" (see above, i. no. 244 *b*).

A most minute histological examination of the dura mater has lately been instituted by Key and Retzius;[3] and although they agree with Sappey that the fibres in the various layers of the dura mater intersect one another, they nevertheless acknowledge distinctly the fundamental arrangement of the dura mater into two layers, in these words: "As may be seen with the naked eye, and as has been generally acknowledged, the fibrous fascicles in the dura mater of the brain are chiefly arranged into two principal layers. Each of these principal layers, however, can be resolved into a number of thinner laminæ; for with a pair of tweezers in many places quite a series of laminæ may be pulled off. These laminæ, indeed, are connected with one another by bundles of fibres passing from one into the other; yet often in such laminæ the cells remain in their proper positions. . . . The bundles of the *interior* principal layer are carried across the hemispheres in an antero-posterior direction, and at the same time running from within to without. . . . In the *exterior* layer of the dura mater the bundles of fibres are more interlaced; but their chief arrangement, nevertheless, is in a direction from without to within, and from the front towards the rear. They also follow other directions, crossing one another three or four times. The two principal layers, however, are most intimately conjoined by an interchange of fascicles, so that any separation of the two must be termed an artificial one" (see above, p. 228).

1 "Descriptive Anatomy," English edition, London, 1842, p. 912.
2 "The Human Brain," second edition, London, 1847, p. 143.
3 "Studien in der Anatomie des Nervensystems," etc., vol. i., Stockholm, 1875, p. 157.

4. In respect to the texture of the dura mater Swedenborg says: "The texture of its fibres is partly ligamentary and partly tendinous, for they seem to be single or independent by nature. They are indeed not muscular, because they have no similarity to fleshy fibres, nor are they purely nervous, on which account some call them tendinous. They are, nevertheless, elastic; for when the membrane is loosened from its connection with the cranium, it contracts, and chiefly that production of it which lines the spinal cord" (i. no. 202). Again he says: "That the dura mater is elastic is proved by experience; likewise by its being a tissue of filaments each of which is elastic; it is also proved by the arteries which are in it. When pressed it rebounds" (i. no. 260). In respect to the abundance of blood-vessels in the dura mater, Swedenborg says: "Into the superior lamina of the dura mater many and innumerable blood-vessels flow together, which have been delineated by Ruysch. And as they meet together and are collected from all sides, especially above the sinuses, their pulsation is especially felt there, and not so much in the hemispheres themselves. . . . This is the cause of the opinion that the motion of the brain is similar to, and agrees with, that of the heart. Besides . . . the dura mater consists in a great measure of arteries, and only of a few fibres. This appears sufficiently from a strong and subtle injection like that of Ruysch. If the vessels are even emptied of blood, they are still continuous with blood-vessels. *It is thus that the elasticity of the whole dura mater is preserved*" (i. no. 284).

From these passages it appears that, according to Swedenborg, the dura mater is not only elastic, but also that its elasticity is preserved chiefly by an abundance of blood-vessels.

5. If now we turn to the text-books of modern science with a view of confirming these statements of Swedenborg, we meet there with the following expressions:—

Quain[1] says, "The dura mater is a very strong, dense, *inelastic* tunic of considerable thickness" (ii. p. 569); although in describing its structure he says, "The dura mater consists of white fibrous and *elastic* tissue, arranged in bands and laminæ crossing each other" (ii. p. 571).

Todd[2] also says: "The dura mater is a dense membrane composed almost exclusively of white fibrous tissue. It has all the characters, physical and vital, of that texture, possessing great strength and flexibility *with but little elasticity*" (p. 4).

In respect to the vessels of the dura mater, however, Sappey expresses himself thus: "The cranial dura mater is much less vascular

[1] "Elements of Anatomy," eighth edition, London, 1876.

[2] "The Descriptive and Physiological Anatomy of the Brain, Spinal Cord, and Ganglions," London, 1845.

than the ligaments, tendons, and the aponeuroses of the members. Among all the dependences of the fibrous system there is in fact none which is poorer in vessels. On examining this membrane under the microscope, one is struck with the extreme paucity of capillaries passing through the same" (iii. p. 20) ! !

6. Not all authors, however, agree in attributing such few blood-vessels to the dura mater. So says Luschka :[1] "In accordance with its principal vocation to serve to the bones of the cranium in the capacity of an internal periosteum, the dura mater is furnished with an *uncommonly copious supply* of arterial vessels" (p. 144). And Solly states : "Dr. Knox, in the *Lancet* of the 19th October 1839, remarks that in some animals the vascularity of the external layer [of the dura mater] is very striking, as in certain Cetacea—the Rorqual, for example—where there is *a perfectly distinct vascular layer* between the dura mater, properly so called, and the calvarium" (*loc. cit.* p. 143). But as to the number of capillaries in the dura mater Cappie[2] says : "The circulation of the brain itself is almost entirely capillary. Its substance is penetrated by scarcely a single blood-vessel of size. Its arteries ramify external to the organ; and *in the dura mater they subdivide to such a degree as to convert that membrane into an extremely fine and close network*" (see above, p. 228).

The existence of capillary nets in the dura mater is also affirmed by Paschkewicz,[3] who discovered in it "two nets of capillaries, of which one is superficial, and the other lies more deeply embedded in the interior leaf, immediately under the epithelium; which two nets intercommunicate, and, besides, are connected with the veins, but not with the subdural space" (see above, p. 231).

As to the more minute arrangement of the blood-vessels and capillaries in the dura mater, Key and Retzius,[4] on the basis of a most painstaking, histological examination of the dura mater, resulting in a series of admirable microscopical representations of the same, make the following statement : "On the *exterior* surface of the dura mater [which is turned towards the cranium] arterial branches are carried along in a serpentine fashion, accompanied on each side by veins, a little broader, which, with their interior boundary lines, accommodate themselves to the windings of the arteries. The arterial branches, and the veins together with them, divide in a dichotomous manner, and their twigs continue on the exterior surfaco in acute or right angles. The veins

[1] "Die Anatomie des Menschen," vol. iii., part 2, Tübingen, 1867.
[2] Cappie (James), M.D., "On the Encephalic Circulation and its Relation to the Physiology of the Brain," Edinburgh, 1859, p. 66.
[3] Petersburg. Med. Zeitschrift, 1871, as quoted by Messrs. Key and Retzius in vol. i. p. 156.
[4] "Studien," etc., vol. i., Stockholm, 1875, pp. 163-165.

often communicate with other veins. The arteries also anastomose. On the *interior* surface of the dura mater is discovered another network of vessels, the meshes of which are usually oblong. Here and there, in the nodes of the meshes, there appear peculiar, ampullary enlargements of different sizes, which usually lie horizontally, and are of the shape of pears or clubs. These enlargements, as well as the fine capillaries themselves, in a natural state always carry blood. What is the relation of the interior to the exterior net? On carefully examining the preparations, it will be found that here and there delicate vessels in an oblique direction are carried through the dura mater from the arteries of the exterior system towards those of the interior system, pouring out their contents. These vessels are the communicating branches of the arteries, or the capillary arteries. In other places there are still larger expansions, the varying, fantastical forms of which cannot be easily described; but they may be studied in the accompanying illustrations. On examining these expansions or bags more closely, it appears that they usually occupy a transverse position in respect to the capillaries, of which they receive a number on each side; and then they pursue their course for a while on the surface; after which they dip in an oblique direction into the substance of the dura mater, in order, finally, to enter into a vein. These are the roots of the veins which connect the capillaries of the interior surface with the veins of the exterior surface. Here, then, we have the complete system of vessels before us" (see above, p. 231 *et seq.*).

These gentlemen further say: "In certain places, especially near the falx cerebri and the tentorium, the vessels are so numerous and closely crowded together, and at the same time so wide, that when they are filled with blood the tissue appears almost all red, and that only small interstices exist between the vessels. The wide roots of the veins are collected in large bundles, whence arise the larger branches" (see above, p. 232).

7. On studying the bearing of these facts on the theory propounded by Swedenborg, we find that they completely bear out this statement of his: "Into the superior lamina of the dura mater many and innumerable blood-vessels flow together; . . . and as they meet together and are collected from all sides, especially above the sinuses, their pulsation is especially felt there, and not so much in the hemispheres themselves. . . . Besides, the dura mater consists in a great measure of arteries, and only of a few fibres. . . . If the vessels are even emptied of blood, they are still continuous with blood-vessels. *It is thus that the elasticity of the whole dura mater is preserved.*"

The elasticity is preserved, because, when the cerebrum during its expansion presses uniformly against the dura mater, the blood is squeezed out of the capillaries into the ampullary enlargements, and the dura in consequence is flattened out; but as soon as the pressure of the cerebrum relaxes, there is a new infusion of arterial blood into the capillaries and blood-vessels of the dura mater in general, whereby its two arterial nets are filled up, and its whole substance is expanded.

The vessels, however, according to Swedenborg, "are collected chiefly above the sinuses, so that their pulsation is principally felt there," which is also borne out by the researches of Key and Retzius, who state that "near the falx cerebri and the tentorium the vessels are so numerous and so closely crowded together . . . that the tissue appears almost red."

The reason, however, why there is such a collection of blood-vessels above the sinuses, Swedenborg explains thus: "The dura mater has a double motion, namely, one which is expansile, and another which is pulsatile. The former it derives from the brain, and the latter from its own arteries. Reaction and elasticity are required in order that it may concur in a general manner with the motion of the brain; for when the latter has reached the extreme bounds of its expansion, then the dura mater urges it to enter upon the reciprocal period of its contraction" (i. no. 261).

Concerning this expansile motion of the dura mater Swedenborg says further: "It is manifest that the expansile motion of the dura mater begins near the borders of the hemisphere and near the larger sinuses, and that it is continued thence on both sides to the circumference; also that at a distance from its sources it becomes slower, and finally is obliterated" (i. no. 251).

From this it follows that as the greatest reactive power of the dura mater is required near the falx cerebri, and as that power is imparted to the dura mater largely by its blood-vessels, these vessels must be collected most abundantly near the sinuses.

8. Nevertheless, the blood-vessels alone do not impart to the dura mater its elastic, and hence its reactive quality; for according to Swedenborg they simply "*preserve* its elasticity." Its elastic quality is mainly caused by a tubular system in its internal lamina, containing "a lymph impregnated with spirit."

On this subject Swedenborg says: "The interior lamina consists of ducts or tubes which convey the nervous juice. . . . It follows thence that the dura mater is elastic, and that when it is stretched or extended it recovers itself spontaneously. For not only does it receive new juice, but that which is contained in it cannot be discharged; and hence there arises the reactive power of the membrane. The interior lamina seems to be chiefly elastic; *for it is that which conveys the nervous juice.*" Again we read: "The interior membrane is required to be most elastic, in order that it may poise the motion of the sinuses, and by virtue of its elasticity may react, and at the same time act upon, the inflowing and outgoing vessels" (i. no. 286*c*).

As to the origin of the nervous juice which circulates in the dura mater, Swedenborg says: "The interior lamina of the dura mater . . . is a vehicle for the lymph impregnated with spirit which is set free when the nerves are distributed over the muscles and periostea" (see no. 286*c*). The collection of this nervous juice through the periosteum into the vertebral theca, and its ascent thence into the cranial dura mater, are discussed in the note on the "Cerebro-spinal Liquid" in vol. ii.; but the mode in which from the spine it is spread over the dura mater of the cerebrum is described in no. 286*d*.

The existence of such a system of ducts or tubes in the dura mater conveying the nervous juice or the cerebro-spinal liquid is proved by Key and Retzius[1] in what follows: "On making injections by puncture, there are often filled in the tissue of the dura peculiarly formed *systems of little tubes.* Thus from the punctured place the injected fluid in this case shoots out in pencil-like forms which run in a parallel direction, and are in close proximity to one another. If, as happens usually, the injection penetrates into several layers of the dura, the tubular systems of the diverse layers cross one another in various angles in the directions of the fibrillæ. If the injection is very strong, the little tubes are so much crowded that the dural tissue can be scarcely perceived. The little tubes agree perfectly in their form with Bowman's 'corneal tubes.' Each tube is usually quite straight, and, as may be seen in vertical cuts, its shape is generally cylindrical, and it terminates in sharp points. Often, also, they become dissolved into a number of finer tubules, which either lie very closely together, or become separated from one another. In this case only a thin strip of the dural tissue is visible between the several tubules. Only rarely, however, they anastomose. As a matter of course the form and arrangement of these tubular systems depend necessarily upon the structure of the dura mater; that is, upon the arrangement of its fibrillary fascicles. . . . *It is highly probable that these tubular systems represent the lymph canals (Saftcanäle)*; [that is, canals or tubes conveying the cerebro-spinal liquid or the nervous juice]" (see above, p. 233).

9. After thus vindicating for the whole of the dura mater an elastic character, by virtue of the abundant blood-vessels and lymph-canals which enter into its composition, it remains to be shown that this elastic quality is concentrated near the sinuses, because the expansile motion of the dura mater begins near the borders of the hemisphere, and near the larger sinuses, and is continued thence on both sides to the

[1] "Studien," etc., vol. i. p. 165.

circumference. Swedenborg says: "Near the sinuses, that is, the longitudinal, and especially in the neighbourhood where it meets with the lateral and the straight sinuses, in the concave part of the membrane, there appear ligamentary, tendinous, and elastic fibres, not unlike muscular—chiefly, however, in the anterior and posterior parts of the falx. These fibres, on account of their similarity to those of the heart, resemble muscles" (i. no. 206). In another place he says: "The dura mater in respect to its expansile motion is passive; yet by virtue of its elasticity, and in its capacity as a *muscular tendon*, it contributes in a general way to the reciprocal expansile motion of the brain" (i. no. 250).

The muscular appearance of the dura mater in the neighbourhood of the sinuses, as we have seen, is caused by the great abundance there of blood-vessels; but according to the unanimous testimony of modern science, the dura mater, even in the neighbourhood of the sinuses, is void of genuine muscular fibres.

Is Swedenborg therefore wrong in attributing to the dura mater qualities resulting from the possession of muscular power? The dura mater possesses such qualities, especially in the neighbourhood of the sinuses; but these qualities are due to a peculiar cavernous arrangement of its tissue, near the sinuses, which was first discovered by Key and Retzius.[1] On this subject they say: "In the dura cerebralis of man we discovered, especially in some particular places, a peculiar kind of hollows or *lacunæ* which are perhaps of some importance. At all events, they are very remarkable from a histological point of view. On making a vertical section of a dura which has been well hardened in Müller's fluid or in alcohol, or still better in hyperosmic acid, in the neighbourhood of the longitudinal sinus; and on magnifying the tissue, it is usually found more or less cribriform, that is, perforated by a system of hollows; the individual spaces of which are generally of the same shape and size, and are not filled by any organized substance, but by a clear liquid. Often this system of lacunæ is so copiously developed that the intervening partitions of the dural tissue appear like a mere thin trabecular system. In other places, again, the lacunæ are more scanty, and the dural tissue is more plentiful. They are in the exterior, as well as in the middle layer of the dura, but more rarely in its interior layer. They are especially numerous in the portion which appears triangular in cross-sections, and which on either side forms the lateral walls of the longitudinal sinus; as well as farther towards the sides, and also above the sinus in its roof. . . . On examining the lacunæ under a higher magnifying power, it appears that generally they do not communicate directly, but are in mere juxtaposition; and often are separated only

[1] "Studien," etc., vol. i. pp. 166, 167.

by thin partitions of connective tissue. Now and then, however, they are found to communicate openly; at times also several meet in one lacuna. Generally the fundamental form of these lacunæ is that of a circular or oval little bladder or hydatid which is drawn out into a point at both its extremities, so that in a longitudinal section they usually appear of a roundish or oval shape, but in cross-sections of a round figure. . . . Sometimes two lacunæ are connected by their points, by which they run into one another. . . . They are scattered in the connective tissue of the dura, and parallel with the longitudinal axis of the fibrous bundles of the dura. . . . After looking in vain in the interior of the lacuna for a cellular covering, we succeeded in finding there a thin, *elastic, little membrane.* This membrane, which contains a large number of fine filaments, and therefore in cross-sections appears punctated, is so closely attached to the wall of the lacuna, that it can be separated from it only with great difficulty. . . . The lacunæ occur in several places in the dura mater, but chiefly in the neighbourhood of the sinuses, and, indeed, in varying numbers" (see above, p. 229 *et seq.*).

Here we have the description of a tissue which, so far as its elastic qualities are concerned, is fully the equivalent of the muscular bands (*lacerti*) which Swedenborg on the basis of the anatomical authorities of his day claimed for the neighbourhood of the sinuses; and which muscular bands, according to him, initiate the reactive expansile movement of the dura mater.

10. This expansile movement of the dura mater, Swedenborg further says, "is continued on both sides from the neighbourhood of the sinuses to the circumference, and at a distance from its sources it becomes slower, and is finally obliterated."

This also is borne out by the facts of the case, as reported by Key and Retzius;[1] for the system of lacunæ described above is situated in a peculiar transverse layer of fibres radiating from the neighbourhood of the sinuses to the circumference of the dura mater. Their statement on this subject is as follows: "From the neighbourhood of the superior longitudinal sinus there radiates over the whole interior surface a layer of fascicles running in a more transverse direction. . . . It is these tracks of transverse fibres which, in the neighbourhood of the sinus, form a kind of cribration" (see above, p. 229).

We see, therefore, that modern science, far from disproving the truth of Swedenborg's statement in respect to the reactive and elastic quality of the dura mater, shows, on the contrary, that this membrane, especially in the neighbourhood of the sinuses, possesses all the qualities of an *elastic tendon*, whereby it is enabled "to contribute in a general way to the reciprocal expansile motion of the brain."

[1] "Studien," vol. i. p. 157.

11. In conclusion, we find nothing in the facts advanced by modern science which militates in the least against the theory advanced by Swedenborg in respect to the chief use and function of the dura mater, which he sums up in these words: "The dura mater conjoins the motion of the heart, or the pulsation of its arteries, with the motion of the brain or the animation of its fibres, for it undergoes a twofold motion; namely, one which is pulsatile, and which it derives from its own arteries, and another which is expansile and constrictive, and which is imparted to it by the brain. . . . That it is possible for these two motions to exist together in one and the same membrane, appears clearly everywhere in the body; especially in its general membranes, namely, the pleura, the peritoneum, and the diaphragm. In the pericardium also it is shown that two motions may thus exist together most conjointly; nay, even in the heart, and in all its arteries. This agreement of two motions may also be demonstrated mechanically" (i. no. 281).

NOTE III.

THE CHYMICAL LABORATORY OF THE BRAIN.

A. *General Remarks.*

1. According to Swedenborg there are three general functions of the brain—(1) the function of sensating and perceiving, (2) that of determining and acting, and (3) that of conceiving and bringing forth the nervous fluid or animal spirit and the blood.

"For the purpose of preparing the blood," he says, "the soul has established in the cerebrum an illustrious chymical laboratory, which it has arranged into members and organs, and by the ministry of these it distils and elaborates a lymph animated by the animal spirit, whereby it imbues the blood with its own inmost essence, nature, and life. This is the object of the organs of the cerebrum, namely, the corpus callosum, the fornix, the three ventricles, the choroid plexus, the glands [or tubercles] of the isthmus, the infundibulum, the pituitary gland, the cavernous sinuses, and several more" (i. no. 90).

Modern science is acquainted with only two of these functions of the brain, namely, sensation, and determination which results in action or motion; and hence it is in a state of complete ignorance in respect to everything that concerns the functions of the above-named organs of the brain.

Alluding to the general darkness which prevails among the men of science respecting the functions of the brain, Cruveilhier[1] says: "The structure of no other organ in the body excites so much curiosity, and unfortunately there is none whose structure is involved in greater obscurity. Notwithstanding the real advances that have recently been made in our knowledge of the anatomy of the brain, we must still acknowledge with Steno that the human mind, which has carried its investigations even into the heavens, has not yet been able to comprehend the nature of the instrument by which its own operations are performed, and that its powers seem to abandon it as soon as it turns its attention to the organ in which it resides" (see above, p. 20).

Some light has since Cruveilhier's time been thrown on the functions

[1] "Descriptive Anatomy," London, 1842, p. 908.

which are exercised by some of the convolutions of the brain, as well as by the corpora striata and the optic thalami, and likewise to some extent by the corpora quadrigemina; but the functions of the rest of the organs belonging to the chymical laboratory of the brain are still shrouded in dense darkness; wherefore Cruveilhier's remarks respecting the pineal and the pituitary glands, for instance, still hold good.

Respecting the former he says: "The hypothesis of Descartes concerning the function of the pineal body is a striking example of the abuse of an imperfect knowledge of anatomy; according to him the soul is seated in the pineal gland, and it directs all the movements of the body by means of the peduncles, which he regards as the gubernacula or reins of the soul. . . . Morbid conditions of the body will perhaps throw some light upon its functions, but they have not yet been sufficiently studied" (*ibid.*, p. 994).

Respecting the pituitary gland he says: "The functions of the pituitary gland are enveloped in the greatest obscurity. Its constancy in all vertebrated animals and its great vascularity are sufficient evidence of its importance. It certainly communicates with the third ventricle, but for what purpose?" (*ibid.*, p. 975.)

Other authors are not so frank in acknowledging the state of darkness prevailing among the men of science in respect to the functions of what Swedenborg calls the chymical organs of the brain. The anatomists, indeed, treat us to a minute description of these organs, but preserve a profound silence in respect to their use or functions; while the physiologists have something to say respecting the functions of some of the convolutions of the cerebrum, and also concerning those exercised by the cerebellum, the medulla oblongata, the spinal marrow, and the central ganglia; but in vain do we seek any allusion in their text-books to the functions exercised by any of the organs belonging to what Swedenborg calls the chymical laboratory of the brain.

That function which Swedenborg assigns to the chymical laboratory of the brain, and which consists in supplying "a most refined lymph" identical with "the white or purer blood," from the corpuscles of which are organized the grosser particles of the red blood, modern science attributes to the lymphatic system. On this subject says Dr. Carpenter, "The chyle and lymph seem to be continually supplying, not merely the *pabulum* for organization derived from the food, whereby the components of the liquid part of the blood are replenished as fast as they are withdrawn; but also the rudimentary *corpuscles* which are to be progressively metamorphosed into the particles that float in its current" ("Human Physiology," seventh edition, sec. 179).

Swedenborg admits that the lymphatics "convey a lymph purified of all dregs," and thus of a nature akin to that prepared by the brain in its chymical laboratory. He also declares "that the lymph of either kind," that is, that prepared by the brain, and that secreted by the lymphatic glands, "is not purely elementary, but is intermixed with animal essence, such as is suited to the blood, in order that it may be recompounded" (ii. no. 514). But while the brain generates in its own bosom "the animal essence," that is, the spirit which constitutes the formative, and hence the vital element of the blood;—which spirit the brain afterwards mingles with serum in its chymical laboratory, and thereby renders fit to enter into the composition of the blood;—the lymphatic vessels, according to Swedenborg, simply "derive their juice from the last of the little arteries," and they "collect it from every viscus, muscle, and gland, and afterwards convey it into the thoracic duct" (ii. nos. 517, 518); they therefore receive it fully prepared from the blood, and do not generate it in the first place, as does the brain. Wherefore the lymphatics are simply veins of a higher order, that is, veins absorbing from the least arteries a higher or purer kind of blood, which they are instrumental in reintroducing into the blood.

B. *The Function of the Valve of Vieussens.*

2. According to Swedenborg, "the sphere . . . of the operations of the *cerebrum* is distinct from the sphere of the *cerebellum*" (i. no. 275). This he corroborates by the following considerations: "Each of these organs [viz. the cerebrum and cerebellum] is enclosed within its own bounds, and the cerebrum is separated from the cerebellum by a strong and fourfold partition, and each is furnished by its own artery, and its own vein; lest, if there was one common to both, natural things or those governed by nature [which are presided over by the cerebellum] should be mixed up with voluntary things [or those which are under the control of the cerebrum]" (i. no. 390).

This distinction between the two brains extends also to the liquid contained in the ventricles belonging to each of them. On this subject says Swedenborg: "Through emissary ducts or peduncles the cerebellum excretes a juice into the fourth ventricle, providing [thereby] for the subjacent roots of the nerves; while the . . . cerebrum cares for the mass of the blood; wherefore as the two brains differ in use, they also differ in structure." In the same place he continues, "The lymph secreted in the cerebrum is of a coarser kind than that which is collected in the fourth ventricle" (i. no. 713). As a reason why the lymph secreted from the cerebellum is of a superior nature to that excreted by the cerebrum, Swedenborg gives the following: "The lymph which the peduncles convey into the fourth ventricle out of every cleft of the cerebellum and out of the medullary branches of its arborescent organism, must needs be most refined, and of a spirituous nature. . . . For the cerebellum goes through its alternate motions with constancy and tranquillity, in deep silence, and with an ever-serene complexion. The cerebrum, on the other hand, very often displays in its motion inconstancy, impetuosity, and again inactivity, wherefore a grosser species of lymph is excreted there" (i. no. 713).

The lymph secreted in the cerebellum, and collected in the fourth ventricle, is the so-called cerebro-spinal fluid, which in its character of nervous juice circulates through the coatings encompassing the fascicles, as well as the individual fibres of which the various nerves are composed. But the lymph which collects from the cerebrum in the lateral ventricles, and which in the chymical laboratory of the brain is distilled into the white or purer blood, passes through the infundibulum and the pituitary gland into the petrosal sinuses, and thence through the medium of the jugular vein is conveyed to the heart.

3. In order to prevent "the grosser lymph" of the cerebrum from mixing with the more refined lymph of the cerebellum, the aqueduct of Sylvius, which is one of the outlets of the third ventricle, is closed by a membranous septum, called *the valve of Vieussens.* On this subject Swedenborg says, "This valve, which great in use, but small in size, . . . closes up . . . the approaches, and shuts the door tightly, lest any liquid of the cerebrum should flow into the fourth ventricle, and *vice versa*" (i. no. 711).

This statement Swedenborg makes on the strength of Vieussens' description of the valve which is called after him. Vieussens says: "It is to be noted that the aqueous juices . . . are not able to penetrate through the aqueduct of Sylvius to the calamus scriptorius, because the 'valvula major cerebri' totally prevents their access to it. This is proved by the following experiment: If, the convex part of the cerebrum having been removed and its lateral ventricles opened, the third ventricle and the aqueduct of Sylvius are filled with water, and the same water is afterwards drawn out by the aid of a little sponge; and if afterwards the cerebellum is dissected through its middle from the front backwards, and opened out sidewards, the cavity of the calamus scriptorius is discovered, where not even the least drop of water is found; therefore we maintain that admittance into the fourth ventricle is denied to those aqueous juices which are received in the aqueduct of Sylvius" ("Neurographia," etc., chap. xvii. p. 110).

The actual function itself which the valve of Vieussens performs in the economy of the brain, Swedenborg describes as follows: "The fourth ventricle and the aqueduct of Sylvius are like a pair of scales, the vertical beam of which is the valve of Vieussens; for as soon as one of them rises, the other is as it were pressed down, since one acts upon the other through the medium of the valve, because their motions alternate. The moisture which is injected into the aqueduct presses against the valve, and bends and bulges it out in the direction of the upper and hence widest part of the fourth ventricle; but when the ventricle swells reciprocally and exerts a pressure, then the valve is driven into the aqueduct, and closes it up almost completely, urging its lymph through the foramen under the pineal gland into the third ventricle, and *vice versa.* This valve . . . is also like the tongue of a pair of balances, like the central point of a seesaw, or like an axis which is moved around by a wheel; wherefore it is also of a delicate structure, pliable, medullary, the grey substance with which it is interspersed co-operating with it. It is covered on all sides with a thin membrane which is continued into the fourth ventricle, as well as into the aqueduct, so as to apply itself to both; it rests obliquely or lies in a declivitous position, being attached to a certain process of the corpora quadrigemina, and to fibres sent out from the fornix as to a *frænulum*, or as to the pole of a waggon, and likewise to the extremity of the vermiform process; perchance also to the fibres of the first process of the cerebellum towards the corpora quadrigemina. In this wise it is fastened to the fibres of the cerebrum, as well as to those of the cerebellum, accommodating itself to either part. It also remains secure; for it occupies a middle and central position like the tongue of a pair of scales, and guards the equilibrium; and in addition it is protected by the vaults and walls of both cavities which rise up against it, and to which it applies itself when pushed inwards. Its delicate structure and small size answer completely to the measure and force of the acting lymph; just as the semilunar valves of the heart correspond to the impulse of the sanguineous stream" (i. no. 711).

4. Let us now hear the voice of modern science on the subject of the valve of Vieussens and the aqueduct of Sylvius.

Dr. Mark Sée,[1] editor of the last edition of Cruveilhier's "Anatomie Déscriptive," and director of the anatomical operations at the Faculté de Médecine in Paris, says, "At times [in making injections into the sub-arachnoid space] it has happened to me to find the velum interpositum throughout its whole thickness dyed blue, and also the middle and lateral ventricles filled with the injecting fluid, without the least particle of the substance having penetrated into the fourth ventricle." Dr. Sée thus at least partly supports Vieussens' statement

[1] "Sur la communication des cavités ventriculaires de l'encéphale avec les espaces sous-arachnoïdiens" (Revue mensuelle de Médecine et Chirurgie, t. iii. p. 295 *et seq.*).

by declaring that at times the passage between the third and fourth ventricles is found closed. Cruveilhier, on the contrary, in describing the aqueduct of Sylvius and the valve of Vieussens, says: "The aqueduct of Sylvius . . . is a canal which establishes a communication between the third and fourth ventricles—*iter a tertio ad quartum ventriculum*. . . . It was stated by Vieussens that the opening of the aqueduct into the fourth ventricle was provided with a valve. But this statement is at variance with the results of observation" (Descriptive Anatomy, English edition, p. 992).

This statement of Cruveilhier, which is confirmed by all the leading text-books on anatomy in modern times, means in so many words that the valve of Vieussens does not close the passage from the third into the fourth ventricle.

Which of these facts is correct? We maintain that when all the facts of modern science which really bear on the subject are carefully considered, it will be found that these facts do not contradict, but rather support Vieussens' statement.

5. In the first place, it is admitted that the aqueduct of Sylvius is hemmed in by the valve of Vieussens. Thus Cruveilhier says, "The anterior surface of the valve of Vieussens is convex, and forms the posterior wall of the aqueduct of Sylvius" (*ibid.*, p. 949). The question therefore arises, (1) Whether the lower free end of the valve presses against the bottom of the aqueduct in such a manner as to prevent the passage of a liquid from the fourth into the third ventricle, and *vice versa?* and (2) Whether this passage is ordinarily used by the cerebro-spinal fluid in order to penetrate from either of these ventricles into the other?

Before discussing whether a liquid passes from the fourth into the third ventricle, or *vice versa*, it seems necessary to show that there is in these ventricles a liquid in a state of motion. Magendie has proved this by the following experiment, which we quote from Paulet (Céphalo-rachidien liquide) in "Dictionnaire encyclopédique des Sciences médicales," Paris, 1873): "After exposing in a living he-goat the interior of the cerebral ventricles, this physiologist saw how the liquid contained in these ventricles rose at each expiration, and subsided at each inspiration" (vol. xiv. p. 59).

This liquid, Magendie holds, is identical with the cerebro-spinal liquid which bathes the brain and the spinal cord on the outside. The passage of this liquid into the lateral ventricles through the aqueduct of Sylvius he describes as follows :—

"Aqueous or other injections made from the spine into the subarachnoid space have never failed to arrive in the lateral ventricles. The route which they follow *is known to every one;* and if I detail it here, it is only for the purpose of not omitting anything important.

"The liquid first enters the ventricle of the cerebellum which it fills up completely, distending its walls; *it raises the valve of Vieussens;* afterwards it penetrates into the canal which leads from the fourth into the third ventricle, and which by Sylvius has been so appropriately called the aqueduct," etc. (Recherches sur le liquide céphalo-rachidien, 1842, pp. 28, 29.)

While, according to Magendie, there is thus an uninterrupted passage for a liquid from the fourth ventricle *into* the aqueduct of Sylvius, Key and Retzius on the other hand, on the basis of injections made with congealing substances from the lateral ventricles, declare that there is an open passage for a liquid *out of* these ventricles through the aqueduct of Sylvius into the fourth ventricle (Nord. Med. Archiv., vol. vi. no. 5, 1874).

We admit that in dead, collapsed brains the valve of Vieussens may afford a passage to injections, especially if they consist of heavy, congealing substances, such as glue or paraffine, which were used by Key and Retzius. But the question arises, How is it in the *living* brain? For it is to the living brain that Swedenborg appeals for the truth of his theory, as in the following pointed passage: "In order to perceive distinctly the operations of the brain, we must represent to ourselves every part as living; that is, we must regard every part as set in motion, and not as it is presented to us in a corpse, collapsed and extinct" (i. no. 465).

6. But even lifeless brains do not afford such an easy passage to injections from the sub-arachnoid space into the cerebral ventricles through the aqueduct of Sylvius, as is maintained by Magendie. Thus, in addition to the passage already quoted from Sée, in commenting on the statement which we have quoted above from Magendie, Sée further says, "From the fact that the liquid injected through the spinal cavity made its way into the lateral ventricles, it does not follow necessarily that it pursued the way indicated by Magendie, and surely that gentleman himself has not seen the liquid making its way successively through the different parts pointed out by him" (*loc. cit.* p. 295).

And in commenting on an experiment of Paulet, who injected the aqueduct of Sylvius with vermilion from the spinal cavity, he says: "If the experiments of Magendie, and especially those of Paulet, prove a communication of the sub-arachnoid liquid with the ventricular liquid, these same experiments do not at all show that said communication took place through the foramen of Magendie [*i.e.* through the posterior part of the fourth ventricle], or *only* through that foramen; since the coloured injection which was found in the aqueduct of

Sylvius could also have been conveyed thither by an opposite way from the third ventricle; that is, if it is once admitted that there is an entrance into these cavities through other channels than those of the foramen Magendii and the fourth ventricle" (*loc. cit.* p. 297).

To point out the whereabouts of these other channels of communication is the object of Dr. Sée's paper.

7. The mode in which the passage of the aqueduct into the fourth ventricle is closed up in the *living* brain, according to Swedenborg, is as follows:—

The whole of the living brain, as shown in Note i., undergoes constantly an alternate motion of expansion and constriction; and the expansile force of the brain, as shown in the same note, abides in the grey substance of the brain. On this subject says Swedenborg:—

"It is the cortical or grey substance which is expanded and constricted, or from which the cerebrum has its animatory motion; for its parts are globules of a roundish shape approaching the oval. They are engirded by a thin or most delicate meninx or membrane; they are distinctly separated from those parts to which they are mutually related, and which are in their confines, so that each single globule is movable or capable of expansion and compression within its own space. . . . We must not look for the origin of the motion of the brain anywhere else than in these its organic parts; for only in these does the brain begin to be a brain. . . . The number of these grey particles is so great that while each single particle expands itself, the whole mass of the brain is expanded from its bottom and from all its depth" (i. nos. 56, 57).

8. The next point for our consideration is this, that both brains, the cerebrum and the cerebellum, expand and subside at the same time. This Swedenborg declares in the following passage: "The cerebellum can be constricted only at the same times as the cerebrum; for the cerebellum and the cerebrum are so conjoined, and at the same time distinct from one another, that the one communicates its motion to the other—except when one, against its own will, is unable to act with the other" (i. no. 678); see on this subject Note i. p. 677 *et seq.* From this, however, it follows that the medulla oblongata and the spinal marrow also expand and contract at the same time as the cerebrum and cerebellum; since they are continuations or prolongations of these organs.

But if the whole encephalon goes through its motion of expansion and contraction at the same time, it follows that all its five ventricles also are dilated and constricted at the same time. Yet in an inverse ratio to the brain itself; for when the brain with its appended medullæ is expanded, the ventricles are constricted, and *vice versa.* This Swedenborg states in the following rules:—

"*First rule.*—Each larger, smaller, and least cavity, as well as each medullary tract, nay, each fibre, artery, vein, and sinus, all except their outlets, are constricted at such times as the cerebrum and medulla oblongata, that is, the cortical and grey substance opens itself, and is expanded; and *vice versa.*

"*Second rule.*—Each larger, smaller, and least cavity, each medullary tract, nay, each fibre, vein, and sinus, at such times as they subside and are constricted, are lengthened out, and corrotated in respect to their width; and *vice versa.*

"*Third rule.*—The liquid which is contained in cavities, anfractuosities, sulci, and fissures, at each constriction, that is, at each systaltic movement, is pressed towards the poles, and thus towards the centres of rest and the axes; at the time of expansion, however, the liquid is driven towards the circumferences" (i. no. 467).

These principles or rules of motion as applied to the lateral ventricles exhibit the following results :—

"Both lateral ventricles are constricted whenever the corpora striata and the thalami optici rise, which takes place when the cortical cerebrum is expanded; then also the medulla of the corona radiata or centrum ovale, corpus callosum, fornix, Vieussens' 'centrum semicirculare' [inner capsule], and the remaining medullary tracts, is constricted: so likewise the cavity which is enclosed within them; for the corpora striata with the thalami optici constitute the upper wall and the bottom of the ventricles, and the remaining medulla is circumambient, and constructs the ceilings or roofs of the same; and *vice versa.*

"Each lateral ventricle during the time of its constriction, or during its systole, is lengthened out, and contracted in width, and *vice versa;* for the corpora striata, the beginnings of the medulla oblongata, whose backs bulge out in the cavity, then swell throughout their whole length, and spread out laterally: wherefore the medulla which encloses these bodies, runs through them, and is inserted between them, is lengthened out, and therefore diminished in respect to its other dimensions.

"It hence follows that the posterior and descending cornua of the lateral ventricles . . . then subside and close up completely, and the upper or broader parts of the ventricles become very narrow and contracted" (i. nos. 468, 469).

The above rules, however, when applied to the fourth ventricle show the following results :—

"This ventricle is constricted and covered up in its middle when the superincumbent peduncles become lengthened, and stretch themselves out on all sides; but the reverse happens when they draw themselves back. The systole of this cavity therefore is caused when the cerebellum stretches its fibres, that is, when that organ expands itself; but under a reverse condition of the cerebellum this cavity has its diastole. The very rima or indentation running through its middle indicates that at the time when the ventricle has its systole its edges [in the middle] are folded up, and its bottom is raised up from below by the opposite medulla, *i.e.* the pons Varolii. When the ventricle, however, is constricted, the enclosed lymph is expelled from its middle towards the calamus scriptorius in its lower part, and thus is pressed into the above-named duplicature [*i.e.* the *tela choroidea inferior*]. But when the ventricle is enlarged and swollen with lymph, then the lymph presses against the valve of Vieussens. When at such times it impinges against this valve, the aqueduct of Sylvius, under the corpora quadrigemina, is compressed and emptied of its contents, and *vice versa*, just as the periods alternate" (i. no. 715).

From this description of the motion of the encephalon it appears that the aqueduct of Sylvius is expanded when the ventricles are constricted, and *vice versa.*

The method by which it is expanded is as follows :—

"At the sides of the aqueduct there is medullary substance, in the bottom it is striated [that is, interspersed with grey substance], and in the roof there is cineritious substance intermixed with it" (i. no. 516).

From this it follows that the bottom of the aqueduct is capable of being raised up or of swelling when the thalami optici rise and the lateral ventricles are constricted. We read further :—

"The greatest help, however, in the dilatation of the aqueduct is afforded by the third and fourth ventricles, between which it is situated; for when each of these ventricles is compressed into a mere fissure, and stretched out towards the extremity of each, the intermediate space is necessarily increased and transformed into a wider sinus or bosom, especially at its bottom, *which is raised up higher* when the third ventricle in its state of compression is swollen with lymph; and *vice versa*" (i. no. 527).

The shape of the cavity of the aqueduct immediately in front of the valve of Vieussens is represented by the annexed figure, which we introduce from Gerlach's "Mikroskopische Studien" (Erlangen, 1858).[1] If now, according to

[1] In respect to the various shapes which the aqueduct has in various places, see chapter xv., on the Corpora Quadrigemina and the Aqueduct of Sylvius, no. 522*p*, and also sub-section E of our present note, no. 41.

Swedenborg, during the expansion of the aqueduct, *its bottom is drawn up*, it follows that the crena or notch in the bottom of the aqueduct is completely filled up and obliterated, and thereby the passage from the aqueduct into the fourth ventricle is closed; for the sides and the ceiling of the aqueduct, as we have seen, are completely hemmed in by the valve of Vieussens.

But when the aqueduct, on the other hand, is contracted, its medullary sides are swollen and shortened, its ceiling therefore is drawn down, and its striated bottom constricted, and thereby its lower extremity, which is directed towards the valve of Vieussens and the fourth ventricle, is reduced to its smallest calibre. The valve of Vieussens also, by the lymph of the fourth ventricle pressing against it, is driven into the aqueduct, and thereby closes up likewise the passage under the lower edge of the valve.

From the preceding exposition of the principles by which the motion of the liquids in the cerebral and cerebellar cavities is governed, it follows that in the living brain the passage under the valve of Vieussens is closed up; that this valve therefore acts as a barrier between the third and fourth ventricles, and separates completely the cerebral from the cerebellar liquid.

From these principles it follows further, that during the systole or constriction of the fourth ventricle, and thus during the expansion of the cerebellum, the cerebellar fluid is expelled through the openings of the fourth ventricle into the sub-arachnoidal space, where it henceforth becomes known as the cerebro-spinal fluid.

Science, on the other hand, has established the fact (see above, p. 716) that during the expiration of the lungs the cerebro-spinal fluid from the spinal cavity is raised into the cranial cavity, where under the arachnoidal membrane it becomes diffused over the whole brain; while during the expiration of the lungs this same fluid has been noticed to descend from the cranial into the spinal cavity.

From this it follows that during expiration this liquid is borne towards the extremity of the calamus scriptorius, where the foramen Magendii is situated; while during inspiration it retreats from thence.

As it has further been proved by experimental physiology that during the expiration of the lungs the encephalon expands, while during their inspiration it subsides; and as, according to the rules of Swedenborg, the ventricles are dilated during the subsidence of the encephalon, while they are constricted during its expansion; and again, as, according to Swedenborg, the cerebellar fluid is discharged from the fourth ventricle during its constriction—it follows from all this, that this same fluid is discharged from the fourth ventricle *during the expiration of the lungs;* or during the same period, when, as has been proved experimentally, the cerebro-spinal fluid *ascends* from the spinal into the cranial cavity, and thus directs its course towards the openings of the fourth ventricle.

From this, however, it follows further that the cerebro-spinal fluid during its ascent into the cranial cavity is denied admission into the fourth ventricle; that therefore in the *living brain* there is no *entrance* for the cerebro-spinal fluid, in its ascending course, into the above ventricle, and certainly not in its descending course; although there is an *outlet* from the fourth ventricle for the cerebro-spinal fluid which is distilled into it from the cerebellum and the choroid plexus.

9. The course of the cerebro-spinal fluid in the living brain, as determined by the preceding investigation, differs from that which Magendie, Paulet, and Key and Retzius have laid down on the strength of their injections of lifeless brains; but the result at which we arrive is fully borne out by the experimental researches of Dr. H. Quincke which he published in the *Archiv für Anatomie, Physiologie und Wissenschaftliche Medicin* for 1872, in an article entitled "*Zur Physiologie der Cerebro-spinal flüssigkeit*" (Contributions to the Physiology of the Cerebro-spinal Fluid).

In order to discover the course which this fluid pursues in the living subject, Dr. Quincke prepared an emulsion of vermilion, which in the first series of his experiments he injected into the sub-arachnoidal space of the lumbar region of the spine, and in his second series into the sub-arachnoidal space of the brains, of living dogs.

The following are some of the statements in which he summed up the results of his experiments :—

(1) "In none of my experiments did the colouring matter enter the central canal of the spinal cord, or the perivascular spaces of the brain and spine; the reason of which seems to be, that in a normal condition these spaces, indeed, discharge their contents into the sub-arachnoidal space, without, however, receiving any liquid from the sub-arachnoidal space in return.

(2) "The ventricles also, in a general diffusion of the colouring matter throughout the brain, scarcely ever contained free vermilion. In a few cases only it had found its way into the interior of the ventricles, embedded in stray particles of pus, or in flakes formed of such particles by which it had probably been conveyed thither. This negative result shows that it is impossible for a current of this liquid to take place *into* the ventricles; just as little as there is an alternate influx and efflux of this liquid, caused as a collateral result by the flux of the cerebro-spinal fluid under the influence of respiration. If we must still admit an opening in the posterior part of the fourth ventricle, there remains now only the possibility of the . . . flow of a liquid

out of the fourth ventricle; which possibility is supported by the opinion of those anatomists according to whom the choroid plexuses are organs of secretion" (p. 172).

By these results of Dr. Quincke it is rendered probable that a regular discharge of cerebro-spinal fluid from the fourth ventricle takes place through the central canal of the spinal cord, which is a continuation of the said ventricle, whereby the foramen Magendii, and also the foramina discovered by Luschka in the angles of the fourth ventricle, are deprived of much of their importance.

Dr. Sée also is of opinion that the passage of a liquid through the foramen Magendii, which he describes as a large mesh in the pia mater, is not easy, as is commonly supposed. He says, "It must not be supposed that this communication is as large and easy as it appears when the bulb of the medulla oblongata is raised up. When the parts are in their natural position, and when the medulla oblongata occupies the gutter left for it by the *amygdalæ*, it is probable that the foramen Magendii is almost entirely stopped up, and allows the passage of a liquid only under the influence of a certain pressure. At least such has been the result of my experiments on dead bodies. In my injections, even in those which have succeeded best, I have almost constantly seen the coloured liquid infiltrating the pia mater of the medulla oblongata as far as the calamus scriptorius, and thence spreading itself over the pia mater of the cerebellum, without a single drop penetrating into the fourth ventricle through the foramen Magendii; so that the bottom of that ventricle remained perfectly white" (Revue mensuelle, etc., for 1879, p. 302).

This subject will be further discussed in our note on the "Cerebro-Spinal Liquid" in vol. ii.

10. Thus far we have proved that in the living brain the cerebro-spinal liquid is discharged from the fourth ventricle and the central canal of the spinal cord into the sub-arachnoidal space, and that it does not return thence into these cavities. Our next point will be to confirm by the testimony of modern science that in the living brain there is no discharge from the aqueduct of Sylvius into the fourth ventricle, and hence that the lateral ventricles do not discharge their contents through the fourth ventricle into the sub-arachnoidal space. Our confirmations will be drawn from anatomy, pathology, and chemistry.

The anatomical facts of the case have reference to the epithelial surface of the cavities of the encephalon and the spinal cord. In the fœtus all these cavities, from the termination of the central canal near the os coccygis, all the way through the fourth ventricle and the aqueduct of Sylvius into the third ventricle, and thence into the lateral ventricles, are lined with *columnar* epithelium, in which, according to Quain, "the cells are set upright on the surface which they cover" (ii. p. 44 *et seq.*). These columnar or cylindrical cells "bear on their basal or free ends spontaneously moving filaments, named *cilia;* on which account this variety of epithelium is termed *ciliated*" (*ibid.*).

When after birth, simultaneously with the respiration of the lungs, the cerebral and cerebellar fluids enter upon their ascending and descending motion, the first effect which this motion, according to a well-known physical law, exerts upon the epitheliated surface of the cavities, is to wear off the topmost cilia in all those places where there is a constantly alternating motion of these liquids; while the cilia are left undisturbed where there is no such motion. The only place, however, where throughout the whole of the cavities of the encephalon and the spinal cord the cilia are preserved in adult age, is the aqueduct of Sylvius. On this subject Henle says, "The cilia of the ciliated epithelium are regularly preserved during adult age *only in the aqueduct*, more rarely in the sinus rhomboideus—fourth ventricle" ("Handbuch d. systematischen Anatomie," Bd. iii. Abtheil. 2, p. 323). From this, however, it follows that in the *living* brain there is no current, and hence no passage from the third into the fourth ventricles.

The next effect which the constantly-recurring motion of the ventricular and cerebro-spinal liquids exerts on the epithelium is this, that in those parts against which the liquids are propelled in their course, or against which the chief pressure of these liquids is directed when in motion, the columnar epithelium is by-and-by worn down into *scaly* or *tesselated* epithelium (*pavement* epithelium). Such parts, according to Mierzejewski,[1] are as follows: 1. The roof of the fourth ventricle forming its posterior side, and which in a triangular pyramidal hollow extends into the substance of the cerebellum. By the constantly-recurring expansile pressure of the pons Varolii, by which the cerebellar fluid is urged into the apex of the pyramidal roof of the fourth ventricle, the epithelium there "has become so low as to represent a genuine pavement epithelium." 2. The posterior wall of the central spinal canal, against which the cerebellar fluid impinges, when by the contraction of the fourth ventricle that liquid is forced from the fourth ventricle into the central canal of the spine. 3. The anterior wall of the infundibulum, against which the ventricular liquid is borne, when, by the opening of the aperture under the pineal gland, the ventricular liquid rushes from the aqueduct into the third ventricle. On this subject see sub-sections D and E of the present note. 4. The

[1] "Die Ventrikel des Gehirns." (Centralblatt für die medicinischen Wissenschaften, September 2, 1872, Berlin.) The entire paper of Mierzejewski is given in chapter xi. nos. 463*e*, 463*f*.

extremity of the descending cornu of the lateral ventricles against which the ventricular liquid impinges at each expansion of the lateral ventricles. See sub-section D on the Function of the Lateral Ventricles.

The columnar epithelium, on the other hand, is preserved: (1) On the anterior wall of the central canal of the spinal cord, where, according to Mierzejewski, "the epithelial cells are more than twice as high as those of the posterior side;" (2) on the corresponding anterior side of the fourth ventricle; (3) on the posterior wall of the infundibulum and third ventricle; and (4) on the roof and bottom of the lateral ventricles. The preservation of the columnar epithelium in most parts of the lateral ventricles is mainly due to the division of the lateral ventricles into upper and lower compartments through the mediation of the "upper leaf" of the choroid plexus; which arrangement has first been discovered in frozen brains by Key and Retzius; see sub-sections C and D of the present note. By this arrangement the ascent and descent of the ventricular liquid in the lateral ventricles is somewhat impeded, and a considerable portion of the same descends on the upper leaf of the choroid plexus; on which account the epithelium in the lateral ventricles is not exposed to such a constant wear and tear as in other places, and consequently is not worn down so much.

These anatomical facts prove that there is, on the one hand, a movement from the fourth ventricle into the central canal of the spinal cord, and, on the other hand, a movement from the aqueduct of Sylvius towards the third ventricle; while in the aqueduct itself there is no current, its cavity, according to Swedenborg, serving in the capacity of a reservoir or backwater for the surging wave of the lateral ventricles, which through the lateral openings of the posterior foramen "anus" and through the opening under the pineal gland, presses into the third ventricle. Concerning these apertures see sub-section D of the present note.

11. The pathological facts confirming our position that in the living brain there is no discharge from the aqueduct of Sylvius into the fourth ventricle, are taken from well-authenticated cases of hydrocephalus, by which it is shown that the lateral ventricles may be abnormally distended by a serosity, without the fourth ventricle undergoing any essential change.

In Von Ziemssen's "Cyclopedia of the Practice of Medicine," in the general description of Leptomingitis Infantum (Hydrocephalus acutus sine tuberculis), we read in the sub-section entitled "Pathological Anatomy," that while the ventricles of the cerebrum in that disease are always more or less distended with serosity, "the aquæductus Sylvii is sometimes, but not always dilated," and that "the same is true of the fourth ventricle" (vol. xii. p. 474). Besides, in a special case described on p. 473 it is stated that "all the ventricles [*i.e.* the lateral and the third] were greatly distended. . . . The aquæductus Sylvii was somewhat dilated. No essential change in the fourth ventricle." We see, therefore, that even when the aqueduct of Sylvius is dilated, the fourth ventricle may remain quite unaffected, and essentially unchanged—thus showing that in living subjects the passage under the valve of Vieussens is ordinarily closed.

Hyrtl,[1] in commenting on the fact of the fourth ventricle being very rarely found affected by a dropsical accumulation in the lateral ventricles, suggests that in these cases the aqueduct of Sylvius may be "obliterated." He says, "All the cavities of the cerebrum, on account of their serous linings, are predisposed to serous accumulations. Most frequently these have place in the lateral ventricles and in the third. The fourth ventricle is affected but rarely, which makes one think of an obliteration of the aqueduct of Sylvius. This, with the well-known narrowness of the passage, is probably caused by thickening of the serous coating, which attends all dropsical affections" (p. 81).

The fact to which Hyrtl alludes here, in our view, proves simply that in the living brain the valve of Vieussens is closed; and we do not consider it necessary for this purpose to assume a special obliteration of the aqueduct of Sylvius in cases of hydrocephalus.

Henle, in speaking of the aqueduct of Sylvius, says that at either end the aqueduct has the shape of the letter T. The two edges forming the perpendicular line in the letter, in one case he saw joined by a white commissure (*loc. cit.* p. 126), which serves as an indication of how closely these two edges are usually brought together in the living brain.

12. The chemical facts whereby it is proved that in the living brain the passage from the aqueduct of Sylvius into the fourth ventricle is closed up, are furnished by an analysis of the ventricular and sub-arachnoidal liquids, whereby it is shown that chemically these two liquids are quite distinct. This analysis we quote from Hasse's "Krankheiten des Gehirns und seiner Hüllen" (the Diseases of the Brain and its Integuments) in Virchow's "Handbuch der speciellen Pathologie und Theraphie" (Bd. iv. Abtheil. 2, second half, p. 420, sec. 86, Erlangen, 1859). The results of this analysis Hasse himself quoted from a work of Carl Schmidt entitled "Characteristik der epidemischen Cholera gegenüber verwandten Transsudations-Anomalien," from the section of the work bearing the title "Kritisch-statistische Uebersicht der Transsudationsprocesse" (pp. 140-148, Leipzig and Mitau, 1850).

"Schmidt in his researches arrived at the following results:—

"1. The transudation of the *peripheral* groups of capillaries in the

[1] Hyrtl (J.), "Handbuch der topographischen Anatomie," etc., second edition, Wien, 1853.

central nervous system (pia mater and arachnoid membrane) is essentially different from the *central* transudation (from the choroid plexuses, [in the lateral ventricles]). The former, in relation to the percentage of albumen, and the respective percentage of potassium, sodium, phosphoric acid, and chlorine, must be classified among the remaining transudations abounding in albumen; the reverse of this is the case with the latter [*i.e.* the ventricular liquid].

"2. The liquid which is contained in the brain and in the spinal marrow must not, therefore, on any account be regarded as a mere intercellular liquid obtained mechanically by filtration from the circulating blood-cells, and by a preponderating molecular attraction of the brain substance deprived of their albuminates (fibrine and albumen); but it must be considered as a peculiar secretion, in the formation of which the blood-cells on the one hand, and the morphological elements of the central nervous system on the other, must each take an essential part. The transudations between the membranes of the encephalon, indeed, contain 11·4 of albumen in a thousand parts (the pleural fluid 26·1 to 28·5), while the secretion in the ventricles scarcely contains a vestige of it. In reference to the salts, on the other hand, potassium prevails in the ventricular liquid, and sodium in the secretion of the pia mater and the arachnoid membrane [*i.e.* the sub-arachnoid or cerebro-spinal liquid]; in the former, again, phosphoric acid preponderates in a lesser degree, and in the latter chlorine in a greater degree."

Carl Schmidt's results are corroborated by Leubuscher, Hoppe, and von Gorup-Besanez.

Leubuscher says, "Dr. Hoppe at my request instituted some examinations of transudations. . . . These cases confirm the small percentage of organical elements in the transudation of the ventricles of the brain. . . . What causes this difference in the transudation of organical substances we do not know at present" (Die Pathologie und Therapie der Gehirnkrankheiten, Berlin, 1854, pp. 396, 397).

Prof. von Gorup-Besanez in indorsing C. Schmidt's results says, "The cerebro-spinal liquid contains the usual ingredients of all serous transudations. . . . According to Hoppe the albumen occurs in it chiefly in the modification of what is known as albuminate of soda. . . . While the transudations generally contain the salts belonging to the serum of the blood, the character of the inorganic salts in the liquid secreted from the choroid plexuses makes an exception to the general rule. Thus, according to the observations of C. Schmidt, the salts of potassium and phosphates preponderate in it" (Lehrbuch der physiologischen Chemie, second edition, Braunschweig, 1867).

If now the prevailing salts in the liquid secreted in the lateral ventricles are compounds of potash, while in the cerebro-spinal liquid which is secreted in the clefts of the cerebrum and distilled from the cerebellum into the fourth ventricle, the salts of soda preponderate, it follows that these two liquids do not mix promiscuously in the brain; that, therefore, the valve of Vieussens must be closed in the living brain.

13. In summing up the whole of our investigation into the function of the valve of Vieussens, we see that, essentially, modern science has no facts to offer by which to disprove the theory of Swedenborg, according to which the valve of Vieussens acts as a barrier between the liquids of the cerebrum and cerebellum, and at the same time as a uniting medium between the motions of the two organs. On the other hand, however, we have shown that the facts which modern science has elicited respecting the *living* brain, all tend to prove one of the fundamental principles of Swedenborg's theory of the brain; namely, that, according to which the lateral ventricles and the organs contained between them on the one hand, and between the valve of Vieussens and the sella turcica on the other, constitute in the brain a separate sphere which is in a measure detached from the remaining spheres of the cerebrum and cerebellum. This conglomerate of organs Swedenborg denominates the Chymical Laboratory of the Brain, the office of which is to elaborate the white or purer blood, and of which in the course of time the red blood is developed.

C. *The Functions of the Corpus Callosum, the Fornix, and the Choroid Plexuses.*

14. After separating between the cerebral and cerebellar liquids, our next point will be to confirm by the facts of modern science Swedenborg's theory, that the organs of the chymical laboratory of the brain are engaged in the elaboration of the purer essence of the blood, which Swedenborg calls the white, or purer blood. A general statement of the whole of his theory is found in the following passage:—

"The cerebrum mixes the spirit which has been conceived and distilled in the cortical substance with a certain purer lymph, and weds it to the same, and thereby prepares it, so that it may serve as an interior essence to the blood of the body. For the blood consists of two natures—a spiritual and a natural; the former of which is supplied by the brain, and the latter by the viscera which prepare the chyle. Therefore the cerebrum is a gland by eminence—*par excellence*—or is the model of conglomerate glands, and consequently is an *illustrious chymical laboratory.* It receives, indeed, a spirituous essence chiefly from the [cortical] glandules of the posterior region of the surface of the cerebrum, and through fibres it carries the same into the corpus callosum, and from that body through the fornix into the lateral ventricles, where through the offices of the choroid plexus it is mixed with a purer lymph. From the lateral ventricles this lymph is received by the third ventricle, and thence through the infundibulum is conveyed into the pituitary gland, which is the conglobate gland of the cerebrum: and thence by three different ways it is carried into the jugular veins: and after it has undergone there a second mixture, at the end of that vein, or of the subclavian vein, it meets with the chyle of the body which is conveyed thither by the thoracic duct. This is the origin of the twofold nature of which the blood consists" (i. no. 104*n*).

This general statement of Swedenborg's theory respecting the generation of the purer blood in the chymical laboratory of the brain, is supplemented by the following additional statement concerning the action of the corpora striata :—

"The corpora striata contribute their share also to the chymical action of the cerebrum; for they constitute the bottom of the lateral ventricles. They excite the choroid plexuses to action, and allow the infundibulum to pass through them, so as to control and accommodate its action. The corpora striata, or the appendage to the cerebrum, thus excites to action, and to proper operation, the cause which is of the cerebrum. The cerebrum simply pours out the spirit, but the corpora striata express from the choroid plexuses a lymph to which the spirit is being coupled. This lymph must be called the purer blood; for the animal spirit is attached to it as the blood-globule to its serum" (i. no. 70).

The objection that in dead bodies the lateral ventricles are frequently found empty—which fact has given rise to the opinion that in the living brain also these cavities are exempt from moisture—Swedenborg meets by the following argument :—

"This moisture and irrigation [*i.e.* the lymph in the ventricles] in dead brains sometimes does not appear. For in the death-struggle the brain with its arteries, plexuses, and members expends its last forces in the re-creation of the blood, and thus in the recuperation of the life of the blood by the restoration of the body. And this it does by stimulating its own organic forces into the most violent motion, and by expelling, as long as it is able to do so, the spirits while there are any" (i. no. 512).

We shall now follow up the successive steps in the elaboration of the purer blood in the several organs belonging to the chymical laboratory of the brain, commencing with the corpus callosum.

1. *The Function of the Corpus Callosum.*

15. The part taken by the corpus callosum in the generation of the purer blood is detailed by Swedenborg in the following passages :—

"This work [namely, that of furnishing the animal spirit for the uses of the blood] is in charge of the fibres of the convex or posterior portion of the cerebrum ; just as the task of building up the motory and sensory organs of the body is in charge of the fibres of the anterior part. . . . For where the great fissure of the cerebrum [Sylvian fissure] with the lobes ceases, this [convex or posterior] portion begins. The whole of the fibre of this region, namely, is conveyed towards the corpus callosum, a part also towards the fornix" (i. n. 91).

In speaking of the fibres of the fornix, he says, "These fibres are not allowed forth any further, nor do they return to their origins, but they stop there and are consumed there ; wherefore the spirituous juice which they carry is not put to any other uses" (i. no. 443).

16. On the subject of the "animal spirits" modern science is silent; nay, it ridicules the anatomists and physiologists of the last century for their faith in the animal spirits. And yet the more thoughtful among its disciples feel the necessity of admitting the existence of some nervous force analogous to that of the animal spirits. So, for instance, Dr. Todd in his treatise on the "Anatomy of the Brain," etc. (London, 1845), says, "The nervous force is a polar force, resembling electricity in the instantaneousness of its development and in the rapidity of its propagation, but differing from it in several important features" (p. xi). The animal spirits will be found thoroughly discussed in the light of modern science in our note on "Muscular Irritation" in vol. iv. of the present work.

Leaving alone for the present the question as to the character of the nervous force contained within the fibres of the brain, we shall find no difficulty in confirming by the aid of modern science that the fibres which enter into the composition of the corpus callosum are expended upon the chymical laboratory, and are not projected into the body in the form of nerves. But before entering upon this subject we are obliged to protest against the unnatural manner in which the question as to the real homestead of the nervous fibres is generally treated in the modern text-books on the Anatomy of the Brain. For, instead of exhibiting the nervous fibres as emanating from the cerebrum and cerebellum, their birthplace, the text-books present them as making their way from the spinal marrow and the medulla oblongata into the corona radiata, and thence into the convolutions of the cerebrum and into the grey substance of the cerebellum.

Instead, therefore, of finding in the text-books statements to this effect, that certain convolutions send their fibres into the corpus callosum and the fornix, these bodies are exhibited as despatching their fibres into such and such lobes and convolutions. And thus instead of stating that the fibres take their departure from the various convolutions of the brain charged with a precious nervous force, the impression is rather conveyed as if the fibres carried a certain nervous force from the circumferences of the nervous system towards its centres.

In order to understand the function of the corpus callosum, and to do justice to Swedenborg's theory, the whole of this process has to be reversed: the convolutions of the cerebrum must be regarded as the centres and sources of the nervous system, and the fibres must be looked upon as proceeding thence into the corpus callosum and the fornix, through the medium of the centrum ovale or the corona radiata. Swedenborg is just as much justified in presenting the medullary portion of the cerebrum as emanating from the grey substance of the convolutions, as modern science in describing the same as proceeding from the medulla oblongata and the corpus callosum towards the convolutions. Nay, Swedenborg is much more justified in his presentation of the subject, because it is analogous to the method of describing a circle from its centre; while the method followed by modern science is identical with the plan of seeking a centre from the circumference, which is not only a more difficult undertaking, but also one which is opposed to the natural order of things. With this stricture of the method resorted to by modern science in acquainting us with the facts which it has learned respecting the direction of the fibres in the brain, we proceed with our subject.

Science at one time was in doubt whether the fibres which centre in the corpus callosum belong to an independent system of fibres, or whether the corpus callosum with its fibres is simply a collateral production of the peduncular fibres of the cerebrum, that is, of those fibres which pass through, and also originate in, the corpora striata and the optic thalami.

Foville[1] described the corpus callosum as "a commissure formed by the peduncular expanse," the fibres of which do not radiate into the convolutions. Cruveilhier[2] also holds that "the two sets of fibres [namely, those of the corpus callosum, and those of the corpora striata and the optic thalami] are continuous" (p. 1009). If the view set forth by these gentlemen were true, the fibres of the corpus callosum,

[1] Foville, Traité complet de l'Anatomie et Physiologie et de la Pathologie du Système Nerveux-cérebro, Paris, 1844.

[2] Cruveilhier (J.), Descriptive Anatomy, in Tweedie's "Library of Medicine," London, 1842.

through the medium of the medulla oblongata and the spinal cord, would be continued into the nervous system of the body, and they would not expend their animal spirit or their "nervous force" in the organs belonging to the chymical laboratory of the brain, as is maintained by Swedenborg.

Their view, however, is opposed by Reil,[1] Herbert Mayo,[2] Arnold,[3] Solly,[4] Hirschfeld,[5] Meynert,[6] and by the majority of modern authors, who maintain, on the basis of observation, that the fibres which enter into the composition of the corpus callosum form a system independent of that which is produced by the peduncular fibres of the cerebrum; and they further maintain that the fibres of the corpus callosum are continued directly into the substance of the convolutions.

Hirschfeld,[7] in opposing the views advocated by Foville and Cruveilhier, says, "This organ [the corpus callosum] is formed by a plane of layers of fibres which are placed one above the other, which are horizontal, curvilinear, and which embrace one another; their number being indeterminate. This plane of fibres, in its circumference, and on the level of the optic thalami and the corpora striata, becomes the point of departure for fibres radiating in all directions. The one, ascending, direct their course towards the convexity of the cerebrum; the other, descending, direct themselves towards the base. In fine, the horizontal fibres, forming the intermediate body of the corpus callosum, spread and radiate in an anterior, posterior, and also in a lateral direction" (see above, p. 445).

In summing up the results of his investigations, he says:[8]—

"1. The corpus callosum is constituted by fibres which terminate in the convolutions, or which emanate thence.

"2. The fibres of the lower surface of the corpus callosum seem to be continuous on either side with the radiating fibres of the cerebral

[1] Reil (J. C.), "Archiv der Physiologie," edited by himself and Autenrieth, vol. ix., Halle, 1809. An abstract of his articles on the structure of the organs of the brain was published by Herbert Mayo in English, in his "Anatomical and Physiological Commentaries," 2 numbers, London, 1822 and 1823.

[2] Mayo (Herbert), "Outlines of Human Physiology," fourth edition, London, 1837.

[3] Arnold (F.), Bemerkungen über den Bau des Hirns u. Rückenmarks, Zürich, 1838.

[4] Solly (Samuel), F.R.S., "The Human Brain; its Structure, Physiology, and Diseases," second edition, London, 1847.

[5] Hirschfeld (L.), "Névrologie et Esthésiologie. Traité et Iconographie du Système Nerveux et des Organes des Sens de l'Homme." 2de édit., Paris, 1866.

[6] Meynert (Theodor), "The Brain of Mammals," in Stricker's "Manual of Histology," American translation, edited by A. H. Buck, New York, 1872.

[7] "Névrologie," etc., second edition, p. 125.

[8] *Ibid.*, pp. 126, 127.

peduncles; but this continuity is not direct; especially not so in the posterior parts, on account of a raphë existing in the place where the two orders of fibres meet.

"3. There is a decussation of fibres on the level of the thickened, longitudinal borders of the corpus callosum; but this decussation exists between the peduncular fibres and the corresponding fibres of the corpus callosum.

"4. The cerebral peduncles and the corpus callosum send fibrous expansions into the convolutions, so as to form their nuclei.

"5. The corpus callosum is a real commissure of the two hemispheres, and not, as Foville holds, a commissure of the cerebral peduncles" (*ibid.*, p. 446).

Solly,[1] in commenting on this same subject, says: "Mayo, in his 'Outlines of Physiology,' has very clearly proved the manner in which Foville's mistake has occurred, and shown that that gentleman in producing the appearance which induced him to adopt the opinion stated above, breaks through the point where the fibres from the columns [that is, from the medulla oblongata] intersect the commissural fibres [that is, those of the corpus callosum], and then follows the columnar [peduncular] fibres in their course to the striated bodies. Rolando advances the same opinion regarding the composition of this commissure as Foville, quoting the opinions of Tiedemann in support of his own. Notwithstanding such weighty testimony, I am convinced by repeated dissections that they have been deceived, most probably as explained by Mayo in his 'Physiology'" (see above, p. 443).

Arnold,[2] in concluding his arguments in favour of the commissural use of the corpus callosum, says, "By my investigations I have been induced to decide in favour of the views propounded by Gall, Ackermann, Reil, and Burdach, who maintain a decussation of the fibres of the corpus callosum with those of the corona radiata, and a *contiguity* of the two sets of fibres; and to reject the opinion pronounced by earlier and modern anatomists, by Varoli, de la Rue, Willis, Ridley, Malacarne, Mayer, Cuvier, Autenrieth, Tiedemann, according to whom the fibres of the cerebral peduncles are *continued* into the corpus callosum" (see above, p. 442).

Meynert[3] says, "As regards the system of the corpus callosum (trabecular system), microscopic examination of cross-sections from small mammal brains, among which that of the bat has been made the subject of careful investigation by Oellacher, confirms the opinion expressed by Arnold, that the corpus callosum is made up solely of

[1] "The Human Brain," second edition, p. 252.
[2] "Bemerkungen," etc., pp. 72, 73.
[3] "The Brain of Mammals," in Stricker's Histology, American edition, p. 676.

commissural fibres, connecting symmetrical territories of the cortices of the two hemispheres, and not, as Foville wished to prove, of fibres of the projection system, crossing the middle line to enter the ganglia of the opposite side" (see above, p. 446).

17. After thus showing that the fibres which enter into the composition of the corpus callosum are not continued into the cerebral peduncles, and thereby into the nervous system of the body; that these fibres therefore remain confined to the corpus callosum, and to those organs with which it is immediately connected, we approach the question whence the corpus callosum really derives its fibres. But before entering upon this subject we must quote Swedenborg's views on the use of the corpus callosum as a commissure. He says, "The corpus callosum unites and distinguishes in a general way all the members and organs which lie scattered as it were throughout the large palace of the cerebrum, although wedded to distinct functions, . . . a part of which are hidden in its interior organism, and others are exposed on its surface. To some of these it is subjected, upon others it is superimposed, and between others it is inserted. It is *subjected* to the great interstice which separates the two hemispheres, and consequently to the falx cerebri, and to both its sinuses; and likewise to the margins or shores of the convoluted cerebrum raised as it were into waves; of this the corpus callosum is as it were the mainland furnishing to it a safe port. It is *superimposed* upon the third ventricle, viz. upon the middle cavity of the longitudinal axis, and likewise upon the ceilings of the larger or lateral ventricles. It is, however, *inserted* or thrown in between all the parts, separating those on the left side from those on the right, and likewise by outspread wings distinguishing the higher parts from the lower. It is as it were a general lever, stretching its arms obliquely upwards and downwards, and it rests upon the body of the fornix where its fulcrum is. In this way it poises weights, sustains motions, and *unites* the forces of the active cerebrum cut up into so many cavities, sulci, and clefts. Otherwise all the individual parts would lapse into chaos, which being indistinct and undetermined is equivalent to nothing" (i. no. 427).

While thus admitting to the full the commissural use of the fibres of which the corpus callosum is composed, Swedenborg, nevertheless, maintains that this is not the only use which these fibres perform; and he further holds that by the alternate motion of expansion and constriction to which this body in company with all the other organs of the brain is subjected, the animal spirit, or the "nervous force" which circulates through its fibres, is ejected from these fibres into those organs which constitute the chymical laboratory of the cerebrum. On this account, therefore, Swedenborg himself declares that it is of the first importance for us to know whence these fibres derive their supply of animal spirit or of "nervous force;" or in other words, from which provinces of the cerebrum these fibres emanate. He says:—

"The question, however, arises, Whence does the corpus callosum derive its fibres and roots? It is generally admitted that each fibre originates from its cortical or grey glandule; it is also admitted that no fibre lapses into the middle of this belt, where the striæ are parallel; but that they all pursue their course from their origins through the spread wings. The fibres which are thus led forth and pursue their course are continued into the belt, and from its borders are carried transversely towards the raphë in the middle, and again reciprocally from the raphë towards the borders. These spread wings are inrooted in the posterior extremities, or in the substances of the lowest lobe of the cerebrum, that is, in those which rest upon the tentorium and cerebellum; into which there is even a good deal of grey substance inserted. These spread wings are also inrooted, although more sparingly, in the upper lobes of the cerebrum. In this wise the corpus callosum derives its fibres from the upper part of the anterior, and from the lower part of the posterior cerebrum; but it does not derive them from the cortex which occupies the upper surface of the cerebrum near the division of the hemispheres, nor from that which occupies its forepart—prora. On this account also the corpus callosum connects the upper parts with the lower, and those of one side with those of the other; and it thus forms a knot not unlike the Gordian, which cannot be solved except by the dissection of its body. By its means also the hemispheres, and the parts contained within the hemispheres, intercommunicate with one another" (i. no. 428).

In another place Swedenborg says, "The fibre of the posterior region [of the cerebrum] does not pass into the corpora striata, but into the corpus callosum, and thence towards the chymical organs or members of the brain" (i. no. 71). And again, "The whole of the fibre of this region is conveyed towards the corpus callosum, a part also towards the fornix" (i. no. 91).

18. In these passages Swedenborg lays down the following points:—

(1) The spread wings of the corpus callosum are inrooted in the lowest lobes of the cerebrum, that is, in those which rest upon the tentorium and cerebellum.

(2) They are inrooted also, although more sparingly, in the upper lobes; not, however, in the substance near the division of the hemisphere, nor in that which occupies the forepart of the cerebrum.

(3) A portion of the fibre of the posterior region is also conveyed towards the fornix.

From these positions it follows that the influx of fibres must be more plentiful into the posterior extremity of the corpus callosum than into its anterior part; that therefore the posterior end must be broader and thicker, and in short more developed than its anterior portion.

Let us now see what modern science has to say to these positions.

Reil[1] says, "The posterior and broader end of the corpus callosum is much more pushed back towards the middle than the anterior extremity, and all its fibres, *which spread out laterally into the posterior lobes* of the cerebrum, are there gathered into one bundle. Hence the greater bulk of the corpus callosum in that place. The fibres which accumulate there are reflected backwards or downwards, and fasten themselves on the lower or interior surface of the corpus callosum, where they give rise to a superadded thickened border (splenium or bourrelet) which forms the posterior end of the part called *lyra*. . . . From that hinder part of the corpus callosum extend two thick bundles of medulla in the shape of a forceps, which outside of, and beyond, the posterior crura of the fornix, make their appearance in the posterior cornu of the lateral ventricles, forming there the hippocampus minor (or calcar avis), and which are continued almost in a horizontal direction over the posterior cornu to its extremity; and farther still *to the extremity of the posterior lobe of the cerebrum*. . . . These bundles of medulla are partly continuations of the upper surface of the corpus callosum, and partly of the superadded thickened border underneath. . . . The interior layer of the posterior part of the corpus callosum is continued to the outer wall of the posterior cornu of the lateral ventricle. This I call *tapetum*. . . . Another part of the *tapetum* inclines downwards through the mouth of the middle or descending cornu, and invests the lowest part of its outer wall down to the obtuse end of this cornu" (see above, p. 440).

In another place he says, "The posterior thickened border of the corpus callosum [splenium] extends also laterally; but these radiations pass into the bottom walls of the posterior and descending cornua of the lateral ventricles . . . . As the hinder portion of the corpus callosum is continued forceps-like *into the posterior lobes of the cerebrum*, its anterior portion extends also into the anterior lobes. The structure at both ends is the same" (*ibid.*, vol. xi. p. 351).

As to the production of a portion of the fibre of the posterior lobes into the fornix, Reil says,[2] "Immediately in front of the posterior thickened border of the corpus callosum a bundle of fibres leaves the interior edge of the fornix, making directly for the above thickened

[1] "Archiv der Physiologie," vol. xi., Halle, 1809; in an article entitled "Das Balkensystem oder die Balkenorganisation des Gehirnes" (The System of the Corpus Callosum, or the Organization of the Corpus Callosum in the Brain), pp. 179-181.

[2] "Archiv," etc., vol. ix. p. 109.

border; it penetrates between it and the body of the corpus callosum, into the forceps-like productions of the said body, which are lost in the convolutions of the posterior lobe" (see above, p. 477).

Solly[1] expresses himself as follows on the origin of the fibres of the corpus callosum: "The fibres of the front, sides, and superior part of the anterior lobe pass backwards and inwards to the distance of an inch and a half from the anterior extremity of the cerebrum, where they cross the fissure which divides the two hemispheres. The anterior edge of the commissure [*i.e.* of the corpus callosum] consequently forms the posterior boundary of the anterior part of the fissure. In this situation the fibres are folded one upon another; so that on a transverse section of the 'corpus callosum,' the anterior edge appears thicker than the centre, *though it is not so thick as the posterior edge.*

"The fibres from the convolutions of the upper part and sides of the middle lobes run downwards and inwards, being joined by those from the convolutions at the base of the brain." In a drawing accompanying this description of the fibres of the corpus callosum Solly shows that these fibres proceed from the *interior* portion of the upper lobes, and not from that which is nearest to the central fissure, and hence to the falx cerebri; and in the description of his drawing, calling attention to this fact, he says, "It will be seen that these fibres ascend to the convolutions *above the mesial line,*" *i.e.* above the mesial or middle line of the hemispheres themselves.

In respect to the formation of the posterior end of the corpus callosum, Solly says, "Then, again, from the upper, under, and posterior surface of the posterior lobe [the fibres] run forwards and inwards to cross the fissure at the distance of nearly three inches from the posterior extremity of the cerebrum. The fibres from such extensive surfaces are necessarily numerous, and give a considerable thickness to the posterior edge of the 'corpus callosum'" (see above, p. 442 *et seq.*).

As to the origin of some of the fibres of the fornix Solly says, "Some of its fibres run back to be connected with the posterior lobes" (*loc. cit.*, p. 259). On the same subject Cruveilhier says, "Is the fornix an antero-posterior commissure? In support of this opinion I may state that I have seen the right half of the fornix atrophied in a case of destruction of the convolutions corresponding to the tentorium cerebelli" (*loc. cit.* p. 1010).

From the facts adduced by the above authorities it appears—

(1) That the posterior extremity of the corpus callosum is thicker

[1] "The Human Brain," second edition, pp. 251, 252.

and broader than its anterior extremity; that therefore more fibres enter into the composition of this body from the posterior than from the anterior lobes of the cerebrum.

(2) That the fibres which enter into the posterior extremity of the corpus callosum are derived chiefly from the posterior lobes.

(3) That the fibres which enter from the middle and anterior lobes are derived from the interior convolutions of the cerebrum, or from those which are "in the mesial line" of the hemispheres, and not from those which are nearest to the great fissure, and hence to the falx cerebri.

(4) That a part of the fibres of the posterior extremity of the cerebrum passes also into the fornix.

These positions, however, are identical with those which Swedenborg claims in respect to the derivation of the fibres of the corpus callosum.

2. *The Function of the Fornix.*

19. As to the origin of the fibres of the fornix, and the relation which that organ occupies in respect to the corpus callosum, Swedenborg says, "In the body of the fornix the fibre of the corpus callosum is concentrated, and thence it is again ramified, in order that it may perform its functions" (i. no. 37).

Again he says, "The cerebrum concentrates itself from every quarter towards the body of the fornix; namely, from the corona radiata into the ceiling of the lateral ventricles, and thence through the corpus callosum into the body of the fornix; likewise through the 'centrum semicirculare' [inner capsule] and the tænia semicircularis towards its lower part, that is, towards the anterior roots or pillars of the fornix. . . . Therefore the body of the fornix seems to derive its origin from the whole substance of the cerebrum flowing thither from above and from below. For that this organ is a process of the corpus callosum or its fimbriated appendage, is scarcely questioned by any one; nor is there any doubt that the 'centrum geminum semicirculare' [inner capsule] flows into it from below." To this he adds afterwards, "The posterior corona radiata, or the posterior edges of the cerebrum, . . . extend thither through the tænia semicircularis, which, according to Vieussens, is said to originate from the roots of the fornix, and consequently from the 'centrum semicirculare'" (i. no. 445*d*).

On the question, How is the spirit contained in the fibres of the corpus callosum derived into those of the fornix? Swedenborg says, "The medullary substance which through the ceiling of the lateral ventricles is derived into the corpus callosum, is for the most part carried by parallel fibres which are confasciculated, towards the medullary raphë in its middle; and thence towards the body of the fornix. Partly also it is carried into the lateral ventricles, through the posterior crura of the fornix which are on the optic thalami" (i. no. 430*c*).

Again he says, "The animal spirit following the continuous course of the fibres, at last seems to be determined from the corpus callosum towards the body of the fornix. Thither, namely, the nexus tends, in accordance with which we have spun the thread of our induction; for we are not allowed to explore the ways by injections, as in the case of blood-vessels; since the fibres do not become enlarged by degrees like the vessels, nor is there any liquid analogous to the animal spirits, with which they might be injected" (i. no. 430*d*).

As to the manner, however, by which the fibres of the corpus callosum are made to discharge their contents, Swedenborg says, "The fibres of the medullary substance terminate in the surface nearest to the corpus callosum, or in the very ceiling of the lateral ventricles, into which they are *reflected*" (vol. i. no. 430*b*). And in another place he says, "The fibres of the medullary substance of the cerebrum on arriving there [*i.e.* in the corpus callosum], are reflected, and in consequence of this, open themselves and become divided" (*ibid.*, no. 430*e*).

20. The modern authors on the anatomy of the brain are very much divided on the question of what becomes of the fibres which enter into the composition of the corpus callosum. Hirschfeld[1] is decidedly in favour of the view presented by Swedenborg. In speaking of the upper surface of the corpus callosum, he says, "In the middle of this surface there is a furrow running from before backwards, which on each side is bounded by *longitudinal striæ*, called the 'longitudinal nerves of Lancisi.' . . . The striæ intersect perpendicularly some transverse striæ underneath them." In respect to the lower surface of the corpus callosum which is turned towards the fornix, he says, "On the median line of this surface there is a raphë (*raphe inferior*), which is intersected perpendicularly by transverse fibres. The fibres of the one side of the corpus callosum are *not continuations of those of the other side; because they are isolated from one another by the raphë in the middle.* Besides, the fibres on the lower side are less pronounced than those on the upper" (see above, p. 444).

In another place he speaks of the "oblique fibres" of the corpus callosum as being "reflected."

Other authors, and among them Reil, hold that the raphë only *compresses* the transverse fibres, but does not cut or stop their further progress. He says, "Between the raphë of the upper, and that of the lower side, the parallel striæ of the corpus callosum pass through uninterruptedly, yet in the middle they are more closely drawn

[1] Hirschfeld (L.), "Névrologie," etc., second edition, Paris, 1866, pp. 122, 123.

together, and interlaced with one another" (Archiv d. Physiologie, etc., vol. ix. p. 173).

According to Swedenborg there are two spirituous liquids distilled in the brain, and circulating through its white or medullary substance; one of these is the animal spirit or the "nervous force," which is elaborated in the glandules of the grey substance, and contained *in* the individual fibres; the second is the so-called nervous juice which exudes from the capillaries in the brain, and circulates through the interstices *between* the fibres. Both these liquids are set free by the breaking up of the medullary fibres in the corpus callosum; and each of these liquids is committed by the corpus callosum to the fornix; the former, that by the fornix it may be distilled into the choroid plexuses, and the latter, that the fornix may convey it into the optic thalami.

In what particular manner the animal spirit is derived from the corpus callosum into the body of the fornix, Swedenborg does not specify. As the fibres of the corpus callosum in the middle of that body run at right angles with those of the fornix, the latter fibres cannot be said to be derived directly from the transverse fibres of the corpus callosum. The transverse fibres of the corpus callosum, however, become oblique, and enter that body at a more or less obtuse angle, as they approach its anterior and posterior edges—the *genu* and the *splenium.* Nay, the fibres which enter the forceps-like projections of the "genu" and "splenium" of the corpus callosum, according to Reil (see above, p. 736), are produced in a longitudinal direction into the anterior and posterior lobes of the cerebrum; so that in pursuing their course through the body of the corpus callosum they would do so in a longitudinal, and not in a transverse direction. These fibres which thus run in a parallel direction with the fornix would naturally find their termination in the fornix; swelling its bulk of longitudinal fibres, and conveying thither the animal spirit which accumulates in the corpus callosum, and which they receive from the transverse fibres of that body by a system of inosculation. That there is such a communication between the transverse fibres of the corpus callosum and the longitudinal fibres which pass thence into the fornix, receives support by the following statements which Reil makes respecting the longitudinal striæ of the corpus callosum. He says, "In a number of places it looks as if the fibres of the longitudinal striæ [the nerves of Lancisi] passed into the corpus callosum, and, on the other hand, as if fibres of the corpus callosum entered the striæ" (Archiv d. Physiologie, ix. p. 173). He also speaks of the transverse fibres of the corpus callosum as being "more intimately interwoven" in the middle of that organ: by which he means that the parallel fibres are there more or less dissolved into fibrils, and intercommunicate; and hence, when necessary, communicate also with the longitudinal fibres of the corpus callosum, which enter into that body from the "genu" and "splenium," and are continued into the fornix.

21. The mode in which the nervous juice which circulates in the interstices between the fibres is gathered up in the corpus callosum, Swedenborg describes as follows: "*The nervous juice which courses between the fibres is sent towards the optic thalami.* . . . The fibres of the medullary substance of the cerebrum on arriving there [*i.e.* in the corpus callosum] are reflected, and in consequence of this open themselves and become divided. . . . When the fibres of the cerebrum are thus divided, it seems as if the liquid contained between the fibres must necessarily escape thence, and consequently pursue its way whither a similar compages of fibres tends, that is, towards the so-called optic thalami, into which they insert themselves. And this must be the case so much the more, because the texture of the filaments seems to be such that at each alternate time when the ventricles are expanded, they are drawn apart like a net either in width or in length. That such a juice as is called nervous, and which together with an oily lymph contains some spirituous quality, is carried towards the optic thalami, is confirmed also by the longitudinal striæ of which Winslow and Lancisi speak, and which, like two nerves, or two protruding borders, cross at right angles the parallel fibres of the corpus callosum, and then at last are lost in the optic thalami. These medullary striæ are said to pass [at the bottom of the great fissure of the cerebrum] under the arachnoid membrane, which is a general vessel or duct for that juice or lymph, or which conveys all that superfluous juice where exigency requires it" (vol. i. no. 430*e*).

This passage, detailing the function of the longitudinal striæ, is taken from Swedenborg's first work on the brain, which he wrote before the year 1738. In the second work, which he prepared between 1740 and 1742, he trimmed down his analysis closely to the acknowledged facts of the science of his day; and as he felt that these facts did not bear out completely his theory respecting the function of the longitudinal striæ, rather than propound a theory not wholly borne out by facts, he cancelled in his second work the whole of his argument respecting the use of the longitudinal striæ. Fortunately, not only the whole of Swedenborg's second, but also the greater part of his first, work on the brain have been preserved, and in the light which science since his time has elicited respecting the brain, we are able to substantiate a number of those points which he had been obliged to give up for lack of a sufficient experimental support.

Among these points is his theory of the function of the longitudinal striæ.

The use of the longitudinal striæ, according to the above passage, consists in this, that while the animal spirit or the "nervous force" contained in the fibres of the corpus callosum, by the alternate expansion and contraction of that organ, through the body of the fornix is urged towards the fimbriated edges of the fornix, whereby it is connected with the choroid plexuses—the nervous juice, or the liquid circulating between the fibres of the corpus callosum, is gathered up by the longitudinal striæ, and conveyed by them into the optic thalami. "These longitudinal striæ," Swedenborg says, "are like two nerves or two protruding borders, which cross at right angles the parallel fibres of the corpus callosum, *and then at last are lost in the optic thalami.*" If we explain the italicized passage so that these longitudinal striæ enter into the composition of the body of the fornix, where they increase the substance of those of its fibres which by its anterior and posterior pillars and crura descend into the optic thalami, Swedenborg's theory of the function of these striæ receives the full support of the facts of modern science.

Concerning the termination of these striæ which are both on the external and internal surfaces of the corpus callosum, Reil[1] expresses himself thus: "The *raphë externa* [the striæ on the external surface] comes from the back of the *rostrum* of the corpus callosum; it follows the course of that organ upwards bending around its knee or *genu*, continues its course through its middle, increases in bulk, and spreads out more as it approaches the posterior edge, around which it bends; and it disappears on the superadded thickened border (*splenium* or *bourrelet*) in the neighbourhood of the *lyra*"—and thus where the corpus callosum rests on the body of the fornix.

Of the longitudinal striæ on the interior surface of the corpus callosum he says: "On the interior surface of that body directly opposite the former band, a similar stria, the *raphë interna*, pursues its course over the septum lucidum and the fornix. This stria also is reflected downwards with the corpus callosum, and girds together lengthways, on its interior side, the singular *genu* of that body. It has dug out for itself on its surface a shallow furrow, to the edges of which is fastened the septum lucidum. In a posterior direction it passes over the fornix, entering far into the posterior pencil-like extremity of the ventricle of the septum. *There it mixes with the fibres of the fornix* which are stretched over the interior area of the lyra; and from the anterior angle of the trigon it goes backwards directly to the thickened border, between which and the corpus callosum it is lost" (see above, p. 435).

[1] "Archiv der Physiologie," vol. ix. pp. 172, 173.

That there is an active communication between the longitudinal striæ and the parallel fibres of the corpus callosum, appears from the further description of Reil, where he says, "In a number of places it looks as if the fibres of the longitudinal striæ passed into the corpus callosum, and, on the other hand, as if fibres of the corpus callosum entered the striæ" (*ibid.*, p. 436).

And that the liquid which circulates between the fibres is then and there expressed, appears from his further statement, that "the parallel bars of the corpus callosum in the middle are drawn more closely together by the longitudinal striæ on either side, and more intimately interwoven."

22. The homestead of the anterior roots of the fornix, according to Swedenborg, is the "centrum semicirculare" or "inner capsule" (see vol. i. no. 445*d*). He also indorses Vieussens' statement, that "the tænia semicircularis originates from the roots of the fornix, and consequently from the 'centrum semicirculare.'"

Both these statements are clearly proved by Jung,[1] who after describing the "centrum circulare" or "inner capsule" as a border substance between the inner nucleus of the corpora striata and the optic thalami, says, "The descending root of the fornix evidently arises from a sudden coalition of a number of medullary fibres from the border substance ['centrum semicirculare']. For further than this substance it can never be traced. The first medullary fibres which enter into the composition of the root must be exceedingly delicate and yielding; for the root breaks off most easily at its place of birth" (see above, p. 480).

"In its very beginning," he says further, "this root appears of the same width as throughout the whole of its course through the optic thalamus;" thus showing that its object is not so much to convey fibres from the optic thalami towards the body of the fornix, and thereby towards the corpus callosum, as to serve in the capacity of a channel for conveying the nervous juice—the liquid circulating between the fibres—from the corpus callosum towards the optic thalami.

The descending root of the fornix, as is shown by the modern text-books on anatomy, by twisting back upon itself forms a loop in which, on the lower surface of the cerebrum, there lies a ganglion, the corpus albicans or candicans, which is also called the bulbus fornicis. From this ganglion the root starts upwards, as the ascending root of the fornix, which finally terminates in the body of the fornix. The corpora candicantia—for there is one for each of the ascending roots of the fornix—are thus ganglia constituting a basis for the anterior pillars of the fornix. Into these ganglia the pillars or roots of the

[1] Jung (K. G.), "Ueber das Gewölbe in dem menschlichen Gehirn" (the Fornix in the Human Brain), Bâle, 1845.

fornix convey the nervous juice collected from the corpus callosum by the longitudinal striæ; and by the expansile and constrictile motion of these ganglia this juice is forced into the medullary substance of the optic thalami.

The mechanism by which this is done is described by Meynert[1] as follows: "The ascending crus fornicis after making an S-shaped curve in order . . . to reach a somewhat external part of the thalamus, passes directly forwards and upwards, and forking into two parts—as may be readily seen in cross-sections—spreads out its fibres in the superior nucleus of the thalamus, whose anterior extremity gives rise to the protuberance on the surface of the thalamus called tuberculum or genu anterius" (see above, p. 484).

A further supply of this nervous juice is conveyed from the corpus callosum to the optic thalami by the inner edges of the posterior crura of the fornix, which are fastened to the upper medullary zones of the thalami during their course through the posterior and descending parts of the lateral ventricles.

23. A third liquid secreted in the cerebrum, and hence conveyed towards the corpus callosum by the fibrous expanse of the cerebrum, according to Swedenborg, is "that grosser liquid which often clogs up the anfractuosities and the medulla of the cerebrum, and which is derived by its pathways towards the olfactory nerves." The meeting-ground of this liquid, says Swedenborg, is in front of the anterior pillars of the fornix, or near the foramen called after Monro. "For the middle centrum ovale [*i.e.* the corona radiata] and the 'centrum geminum semicirculare' [inner capsule] meet in a certain expansion before the base of the fornix; and thence the medulla, after it has become united as it were, goes in a straight direction to the olfactory nerves; this seems to be a kind of royal road for the liquid which cannot pass through this medullary expansion before the base of the fornix" (vol. i. no. 445*b*). In another place he says, "Here in the meeting-ground [near the foramen Monroi] there is a kind of medullary expansion into which flows the substance which on either side encloses the corpora striata, in order that thence it may pass all together towards the olfactory nerves; which appears very conspicuously in the brains of calves and sheep" (vol. i. n. 445*d*).

Whither this liquid is conducted by the olfactory nerves does not concern us here, but, in a separate note on the Olfactory Nerves, it will be discussed in the light of modern science. The point that is of interest here is the manner in which that liquid is collected from the corpus callosum. Swedenborg is silent on this subject, because he lacked a knowledge of those scientific facts which since his time have

[1] In Stricker's "Handbook," etc., American edition, p. 691.

been discovered by Reil. If Swedenborg had been acquainted with the "covered bands of Reil," he would no doubt have assigned to these bands the function of collecting the above grosser liquid from the substance of the corpus callosum.

Concerning these bands Ellis says,[1] "Under the convolution of the corpus callosum lies a narrow band, 'the covered band of Reil,' which bends down before and behind the corpus callosum" (p. 237). The relation of these bands he describes thus, "Along the centre is a ridge or raphë, and close to it are two or more longitudinal white lines (nerves of Lancisi). Still further out may be seen other longitudinal lines (covered band) beneath the convolution of the corpus callosum" (p. 238).

These covered bands Prof. Reil[2] describes as "two firm, long, and permanent strands of longitudinal medullary fibres which like the 'external raphë' are stretched out immediately on the body of the corpus callosum" (see above, p. 437). He says further, "If the convolutions in all the places specified above are raised up, the 'covered bands' are discovered there immediately, in the form of flattened worms which can easily be peeled out." That these "covered bands" terminate in the medullary expansion in front of the anterior pillars of the fornix pointed out by Swedenborg, Prof. Reil[3] shows in the following passage: "Both 'covered bands' make a visible depression or furrow upon each side of the corpus callosum. They curve around that body in front, draw nearer to one another on the *rostrum*, grow narrower and more delicate, at last become like threads, . . . and finally terminate in the angle which the end of the rostrum makes with the peduncles of the corpus callosum. In the same angle also terminate the longitudinal convolutions [gyri fornicati] which accompany the corpus callosum, and wind around the rostrum" (see above, p. 437), and between which and the external surface of the corpus callosum, the "covered bands" lie.

The continuation of Swedenborg's "meeting-ground in front of the base of the fornix," with the olfactory nerves, is shown by the following quotation from Reil:[4] "This convolution [that which rests on the 'covered bands of Reil,' and which terminates at the end of the genu of the corpus callosum together with the 'covered bands'] accompanies the *genu* . . . as far as the 'anterior perforated space,' and *then passes over into the convolution which forms the inner side of the sulcus containing the olfactory nerve*" (see above, p. 436).

[1] Ellis (G. V.), "Demonstrations of Anatomy," seventh edition, London, 1874.
[2] "Archiv der Physiologie," vol. ix. pp. 173, 174.
[3] "Archiv," etc., vol. xi. p. 352.
[4] "Archiv," etc., ol. ix. p. 173.

That the "covered bands" exert an effect on the corpus callosum, such as would naturally result from the withdrawal of some kind of liquid from the corpus callosum, appears from the following statement of Reil: "Under these bands the texture of the corpus callosum is altered; the distinction into parallel striæ or bars is lost on its exterior surface; the stamina of which they consist become more delicate, and they are more closely pressed together" (see above, p. 437).

After thus accounting, on the basis of facts furnished by modern science, for the channels by which the various fluids conveyed to the corpus callosum are led away from it, we shall now follow the animal spirit which by the alternate expansion and contraction of that organ is urged through the body of the fornix into its fimbriated edges, which extend into the cavities of the lateral ventricles.

3. *The Function of the Choroid Plexuses.*

24. After the animal spirit from the body of the fornix has been conveyed into its fimbriated edges, it is expressed thence into the *choroid plexus*, where it mixes with a refined serum of the blood, and thereby becomes fixed. Swedenborg says on this subject, "Thin, very soft, and moist fimbriæ and roots extend from the body of the fornix, and are affixed to the highest coasts of the plexuses. These pour out the pure spirit which by numerous fibres of the corpus callosum is conveyed to its centre of rest, the body of the fornix. . . . The blood is conveyed to meet this spirit; and by coursing through the web of the plexus, it is consociated and mixed with the arriving spirit in every point, and in this wise celebrates as it were a marriage union with its spouse" (i. no. 511). Again he says, "At the time when the cerebrum as well as the optic thalami are expanded, or at the period when the blood-vessels and plexuses are stretched out or elongated, the arterial blood out of the common branch of the carotid and vertebral arteries [the posterior communicating artery], and at the same time the spirit out of the fimbriæ and roots of the fornix, are introduced and forced into the innermost recesses of the plexuses. At the same time also the useless and exhausted blood is expelled into the veins, and by the veins into the straight sinus; and likewise the moisture which has already been prepared in the little follicles of the plexuses, or the spirit which has been wedded to, and fixed into, its virgin serum, is expressed into the ventricles. The reverse, however, takes place during the time of the constriction of the cerebrum and the optic thalami, namely, during that of the relaxation of the plexuses" (i. no. 513).

25. In which manner the animal spirit from the fimbriæ of the fornix is derived into the choroid plexuses, Swedenborg does not say; for the science of his day is silent on this subject. Nay, on the strength of the facts of his day, Swedenborg was at one time uncertain whether the animal spirit is not discharged from the fornix immediately into the lateral ventricles, in order to be fixed there to the serous lymph, which distils out of the choroid plexus. Afterwards, however, he insisted that the marriage of the animal spirits with the serous lymph of the blood takes place in the choroid plexus; that therefore the fimbriæ of the fornix, in some way or other, must be continued into the framework of the choroid plexus. This rational induction of Swedenborg has been verified recently by Key and Retzius[1] in their investigations into the topographical arrangement of the choroid plexuses, and the connection of these with the fimbriæ of the fornix and the velum interpositum. From their classical presentation of the subject we quote as follows:—

"The dispositions which we are about to set forth, we have first observed in transverse sections of frozen brains, which in their frozen condition were placed in Müller's fluid and in alcohol. Afterwards we succeeded in corroborating our results by observations made with brains the interiors of which were well hardened in alcohol. In such preparations it becomes apparent that the lateral plexus . . . is not suspended freely from the edge of the fimbria in the ventricle; but that in reality it consists of two leaves, an upper leaf and a lower. . . . From the thin, sharpened edge of the fimbria there runs out an immediate continuation of the same, namely, a kind of thin, narrow outgrowth, which may be called the root of the plexus. This root very soon, sometimes close to its origin, is cleft into two very thin leaves, which bend asunder, each describing the form of an arc. The *upper* leaf turns upwards towards the roof of the ventricle, following the same as far as the lateral edge of the ventricle itself. There it ends in an edge which is mostly free. In this position it is held by blood-vessels which here and there pass into it from the roof of the ventricle. . . . With the velum interpositum this upper leaf has no connection whatever. The *lower* leaf . . . extends from the common root, along the edge of the fimbria, towards the bottom of the ventricle; and at some distance from the tænia semicircularis, which is between the corpus striatum and the optic thalamus, it passes over immediately into the ependyma of the optic thalamus. . . . Where the lower leaf is fastened to the thalamus long projections or villi are usually thrown out, which are directed outwards, so that with their

[1] "Studien in der Anatomie der Nervensystems," etc., Stockholm, 1875, vol. i. pp. 104, 105.

extremities they cover the thalamus, and reach the border of the corpus striatum. . . . The lower leaf of the choroid plexus now enters into a most intimate conjunction with the edge of the velum interpositum" (see above, p. 601 *et seq.*).

Concerning the texture of the choroid plexus they say,[1] "The fundamental tissue proper of the choroid plexus originates chiefly from the fimbria of the fornix. . . . If we leave out of consideration the choroid projections, the fundamental mass of the two leaves consists of a fibrillary tissue with comparatively large, protoplastic cells. This tissue in the root [of the plexus] is shown to be an immediate continuation of the edge of the fimbria of the fornix, as well as of the ependyma on its upper surface. Besides, both leaves, everywhere on their free surfaces, are covered by an epithelium which is a continuation of the epithelium of the ependyma, and which invests also the choroid projections shooting out from the two leaves" (see above, p. 603).

From this it follows that the fimbria of the fornix, and hence the fibres of the corpus callosum, are continued directly into the membranous tissue of the choroid plexuses; that therefore through the fibres of this tissue the animal spirit is brought into direct contact with the lymph which distils from the blood of the vascular loops of the choroid plexus.

26. The blood-vessels are conveyed to the choroid plexus by the pia mater, which is the common vehicle for the distribution of the blood-vessels throughout the encephalon. In the form of the velum interpositum the pia mater conveys the vessels as far as the edge of the fimbria of the fornix, but there it leaves the vessels to follow their own course. Luschka[2] tells us that "in the peduncle of each choroid projection there may be distinguished stems of two kinds of blood-vessels, of which the one has the character of an artery and the other of a vein. In accordance with the number of lobules belonging to each choroid projection these stems are divided into a varying number of little branches. These little branches give rise to very numerous loops folded in many ways," etc. (see above, p. 605.)

27. As to the precise method by which the animal spirit of the brain is married to the serum of the blood, Swedenborg says, "The whole fabric of the plexus is glandular, or at least glandular in appearance. The blood circulates in it, as through anfractuous little gyres; and it instils its serum into every least cavity, into every least place, where the fibre also instils its spirit. Thence is conceived and born

[1] "Studien," etc., vol i. pp. 105, 106.

[2] Luschka (H. von), "Die Adergeflechte des menschlichen Gehirns," Berlin, 1853 p. 118.

that moisture which the succeeding organs separate, filter, and reetify" (i. no. 511). With regard to the manner in which the moisture which is coneeived in the choroid plexus is distilled into the lateral ventricle, he says, "The newly-born moisture which by its impregnation with a copious supply of spirit has been made liquid, is discharged from the follieles of the plexus abroad through an equally great number of little emissary duets and arteries whieh are situated in the membrane or meninx eneompassing the plexus. Thus by little mouths it is distilled thenee into the eavities of the ventrieles, at either side of the optie thalami. . . . That these glandular beginnings have emissary branehes cannot be denied, sinee the membrane itself, whieh is said to be a production of the pia mater, is thin, and when it is stretched out, constantly sweats out a eertain juice" (i. no. 512).

28. That a moisture is eonstantly secreted from the ehoroid plexus is fully admitted by modern seience; but the mechanism by which this is done differs somewhat from that whieh Swedenborg sketched in the light of the seienee of his day. Luschka,[1] who has investigated this subjeet more minutely than any of his predecessors, says on this subject, "In elaiming for the choroid plexuses a glandular nature, an expression is given of their functional significance, although not of their natural organization. As the ehoroid plexuses were formerly looked upon as organs of secretion, so we are still justified in regarding them in the same light. But while formerly the seeretory ageney of the choroid plexuses was attributed to specially individualized glands, modern investigation acknowledges as the souree of this activity a cellular tissue spread out over their surfaee" (see above, p. 605).

This cellular tissue is the epithelium which is spread over the whole of the choroid plexus. On this subject we read in Luschka's monograph[2] of the choroid plexuses, "The epithelial cells of the choroid plexuses . . . form a coating which can easily be stripped off, and the ingredients of whieh are so loosely connected that at the least disturbance they fall apart. The epithelium eneompasses throughout their whole width the vaseular loops filled with blood which shine dimly through it; producing thereby the appearance of extraordinary thickness. . . . By far the greater part of the epithelial cells have a polygonal form, and a delicate granular appearanee" (see above, p. 606).

These epithelial eells, Luschka tells us, are eonstantly generated anew, and they pass through several metamorphoses until they finally reaeh their polygonal shape. "These cells," he says,[3] "which by their continual growth, and by pressing against each other beeome poly-

[1] "Die Adergeflechte," etc., Berlin 1853, p. 10.
[2] *Ibid.*, p. 122. [3] *Ibid.*, pp. 124-127.

gonal, in the course of time are changed in a remarkable manner. Their finely-granulated contents, as well as their nuclei, are gradually dissolved into a homogeneous mass, clear as water, which passes through the walls of the cells, and which appears on their surface in the form of bright little drops. . . . Those epithelial cells which are furthest developed into vitreous, clear vesicles, usually occupy the extreme surface of the epithelium, and they are those of its loosely-connected constituents which seem ready to drop off. Such vitreous, clear cells of the choroid plexuses which have dropped off are accordingly also found floating in the liquid of the cavities of the cerebrum."

Respecting the physiological function of these epithelial cells Luschka says further, "The contents of the cells, after becoming homogeneous and liquid, penetrate through the envelope of the cell; while new blastema, on the other hand, is received into the cell from the blood, in order to undergo the same chemical change, and afterwards to pass out of the cell. . . . In favour of this kind of activity in the cells belonging to the choroid plexuses," he says, "we may point not only to the fact that there are actually found sometimes cells which look as if they had been emptied, and as if they had collapsed by such a cause, but also to the fact that during a longer existence of the cells there are formed in them peculiar elements, which are set free by their final dissolution. Very many cells in the choroid plexuses, however, after their contents have become homogeneous, are dissolved forthwith completely; or else they leave behind some small vestiges of their envelopes, which are found sticking to neighbouring cells in the form of pieces of a crescent shape, or describing some other figure" (see above, p. 608 *et seq.*).

From this description it is made very plain that it is in the epithelial cells that the marriage of the serum of the blood takes place with the spirit of the fibres. At first, as long as the cells contain simply serum, their contents appear granular and nucleated, but by-and-by when the serum is thoroughly impregnated with spirit, the contents of the cells become clear and transparent, and the liquid itself penetrates through the walls of the cells, and is discharged into the lateral ventricle. This process is naturally accelerated by the animatory motion of the brain, by which in alternate times a new supply of spirit and of blood is conveyed to the choroid plexus.

In conclusion, it is shown clearly that the facts of modern science, so far from disproving Swedenborg's theory of the uses and functions of the choroid plexuses, actually confirm it in every particular, and indeed much more fully than was done by the facts of his own times.

D. *The Function of the Lateral Ventricles and of their Foramina.*

29. After the spirit of the fibres has been properly coupled to the serum of the blood, and after the lymph thus obtained through the epithelial cells of the choroid plexus has distilled into the cavities of the lateral ventricles, the next step in the elaboration of the purer blood consists in conveying this lymph into those organs where it is to be purified of all grosser admixtures, and further refined. For this purpose it must be introduced, through appointed channels, from the lateral ventricles into the third or middle ventricle.

On this subject Swedenborg says, "The newly-born moisture, which by its impregnation with a copious supply of spirit has been made liquid, is discharged from the follicles of the choroid plexus . . . into the cavities of the ventricles, at either side of the optic thalami. Thence by a swift and declivitous course it is conveyed at the very time when the ventricles constrict themselves, towards the anterior and posterior foramina called 'vulva' and 'anus'" (i. no. 512).

The mechanism by which this is effected Swedenborg describes as follows: "When the posterior and the descending cornua of the lateral ventricles close up, and the ventricles are contracted, the liquid which they contain is urged towards the centres of rest—the pineal gland and the body of the fornix—and thus towards those two foramina called 'anus' and 'vulva,' that is, towards the axis. For during the period of constriction of the ventricles a certain sulcus or byway is hollowed out between the corpora striata and the optic thalami which are then swelling; and indeed along the intermediate medullary tract [tænia semicircularis] which tends towards the anterior foramen. And the same is repeated in the lower part of the optic thalami, in a direction towards the posterior foramen" (i. no. 470).

Of these foramina themselves he gives the following description: "There are two foramina which from [each of] the lateral ventricles lead into the third ventricle. One is almost under the 'nates'—the anterior tubercles of the corpora quadrigemina—and under the pineal gland, and the other near the fornix; the former by the ancients is called 'anus,' and the latter 'vulva.' They open immediately into the [third] ventricle as well as into the aqueduct. They are raised up and down, and are opened more or less widely, just as the corpora striata and the optic thalami contort the ventricles and their medullary walls. The actual orifices of the foramen 'anus' are encircled by fibres sent out from the medullary tract which is inserted between the thalami [stria pinealis]; and they are obliterated when the thalami are forcibly drawn apart. The edges or margins of this foramen, according to Vieussens, terminate in the uppermost coast of the third ventricle" (i. no. 458).

Concerning this latter foramen Swedenborg says further, "The posterior foramen called 'anus' leads into the aqueduct of Sylvius, or into the passage under the 'testes,' in a twofold way, that is, from both lateral ventricles. Hence it is of a twofold nature, although terminating in a single sinus or bosom. Thence through the foramen under the pineal gland a passage is afforded into the third ventricle. This posterior foramen is opened on either side as often as the lateral ventricles and the third or middle ventricle are closed, for then it offers itself with an open mouth, and draws in the lymph with full lips. The reverse happens when the ventricles by the action of the corpora striata, the optic thalami, and the fibres of the roof, allow themselves to be expanded.—In order that this twofold foramen may fulfil its duties properly, two tubercles, namely, the anterior ones of the corpora quadrigemina, are placed near it. These at the time when the foramen is to be opened, expand themselves along with the optic thalami, and thus relax the fibres, and stretch open the aperture of its mouth down to the bottom. In this wise they afford to the moisture which is expressed from the choroid plexuses an opportunity of passing in.—The posterior commissure also is then stretched out, and draws apart the edges of the sphincter" (i. no. 525).

In another place Swedenborg adds the following particulars concerning the manner in which the posterior foramen is opened: "The posterior foramen is opened by the fibres of the posterior commissure which is placed before the 'nates.' This commissure is then stretched out, and it relaxes the reins of the sphincter by which the margin of the foramen is constricted. This foramen, besides, is situated low down, and almost at the base of the ventricles, so that when their cavity is constricted, with an open mouth it sips in the liquid which flows towards it. It is, however, raised up when the ventricles are dilated, so that with a descending trough it may pour the lymph which it has received into the third or middle ventricle" (i. no. 473).

The relations existing between the two foramina Swedenborg describes as follows: "The first mixture of essences, namely, of the spiritnous essence with the fresh and purer serum of the blood, is conveyed to the posterior foramen—*anus*—and is introduced into the third ventricle by the meeting-place of the three passages under the pineal gland, and thence into the infundibulum. Whatever the latter does not receive or sip in with its mouth, it cannot, however, as it seems, regurgitate or throw back by the posterior foramen; wherefore it casts it out by the anterior foramen—*vulva*—which is excavated under the fimbriated appendage of the fornix" (i. no. 563).

Of this anterior foramen—the foramen of Monro—Swedenborg gives the following particular description: "The anterior foramen opens under the middle of the body of the fornix, and it is drawn apart by the aid of the fimbriæ and roots of the fornix, which thence [*i.e.* from the middle of the fornix] branch out in an anterior and posterior direction. Thus when the septum lucidum and the third ventricle, and likewise the corpus callosum, are lengthened out, and when the optic thalami are swollen and exert a pressure forward, then those bands are relaxed by which this aperture during the period of the dilatation of the ventricles is constricted" (i. no. 473).

An additional use of this foramen, according to Swedenborg, is that through its medium the contents of the two ventricles are equalized. He says, "The anterior foramen leads into the associate lateral ventricle, and communicates to it the lymphs of the other ventricle, so that the burthen may be borne equally, and shared out with an even balance, for otherwise an unequal effect and a diverse action would result in each hemisphere" (i. no. 472).

The action of the lateral ventricles in respect to the lymph received from the choroid plexuses, Swedenborg sums up thus: "The superfluous lymph of the third ventricle which is cast out by the anterior foramen, flows back again into that very focus which is the common mart or emporium of each lateral ventricle. Thence as it were by a circle it returns to its first threshold or its first prison under the 'nates' and the pineal gland; and again and again it flows and reflows from foramen to foramen by a kind of chymical circulation, lest the third ventricle should ever lack its supply of liquid; even though the fibres and the blood-vessels of the cerebrum should not be constant in their supply of contributions" (i. no. 564).

30. If, after reading this minute description of the foramina of the lateral ventricles and their uses, we turn to the writings of the anatomists for confirmations of Swedenborg's theory, he himself directs us to Vieussens and Ridley.

Vieussens[1] says, "The 'vulva' is nothing else than a foramen near the anterior region of the lateral ventricles, which is hidden under the fornix and hollowed out near its roots; by its means the lateral ventricles communicate with the third. The 'anus,' however, is another foramen which is hidden under the hinder part of the fornix, and hollowed out near the 'nates'—anterior tubercles of the corpora quadrigemina—by means of which the lateral ventricles communicate in like manner with the third ventricle. These foramina, however,

[1] "Neurographia," etc., p. 64.

the names of which seem to have been taken either from their shape or their position, are entirely obliterated when one of the optic thalami is drawn apart from the other. Their margins terminate in the highest strand of the third ventricle" (see above, p. 513).

Ridley[1] makes the following statement: "Within this cavity (*i.e.* the ventricles) of the brain there are also two passages into the infundibulum, and thus into the pituitary gland; of which the one nearest the front is called by the odd name 'vulva,' and the one more in the back part 'anus,' from their situation, and which with the rima or cleft between them is called the third ventricle.—The places from which all the water of the cerebrum gradually issues, by the more modern anatomists are described under the name of the 'tria foramina,' situated so as to give passage from all the eminent regions of the brain, from whence access can be had to them for the water (or rather lymph, properly so called) to fall into the aforesaid infundibulum. The first of these is near the 'testes,' under the pineal gland, or at the beginning of the rima, where two [foramina] meet in a certain aperture under the 'nates;' . . . and the last is at the end of the rima, or just under the roots of the fornix; and all end at length in the infundibulum—though by two different passages" (see above, p. 514).

Winslow, to whom Swedenborg also refers, says, "Where the convex parts of the two anterior corpora quadrigemina join the convexity of the thalami optici, an insterstice is left between these four convexities which communicates with the third ventricle. Instead of the ridiculous name of 'anus' which has been given to this opening, it may be called 'foramen commune posterius' to distinguish it from another, the 'vulva,' to which we give the name 'foramen commune anterius.'—The third ventricle under the foramen commune anterius opens into the infundibulum, and through this foramen communicates with the lateral ventricles" ("Exposition," etc., sec. x. no. 81).

31. Already during Swedenborg's time the existence of all these foramina was denied, and indeed by no less an authority than Haller. In treating of the lateral ventricles he said, "It has long been asserted that the right ventricle opens into the left where the two choroid plexuses meet, between the optic thalami, the fornix, and the choroid plexus, so that there is in reality but one ventricle. Often have I tried to find this opening by blowing. Nevertheless, by a gentle inflation I did not find that the air passed out of the right into the left ventricle; nor that water injected into one ventricle affected that of the other side. Long ago Steno also has made a note to this effect, that there is no passage between the fornix and the thalami" ("Ele-

[1] "Anatomy of the Brain," pp. 124, 125.

menta," etc., iv. p. 42). Of the third ventricle he said, "When all the parts are in a healthy state, it does not communicate with the lateral ventricles. When these were filled with water, the third ventricle has been found empty. It is bounded by the plexus which we described above" (*ibid.*, p. 55).

Still Haller seems to be inclined to admit an opening at the extremity of the fourth ventricle; for he says, "Where the choroid plexus passes out of the ventricle, water easily makes a way for itself into the space which surrounds the spinal cord" (*ibid.*, p. 77).

Haller's work, which was published in 1762, seems to have effectually stopped up the foramina of the lateral ventricles in the eyes of the anatomists until 1783, when A. Monro published his "Observations on the Structure and Functions of the Nervous System," where he demonstrated anew the existence of the anterior foramen, which by the ancients was called "vulva," but which since Monro's time has been called "the foramen of Monro." But he denied the existence of the posterior foramen called "anus;" for, says he, "The choroid plexuses of the lateral ventricles are connected together by a broad vascular membrane which adheres closely to the fornix about it [*i.e.* about the body of the fornix], and to the thalami nervorum opticorum below it. Hence too this membrane covers and shuts the hole called 'anus,' and prevents the lateral ventricles from communicating with each other, or with the third ventricle at any place but that before described" (chap. iv. sec. i. p. 12; see above, p. 518). He also denied the existence of any opening at the end of the fourth ventricle in these words: "The bottom of the fourth ventricle has *no such communications* with the cavity of the spinal marrow, as Dr. Haller supposed, being completely shut by its choroid plexus and pia mater" (*ibid.*).

32. As Haller's declaration about the isolated position of each of the ventricles influenced science up to Monro's time, so Monro's doctrine concerning the foramina of the lateral ventricles has swayed science until our own day. His declaration respecting the closing up of the fourth ventricle in the direction of the spinal cord was indeed disproved more than forty years ago by Magendie, after whom the foramen now generally admitted at the end of the calamus scriptorius is called; but not until 1872 has the posterior communication between the lateral ventricles and the third ventricle which had long been known to the ancients, been re-established. As Monro in 1783 rediscovered the anterior foramen called "vulva," so Mierzejewsky[1] in 1872 again established the existence of that posterior communication which in olden times has been styled "anus." From his paper, which

[1] Mierzejewsky (Dr. J.), "Die Ventrikel des Gehirnes," in "Centralblatt für die medicinischen Wissenschaften," tenth year, September 28, 1872. Berlin.

is dated from the anatomical institute in Göttingen, we extract as follows :—

"The ventricles of the brain, . . . which years ago had been most carefully observed, in modern times, when the whole doctrine of the brain has experienced most sweeping changes, have not been treated with that attention which their significance in many pathological cases seems to demand. On this account, I undertook, under the direction of Dr. Merkel, a thorough histological and topographical examination of their parietes, as well as of the communications which exist between them, and likewise between them and the neighbouring parts (see above, p. 521). In order to find out in which way the ventricles of the brain communicate with one another, . . . injections were made with coloured liquids and congealing substances. The brain was injected *in situ* through an olfactory bulb which had been laid bare; or else, after having been removed uninjured, it was injected in various places. *The place where the ventricles communicate was found to be in the neighbourhood of the pineal gland* [and thus in the meeting-place of the posterior foramen of either side, as pointed out by Swedenborg and others]. *From this point the fluid passes out of the injected lateral ventricle into the three other ventricles.* Only after the injection has been continued for some time, and when a stronger pressure is exerted, that communication between the lateral and the third ventricles which is above the optic thalamus [*i.e.* the foramen of Monro] is utilized."

33. Here then we find the existence of a posterior foramen leading from the lateral ventricles into the third ventricle fully vindicated. Mierzejewsky, indeed, does not point out the particular place in the lateral ventricles whence the fluid passes "into the neighbourhood of the pineal gland;" but he plainly asserts the fact that from some place in the posterior part of the lateral ventricle the injected fluid passes "into the neighbourhood of the pineal gland," and that thence "it passes out *into the three other ventricles*," that is, into the third ventricle, into the lateral ventricle of the other side, and into the fourth ventricle. He also says that "only after the injection had been continued for some time, and when a stronger pressure is exerted," is the anterior foramen, or that called after Monro, utilized.

Leaving to some future observer to point out the precise place where the fluid from the lateral ventricle passes "into the neighbourhood of the pineal gland," we may observe that this passage will probably be found under the lower leaf of the velum interpositum, which from the top of the third ventricle, under the fornix, extends into the lateral ventricle, where, according to Key and Retzius, it "enters into a most intimate conjunction with the lower leaf of the choroid plexus"—to this we shall advert presently. From this lower leaf of the plexus, which is fastened to the optic thalamus in the neighbourhood of the taenia semicircularis, choroid villi shoot out. Among these villi, we suggest, the passage in question will be found, between the lower leaf of the velum interpositum and the surface of the thalamus opticus.

24. The next question is the interesting one, why the injected fluid should by preference seek the posterior foramen; and why "only after the injection has been continued for some time, and when a stronger pressure is exerted," is the anterior foramen or the foramen Monroi utilized. The discoveries made by Key and Retzius explain the reason. According to these observers, as has been shown above (p. 691 et seq.), the membranous framework of the choroid plexus which is derived from the fimbria of the fornix, not far from the fimbria itself is divided into two leaves. Of these the upper one is fastened by little vessels to the ceiling of the lateral ventricle, while the lower one is attached to the optic thalamus in the neighbourhood of the taenia semicircularis. By the upper leaf, which extends to the opposite side of the lateral ventricle, the whole ventricular cavity is divided into two compartments; an upper and interior, and a lower and exterior. The greatest development of the lower leaf is in the upper tier of the lateral ventricle, between the glomus and the foramen Monroi. Along this line also it is most thickly beset by choroid villi; while during its descent into the descending cornu it decreases in width, and in the number of its choroid villi. The upper leaf of the choroid plexus, on the other hand, has its greatest strength, and hence is most luxuriantly covered with villi, in the descending cornu; while it diminishes in importance, and in the number of its choroid villi, as it approaches the anterior portions of the lateral ventricle. From this it follows that in the descending cornu, where the ascending course of the ventricular fluid commences, the upper compartment of the ventricle is densely filled with choroid villi, and thus opposes a passive resistance to the ascending fluid, while the *lower* compartment, which is comparatively free from obstructions, allows an easy access to the fluid. The passage remains free and unobstructed until the liquid reaches the lower end of the higher level of the lateral ventricle where the posterior foramen is situated. The rest of the lower compartment, as far as the foramen Monroi, is densely crowded with choroid villi which effectually clog up the greater part of the channel, so that the liquid is naturally diverted into the third ventricle through the posterior foramen which is there with open lips; and "only after the injection has been continued for some time, and when a stronger pressure is exerted, the anterior foramen or the foramen Monroi is utilized" for the transmission of the liquid into the remaining ventricles.

35. Swedenborg speaks of two grooves or byways which are formed in the bottom of the lateral ventricles when the corpora striata and the optic thalami begin to swell; of which one leads to the anterior and the other to the posterior foramen. He says, "During the period of constriction of the ventricles a certain sulcus or byway is hollowed out between the corpora striata and the optic thalami which are then swelling; and indeed along the intermediate medullary tract [tænia semicircularis] which tends towards the anterior foramen. And the same is repeated in the lower part of the optic thalami, in the direction of the posterior foramen."

The facts elicited by Key and Retzius confirm the existence of two such grooves; only the one formed by the "tænia semicircularis" seems to introduce the ventricular fluid into the posterior foramen; while the other gutter, which is formed where the upper leaf of the choroid plexus bulges out from the fimbria of the fornix, seems to convey the fluid to the anterior foramen, and thus to the point where the two lateral ventricles meet, in order to equalize their contents. On the return journey also, from the anterior into the posterior and descending cornua, the ventricular fluid seems to select the groove of the upper choroid leaf, because it is less obstructed by villi in the neighbourhood of the anterior foramen. The liquid, however, passes then freely from the upper into the lower compartment, because the corpora striata and the optic thalami are then subsiding, and the lateral ventricle is distended throughout its whole width, so that the interstices between the various little vessels to which the upper leaf is fastened are then brought into use.

36. The anterior cornua of the lateral ventricles, beyond the foramen Monroi, and on either side of the septum lucidum, seem to be diverticles for the ventricular lymph during the constriction of the ventricular cavities; while the posterior cornua are diverticles for the same liquid during their dilatation. The axis proper, however, of the ascending and descending ventricular liquid seems to be along the choroid plexus, the axis itself being marked out by the tænia semi-circularis, which extends from the foramen Monroi to the hippocampus major in the descending cornu.

37. Mierzejewsky points also to a place in the lateral ventricles where the ventricular liquid escapes out of the system of ventricles. He says, "The coloured injecting fluid, moreover, leaves the system of ventricles in order to pass into the sub-arachnoidal space. It escapes in definite and identical places. The coloured mass is always discovered first in the base of the cerebrum, whither it makes its way through the descending cornu of the lateral ventricle, and over the hippocampus major. The fissure through which the communication is

effected extends from the corpora quadrigemina to the gyrus uncinatus." This escape would naturally take place while by the expansion of the grey matter of the hippocampus major, optic thalamus, and the surrounding cortex, the medullary substance in the fundus of the descending cornu is relaxed; while the aperture or slit would be closed by the tension of the medullary substance during the constriction of the hippocampus major and the cortex. During the expansion of the cortex, however, the descending and posterior cornua are entirely closed up, and the ventricular fluid is urged into the anterior area of the lateral ventricle; whence through the posterior foramen it is driven towards the axis of the brain, and thus towards the third ventricle. Besides, the cerebro-spinal fluid also, which during the expansion of the encephalon is forced from the spinal cord into the cranial cavity, exerts a pressure on the hippocampus major and its surroundings from without, and thus helps to close up any possible aperture in the fundus of the descending cornu. Nothing therefore short of an extraordinary dilatation of the lateral ventricle by a dropsical humour would cause this liquid to be discharged from the descending cornu during the expansion of the grey matter, and hence during the period of constriction of the ventricles. Such a contingency Swedenborg describes in what follows: "In respect to that flood of infected serum with which the ventricles are sometimes surcharged, as in the case of hydrocephali, and which does not come from the choroid plexuses, but is caused by an inroad through the folds of the pia mater [ependyma] covering the lateral ventricles, which are raised up and broken through—it is very probable that it is discharged . . . through some apertures and passages which are not yet discovered; for wherever there is a liquid, there also are ducts or asylums for the evacuations. . . . Such an interstice would be opened when the ventricles, flooded by such an inundation, would violently labour during their times of constriction" (i. no. 529). Mierzejewsky has evidently discovered in the fundus of the descending cornu a duct or interstice which comes into play when the lateral ventricle is struggling to eject "an injected serum" of the kind that Swedenborg describes.

E. *Functions of the Corpora Quadrigemina, the Aqueduct of Sylvius, and the Pineal Gland.*

38. Swedenborg distinguishes between the function of the corpora quadrigemina in connection with the chymical laboratory of the brain, and the function which they exercise in connection with the organs of sensation and motion.

I.

The chymical action of the corpora quadrigemina is twofold; for in the first place the anterior tubercles open and shut the posterior foramina which lead from the lateral ventricles into the aqueduct of Sylvius; and in the second place both the anterior and posterior tubercles are in charge of the aqueduct of Sylvius, which according to Swedenborg is "a receptacle of the lymph of the lateral ventricles," and "a storeroom of the lymph for the third ventricle" (i. no. 528).

The action of the anterior tubercles in opening and shutting the posterior foramina Swedenborg describes thus: "In order that the twofold foramen may fulfil its duties properly, two tubercles, namely, the anterior ones of the corpora quadrigemina, are placed near it. These at the time when the foramen is to be opened, expand themselves along with the optic thalami, and thus relax the fibres, and stretch open the aperture of its mouth down to the bottom. In this wise they afford to the moisture which is expressed from the choroid plexuses an opportunity of passing in. The posterior commissure also . . . is then stretched out, and draws apart the edges of the sphincter" (i. no. 525).

39. Mierzejewsky, as we have shown in the preceding article, has proved the existence of a communication between the lateral ventricles and "the neighbourhood of the pineal gland," and thus he has rediscovered the posterior foramina, called "anus," which lead from the lateral ventricles into the aqueduct of Sylvius.

In explaining the mechanism by which these apertures are opened and shut, Swedenborg states that "the fibres are relaxed," and "the apertures of the foramina are stretched open" when the corpora quadrigemina along with the optic thalami undergo the process of expansion; the anterior tubercles and the optic thalami being "colleagues in the same work," and "mutually attached to one another by fibres and medullary bands" (i. no. 525).

Swedenborg also says that "the posterior commissure is then stretched out, and draws apart the edges of the sphincter."

Meynert shows that "the corpora quadrigemina are directly continuous with the posterior commissure; the entire medullary formation of the posterior commissure, on a longitudinal section of the brain, appearing as an S-shaped appendix to the central part of the medullary substance of the corpus quadrigeminum" (*loc. cit.*, p. 700). As the posterior commissure besides is well known to pass through the substance of the optic thalami, it follows that the posterior commissure furnishes those fibres and constitutes those "medullary bands" by which, as Swedenborg says, "the corpora quadrigemina and the optic thalami are mutually attached to one another."

Meynert also states that the posterior commissure is connected with "the ganglionic substance of the pineal gland, and with that of its pedicle, the habenula," and therefore is in direct association with the stria pinealis, from which Swedenborg, on the authority of the anatomists of his time, derives the posterior commissure.

40. Swedenborg defines the aqueduct of Sylvius as "a receptacle of the lymph of the lateral ventricles," and as "a storeroom of the lymph for the third ventricle."

"In its shape," he says, "it is not unlike a retort with two beaks, and it does not pour more liquid into the third ventricle than is required for the infundibulum and the pituitary gland" (i. no. 528). "The passage under the corpora quadrigemina . . . at the time when the [lateral] foramina are opened, is likewise drawn apart, and absorbs the pure wave which approaches; and, indeed, by the same powers, that is, by the general powers of the optic thalami, and the particular powers of the posterior tubercles of the corpora quadrigemina, which are also assisted in their work by the anterior tubercles. . . . Besides, the grey substance which is interspersed in the sides of this aqueduct, and in the medulla by which it is enclosed, lends a helping hand, so that the fibres may be elongated, and the connection in every direction may be relaxed" (i. no. 526).

41. In nos. 10 to 12 of our present note we have shown on the basis of the researches of modern science, that in the *living* brain the communication between the aqueduct of Sylvius and the fourth ventricle under the valve of Vieussens is ordinarily closed. We have now to show that the aqueduct under the corpora quadrigemina is "a receptacle of the lymph of the third ventricle," which through a foramen over which the pineal gland exercises control, pours its contents into the third ventricle.

In regard to the aqueduct of Sylvius, Gerlach [1] tells us that "during its course it does not preserve the same shape, but alters it continually" (see above, no. 522*p*). He says that "exactly in harmony with that place where the anterior tubercles of the corpora quadrigemina begin [and thus where the aqueduct is placed under the control of the pineal gland] the aqueduct . . . is changed into a mere fissure, which above as well as below is bounded by an acute angle." This fissure, we hold, represents the posterior foramen through which the aqueduct pours its contents into the third ventricle.

"Towards the middle of the anterior tubercles," he continues, "there is an increase in the diameter of the canal from right to left;

[1] Gerlach (J.), "Mikroskopische Studien aus dem Gebiete der menschlichen Morphologie," second article, entitled "Von der Sylvi 'schen Wasserleitung und ihrer Auskleidung," Erlangen, 1858, pp. 23-25.

and in the middle of the anterior tubercles the shape of the aqueduct approaches that of a heart in playing-cards." (See Gerlach's drawings of the diameter of the aqueduct in cross-sections, above, p. 634.) "Henceforth," he adds, "the diameter from right to left increases still more, and both on the top and at the sides the canal appears rounded." We see, therefore, that throughout the whole extent of the anterior tubercles of the corpora quadrigemina the aqueduct increases in size, and assumes the proportions of a regular "receptacle" and "store-room."

"Towards the end of the anterior tubercles," Gerlach says, "the diameter from right to left is becoming continually smaller, . . . and between the anterior and posterior tubercles the canal presents again a broad fissure which above and below is closed by two angles." This fissure, however, on comparing Gerlach's figures 22 and 6 (see above, pp. 635, 634), is seen to be much larger than that under the pineal gland, which, we hold, represents the foramen into the third ventricle.

"Under the posterior tubercles," he says further, "the diameter from above downwards increases more and more, in consequence of the considerable drawing out of the lower angle;" and "towards the end of these tubercles the diameter from right to left again gradually increases, and the upper angle becomes round again." (See his figures 28, 30, and 32, on pp. 635 and 636.)

From this statement it appears that immediately under the quadrigeminal bodies the aqueduct of Sylvius actually increases into a receptacle and reservoir, which by the expansion and subsidence of the corpora quadrigemina, as well as by the motion imparted to the valve of Vieussens by the fourth ventricle (see Note III. no. 3), is alternately filled and emptied of its contents—that is, so far as the pineal gland does not interfere in this process.

42. The respective action of the corpora quadrigemina and the pineal gland, as members of the chymical laboratory, according to Swedenborg, is as follows: The corpora quadrigemina simply admit the ventricular lymph into the aqueduct, and keep guard over it; while the pineal gland opens and shuts the door, whereby the lymph is admitted into the third ventricle. Yet the pineal gland influences the action of the corpora quadrigemina, and these latter bodies assist the pineal gland in its function.

The action of the pineal gland Swedenborg describes thus: "The pineal gland is placed immediately before the anterior tubercles of the corpora quadrigemina, . . . and at the extreme end of the third ventricle, above the foramen called 'anus.' It keeps guard over the third ventricle, the door of which it seems to open from the lateral ventricles and the aqueduct of Sylvius" (i. no. 532).

The *modus operandi* by which the pineal gland acts in conjunction with the corpora quadrigemina Swedenborg describes thus: "The anterior tubercles on withdrawing from one another, or on being compelled to leave their position by the subsidence of the optic thalami, divide as it were the pineal gland between them [that is, they pull it in opposite directions]. Yet on regaining their natural position they at once urge the gland back into its original place. On changing their position, these bodies also draw apart the sides of the passage underneath, and thus the gland opens the approaches over which it acts as custodian" (i. no. 532).

But the pineal gland is not only acted upon by its surroundings; it has also living powers within its own bosom. On this subject Swedenborg says, "The same also [namely, the closing and the opening of the approach to the third ventricle] is effected in a general way by the optic thalami, and in a most particular way by the fibres of the cerebrum which are led forth from the stria pinealis. . . . Yet it is the special office of the pineal gland to be the custodian and the regulator of this one particular foramen, and thereby to act as the dispenser of the inflowing lymph. So, while the optic thalami raise their backs and close up the ventricles, they at the same time consign the reins and the helm into the keeping of this gland; wherefore on the reception of this power the gland also arises, and from its own principles of motion, or from its cineritious substances, it begins to swell, and to close thereby in particular that door which the optic thalami have closed in general. On the other hand, however, the door is opened when the optic thalami subside, and when the gland contracts" (i. no. 544).

43. If we consult modern science on the subject of the pineal gland we find first of all that its ganglionic character, and thus its power of expansion and contraction, is denied by Henle[1] and Grandry.[2] The former is inclined to regard the pineal gland in the light of a lymphatic gland, while the latter, in respect to its structure, desires to put it into the same category with the supra-renal capsule. This view, however, is strenuously opposed by Meynert (*loc. cit.*, p. 700), who says, "The pineal gland should in truth be considered as a ganglion, and, like the ganglionic mass of its pedicle, which is similarly constructed, it is connected on the one hand with the medullary substance of the cerebral lobes, and on the other by means of the posterior commissure with the crus cerebri. It may then be reckoned among the *ganglia of origin*

[1] "Handbuch der systematischen Anatomie des Menschen," vol. iii. "Nervenlehre," Braunschweig, 1871, p. 288.

[2] "Corps pituitaire et glande pinéale," in "Journal de l'Anatomie et de la Physiologie," Paris, 1867, pp. 400-407.

of the tegmentum. It contains cells of two different sizes, the one 15 μ in thickness, the others very small, only 6 μ in thickness, and its structure only differs from that of the other cerebral ganglia in that the cells are crowded very closely together. . . . The neighbourhood of the medullary substance, as well as the universal presence of processes, characterize the cells described as nervous elements."

Swedenborg's idea that the pineal gland acts as a guardian over the approach to the third ventricle, seems to be regarded favourably by Magendie; for he attributes to it certain functions in the circulation of the cerebro-spinal liquid, and thinks that it is an agent for obstructing the communication between the third and fourth ventricles. Cruveilhier[1] in criticising Magendie's theory says, "Magendie thinks that this body performs certain functions having reference to the cerebro-spinal fluid: he has regarded it as a kind of plug, which would obstruct the orifice of communication between the third and fourth ventricles. But in the first place, it is completely fixed by the pia mater, and in the second place, even if it were free, it could not in any case close the orifice alluded to" (ii. p. 994).

In reply to this we have to state, that as little as the pia mater, in the case of the cortical substance of the brain in general, is able to prevent it from swelling and subsiding, just so little is it able to oppose itself to the alternate expansion and contraction of the pineal gland. By its alternate expansion and contraction, however, the grey substance of the pineal gland acts upon the medullary fibres of the posterior commissure, with which, according to Meynert, "the ganglionic substance of the pineal gland, and that of its pedicle, the habenula, is in connection" (*loc. cit.*, p. 700).

These fibres, which together with those of the stria pinealis (peduncles of the pineal gland) encircle the orifice of the aqueduct of Sylvius, by the action of the pineal gland are either lengthened or shortened, and therefore they either enlarge or constrict the foramen under consideration. The pineal gland, besides, is supported in this action by the corpora quadrigemina and the optic thalami.

II.

44. The corpora quadrigemina, however, as well as the pineal gland and the aqueduct of Sylvius, are not merely members of the chymical laboratory of the brain, but like the corpora striata and the optic thalami, they also influence sensation and motion in the body.

The office of the corpora quadrigemina in this respect is stated by Swedenborg thus: "Are there not some fibres of the cerebellum

[1] "Descriptive Anatomy," in Tweedie's "Library of Medicine," London, 1842.

which are inserted into both tubercles of the 'testes' as well as of the 'nates'? By this way these fibres tend upwards into the surface or into the delicate membrane of the optic thalami [*i.e.* the stratum zonale], and at the same time more deeply into them; and thence in conjunction with the fibres of the cerebrum they direct their way towards the bulb, the coatings, the humours, the iris, and the pupil of the eye; that is, chiefly towards those parts of the eye which are being adjusted to the state of the objects [of sight] at the time, and indeed spontaneously, and without any previous will of the cerebrum—which is the office of the cerebellum. Thus the first of its processes or peduncles [*i.e.* of the cerebellum] enters into the caudex of the medulla oblongata and encircles it immediately below the posterior tubercles of the corpora quadrigemina. Thence a way is prepared for it, in company with the fibres of the rounded tops of the corpora quadrigemina, of entering into the surface and structure of the optic thalami" (i. no. 531).

45. The share which the pineal gland has in determining sensation and motion in the body, Swedenborg describes thus: "Whither the fibres of the peduncles [*i.e.* of the pineal gland], which are propagated through the optic thalami, finally tend, must be conjectured. It is probable that in company with the fibres of the cerebellum they enter the optic nerves, *and hence the eye itself;* for the organs of sense derive their origin both from the fibre of the cerebrum and from that of the cerebellum, since there is more of a spontaneous and natural than of a voluntary element in them. If the fibre of the cerebellum flows likewise into the eye, there is no other way by which it can do so except through the isthmus, and thence through the optic thalami into the optic nerves; or by that way whither the fibres of the corpora quadrigemina and of the pineal gland tend" (i. no. 548). He continues, "We may conclude thence what the pineal gland contributes to sensation and motion. In respect to sensation, it sends no fibre from its body towards any of the organs of sense except what it delegates to the eye" (i. no. 549).

The office of the pineal gland, the corpora quadrigemina, and the aqueduct of Sylvius, in respect to sensation, Swedenborg afterwards sums up thus: "The pineal gland with its corpora quadrigemina, and with the whole of its isthmus, seems to perform this function, that those visual rays which from the eye through the optic nerves flow into their thalami, by this way are also transmitted into the cerebellum, and into the whole of its cortical or cineritious substance; for the superior peduncles, the processus ad testes which flows proximately into the cerebellum, receive these rays presently. Any fibre which tends from the cerebellum into the eye, emerges likewise from this process" (i. no. 549).

46. If now we inquire specially what share the corpora quadrigemina have in the determination of the sense of sight, Swedenborg answers, "The fibre of the corpora quadrigemina is directed chiefly towards those parts of the eye which are being adjusted to the state of the objects [of sight] at the time, and indeed spontaneously, and without any previous will of the cerebrum."

What has modern science to say to this? To within a comparatively recent period physiology, on the basis of vivisection, taught that the corpora quadrigemina are the organs of the sense of sight in the brain. This doctrine, as set forth in Dr. Carpenter's "Principles of Human Physiology," (seventh edition, 1869), is as follows: "Of the functions of the ganglia of special sense, those of the *corpora quadrigemina* are the chief which have been examined experimentally. The researches of Flourens and Hertwig have shown that the connection of these bodies with the visual function which might be inferred from their anatomical relations, is thus substantiated. The partial loss of the ganglion on one side produces partial loss of power and temporary blindness on the opposite side of the body, without necessarily destroying the mobility of the pupil; but the removal of a larger portion of it, or complete extirpation, occasions permanent blindness and immobility of the pupil, with temporary muscular weakness on the opposite side" (§ 527). Again he says, "The subservience of these bodies to the exercise of the visual sense appears, on the whole, to be the point best established in regard to their functions" (*ibid.*).

This view has been very much modified by the more recent school of experimental physiology in relation to the functions of the brain, as represented in England by Dr. Ferrier and others. Dr. Ferrier takes exception to the reasoning which would infer that the corpora quadrigemina are the centres of vision, from the mere fact of their destruction producing blindness. He says, "The facts of anatomy and those of physiological experiment mutually support the view that the corpora quadrigemina, though not the centres of conscious vision, are *centres of co-ordination of retinal impressions* with special motor reactions." This definition, however, is identical with that which Swedenborg made one hundred and forty years ago; for he says, "The fibre of the corpora quadrigemina is directed chiefly towards those parts of the eye *which are being adjusted to the state of the objects* [of sight] at the time, and indeed spontaneously, and without any previous will of the cerebrum."

47. If we inquire further, By what means are the corpora quadrigemina able "to adjust the parts of the eye to the state of the objects at the time, and indeed spontaneously, without any previous will of the cerebrum"? Swedenborg answers, that it is on account of the

influx of cerebellar fibres into the corpora quadrigemina; for, says he, "The first of the processes or peduncles of the cerebellum [processus ad testes] enters into the caudex of the medulla oblongata, and encircles it immediately below the posterior tubercles of the corpora quadrigemina. Thence a way is prepared for it, in company with the fibres of the rounded tops of the corpora quadrigemina, of entering into the surface and the structure of the optic thalami." And again he says, "If the fibre of the cerebellum flows likewise into the eye, there is no other way by which it can do so except through the isthmus, and thence through the optic thalami into the optic nerves; or by that way whither the fibres of the corpora quadrigemina . . . tend."

Arnold[1] denies that the first process of the cerebellum enters into the corpora quadrigemina. He says, "Formerly it was universally supposed that the medullary processes of the cerebellum in the direction of the cerebrum enter into the substance of the corpora quadrigemina, on which account these processes were called '*crura cerebelli ad corpora quadrigemina*' [or *ad testes*]. I was the first who showed ('Bemerkungen,' etc., p. 40) that this is a mistake, and that these medullary processes pass under the corpora quadrigemina with a view of reaching the 'tegmentum' of the crura cerebri. Stilling ('Ueber die Brücke,' etc.) confirmed my observation" (p. 720).

Meynert, while admitting the justice of Arnold's remarks, says, "A *processus corporis quadrigemini ad cerebellum* certainly exists, probably made up of fibres from the brachia after their decussation; although this designation is by no means deserved by the tract to which it is usually given—the processus cerebelli ad cerebrum. It properly belongs to the frænulum of the valve of Vieussens, which consists demonstrably of two similar halves, and which runs by way of the valve of Vieussens into the superior vermiform process of the cerebellum" (*loc cit.*, p. 700).

48. Ferrier in analyzing the action of the corpora quadrigemina on the eye says, "Flourens first experimentally demonstrated that the optic lobes [corpora quadrigemina] were the centres of co-ordination between retinal impressions and movements of the iris. When the optic lobes on both sides were destroyed, vision was completely abolished, and the pupils ceased to contract when light was thrown on the retina. This is a proof that in the optic lobes there is an organic connection between the optic and the oculo-motor nerve which supplies the circular or constringent muscle of the iris. This connection has an anatomical basis in tho fact that tho central nucleus of the oculo-motor or third nerve, is situated in the corpora quadrigemina beneath the

[1] Arnold (F.), "Handbuch der Anatomie des Menschen," vol. iii. section ii. Freiburg, 1852.

aqueduct of Sylvius, or the canal which as it were tunnels these ganglia" (*loc. cit.*, p. 71).

This last statement is confirmed by Meynert,[1] who says, "The nerve-cells in the lower half of the aqueduct of Sylvius . . . in the region of the anterior tubercles constitute the common nucleus of origin of the oculo-motorius and trochlearis. . . . From the substance of this common nucleus of the oculo-motorius and trochlearis, in which the *fibræ rectæ* of the nucleus lenticularis terminate, spring the roots of the *oculo-motorius* nerve, being fibrous bundles of considerable thickness. . . . From the same nucleus spring the roots of the *nervus trochlearis*" (see above, p. 629).

Swedenborg was well aware of the relation which the oculo-motor or third nerve holds to the corpora quadrigemina. Thus he says, "The aqueduct of Sylvius seems to afford space for the roots of the nerves tending towards the muscles of the eye, so that they are able to act by a living force. Its grey substance also seems to concur with the cerebrum in causing these nerves to move; namely, the *third* [or oculo-motor] nerve, the *fourth* [or trochlear] nerve, the *sixth* [or abducent] nerve, with the ophthalmic part of the *fifth* nerve. All of these derive their fibres of origin from that neighbourhood, and in a certain measure depend upon the optic thalami, by which the above passage is enclosed, and thus they concur with the sight of the eye itself in the production of a similar effect" (i. no. 531*a*).

49. That the *third* and *fourth* nerves spring from the neighbourhood of the aqueduct of Sylvius has been confirmed above by Ferrier and Meynert. In respect to the origin of the *fourth* or trochlearis nerve Meynert[2] says further, "The nucleus of origin of the trochlearis lies anterior to the aqueduct and in the region of the anterior tubercles, while its final point of exit lies behind the aqueduct and below the posterior tubercles" (see above, p. 629).

Concerning the origin of the *fifth* nerve he says,[3] "Even within the limits of the anterior tubercles, the central tubular grey matter [in the aqueduct of Sylvius] encloses nuclei that give rise to the motor-nerve roots referred to [of the third and fourth nerves], which lie more or less near the *median* line; also a *laterally* disposed sensory-nerve track, the roots of the *fifth* cerebral nerve. The fibres composing these roots originate at the outermost border of grey matter that surrounds the aqueduct of Sylvius" (see above, p. 630).

That the *sixth* or abducent nerve also, in accordance with Swedenborg's statements, is partly derived from the region of tho aqueduct of Sylvius, and thus from the corpora quadrigemina, Meynert[4] admits as

1 In Stricker's Handbook, etc., American edition, p. 703.
2 *Ibid.*, p. 704. 3 *Ibid.*, p. 704. 4 *Ibid.*, p. 737.

probable in what follows. He says, "Whether the innervation of the *sixth* or abducent nerve by certain special centres of co-ordination (corpus quadrigeminum) takes place directly, or whether by means of fibres that cross the median line from the opposite side, must be determined by studying the history, in other parts of their course, of the tracts by which that nerve is connected with the centre in question. Certainly the interesting fact discovered by Gudden is worthy of mention in connection with the influence exercised upon the *sixth* nerve by a distant nervous centre in the neighbourhood of the origin of the third or oculo-motor nerve [*i.e.* the corpora quadrigemina]—namely, that a flattened bundle of fibres passes transversely from the anterior tubercles of the corpora quadrigemina into the crus cerebri (tractus transversus pedunculi), which band Gudden found to attain only to an imperfect degree of development when, in new-born animals, he rendered the retina incapable of performing its functions, and which therefore may be supposed to bear a certain functional relation to that organ" (see above, p. 632).

NOTE IV.

FUNCTIONS OF THE CORPORA STRIATA AND THE OPTIC THALAMI.

1. IN respect to the office of the corpora striata Swedenborg makes the following declarations :—

"The body is a texture of the fibres of both brains, and also of the medulla oblongata and the spinal marrow. That all this, however, takes place by the mediation of the corpora striata which are an appendage of the cerebrum, is proved by many things; namely, by the fact that the fibres of the cerebrum descend chiefly by that channel; further, that its fibres have to be strengthened by more robust ones, in order that they may be able to produce actions; also that by means of these corpora striata the cerebrum may take a rest, and have a respite for its work of reasoning, and as it were may withdraw itself from the body; so that the soul of the cerebrum simply issues its commands, but the corpora striata execute them" (i. no. 88).

"From ossified, or as they are commonly called petrified brains, as well as from acephalous and also hydrocephalous heads, confirmation is obtained of what has been established above from anatomy alone, namely, that the beginnings of the medulla oblongata, that is, the corpora striata, are vicarious cerebra, and that they succeed in the place of the cerebrum whenever it is deprived of its power of acting. For the power of acting of the cerebrum does not extend beyond the above-mentioned beginnings, and thus beyond the medulla oblongata, nor, indeed, does it reach to the spinal cord itself. These carry out into action whatever the cerebrum decrees; the cerebrum without the auxiliary forces of these medullæ being unable to operate anything whatever in the body. For where the primary cause is, there the secondary cause is also present; whenever, indeed, the primary cause is engaged in ruling the least particular things, and in beholding things outside itself. This is the reason why the cerebrum from its own medulla, with the exception of the olfactory nerves, does not send out a single nerve into the kingdom of the body, without the mediation of the medulla oblongata and the spinal marrow. This, I say, has been established from anatomy; for every fibre of the cerebrum immerses itself into, and associates itself with, the fibres of the corpora striata in the medulla oblongata, and summons them around itself as auxiliary forces, before descending further. Thus these fibres are secondary beginnings of the motions in the body; nay, they are even primary beginnings, when the cerebrum is as it were absent, and they take its place. . . .

"From the connection of the medulla oblongata and the spinal cord with the cerebrum, it follows that the former may act from themselves, without consulting the cerebrum, when the latter relaxes and loosens its fibres. These fibres are loosened, when one and the same action has frequently passed the same way. In this case the striated bodies [*i.e.* both the corpora striata proper and the optic thalami] can initiate motions which at first originated with the cerebrum and were voluntary; for it is a well-known fact that voluntary acts by daily habit become spontaneous, or that habit is like second nature. Experience also declares this. The feet with all their articulations and muscles are taught at last to walk as of themselves on a road that has once been pointed out to them, the cerebrum being unconscious of it at the time. The arms learn how to fold and throw themselves about in agreement with each gesture of the body; and every least muscle of the body knows how to accommodate itself to the ideas of the mind, and to oratorical effect and gesture. Mimics, actors, gesticulators, nay, and even flatterers, learn how to dispose and actuate the single motory fibres of the body at a given signal from the cerebrum, so that the countenance, the voice, the gestures, all conspire in expressing one thing in a natural manner. The mind of its own accord, and by usage alone, flows into the expressions of the various languages, and is not conscious at all in what manner the tongue, the lips, the throat, the larynx and windpipe apply themselves. The finger wanders over the chords, and strikes the lyre, the cerebrum itself not knowing anything about it; somnambulists also, while the cerebrum is asleep, indulge in the performance of bodily acts, apparently not their own. This alone is a convincing proof that there is an organ acting as a substitute, in place of the cerebrum which starts the motion. These substituted or secondary organs can be no other than the medulla oblongata [which includes here the corpora striata and the optic thalami known at Swedenborg's time as the upper and lower beginnings of the medulla oblongata] and the spinal cord, through which the cerebrum executes the acts of the body, and from which the fibres of the nerves proceed immediately" (part i. nos. 939, 941).

2. In reading these extracts from Swedenborg's work on the Brain, written one hundred and forty years ago, we seem to hear one of the disciples of modern science, on the basis of the results obtained by vivi-

section, descanting on the function of the corpora striata, or of the "central ganglia," as they call them. So Dr. Althaus says in the December number of the *Nineteenth Century*, 1879 :—

"The *central ganglia* [corpora striata and optic thalami] which constitute the fourth great division of the brain, have the function to render certain complex movements which are intimately connected with sensations, and which are, in the first instance, only excited by volition and consciousness, gradually, as it were, mechanical and automatic. The object of this contrivance is to save time and trouble to the highest portion of the brain, viz. the grey surface of the hemispheres. It is intended that these latter should only be occupied with the most important manifestations of life. The 'central ganglia' may therefore be said to be the confidential servants or private secretaries of the hemispheres, and undertake a good deal of drudgery, in order to leave the grey surface at liberty for the finer and more difficult kinds of the work which falls to our lot in life. Thus we have, in childhood and youth, to learn the actions of walking, talking, writing, dressing, dancing, riding on horseback, decent eating and drinking, singing, playing of musical instruments, etc., by countless conscious efforts on the part of the hemispheres; and full attention is necessary in the beginning in order to enable us to carry out such movements in a proper manner. But the older we grow, the more frequently we have directed our minds to all these forms of activity, the less effort will eventually be necessary on the part of consciousness and volition; and ultimately all such movements will be performed mechanically, and without much, if any, attention to them on the part of the grey surface of the brain. A man who is in the habit of writing much never thinks of the way in which he forms his letters on the paper, over which his pen seems to fly quite mechanically. The same holds good for the various kinds of needlework, embroidery, playing on the piano, violin, etc. If, each time we do anything of that sort, a conscious effort were necessary for all the different parts of which the action is composed, the time at our disposal would not suffice for the hundredth part of the work which we actually get through in life; and some forms of activity, such as finished piano and violin playing, would be utterly impossible.

"A key is thus furnished for the comprehension of many singular occurrences which would otherwise be quite inexplicable. A pianist, for instance, finds himself playing one of Rubinstein's sonatas by heart, and is perhaps thinking all the time of his coming trip to Switzerland, or something else which may happen to engage his attention; that is, the 'central ganglia' play the sonata, while the hemispheres are busy elsewhere. A very worthy country parson told me some time ago that when he reads prayers at church he does so quite as an automaton, for his mind keeps wandering in a totally different direction. A man who knows London may walk from his house through a maze of streets with the greatest precision to his club, where he arrives without having given the slightest attention either to the act of walking or the direction he took, but having been quite in another world of thoughts all the time he was on his way.

"Somnambulism and other automatic conditions, which are observed in certain states of derangement of the nervous system, may be similarly explained. The lower 'centres' are habitually under the absolute control of the highest, that is, the hemispheres; yet this balance of power may be temporarily disturbed by illness or exhaustion of the grey surface, and the 'central ganglia' may then begin to act in their own fashion. What may take place under such circumstances may be aptly compared to certain occurrences which are not uncommon when the family is out of town, and the servants are left in charge of the house. Supposing the hemispheres to have lost their control over the lower 'centres,' elaborate actions may take place which may have all the appearance of deliberate intention, and yet for which the person who commits them can no more be held responsible than the absent master of the house for the misdoings of his servants. The somnambulist who falls from the roof of a house and is killed, is no more a suicide than a man who in the state of epileptic vertigo commits robbery, arson, or murder, can be called a truly responsible criminal" (pp. 1026, 1027).

3. In respect to the relative functions of the corpora striata and the optic thalami, Swedenborg holds that both are subservient to sensation and motion. He says, "The cerebrum is the general motory as well as sensory organ, and it is also the general laboratory of the fluid essences of its body. The optic thalami as well as the corpora striata afford a vicarious aid to the cerebrum in these threefold functions" (i. no. 493).

"In respect to *motion* : The optic thalami, like the corpora striata, follow the sole auspices and beckoning of the cerebrum, and they are not moved until the cerebrum begins to turn the hinges. . . . They divide among one another the offices, and at the same time the provinces, of the medulla oblongata and the spinal marrow which are subjected to them. . . . The corpora striata, as well as the thalami, are the vicegerents of one and the same cerebrum, ministers of the same kingdom, and consorts of one bedchamber or of one ventricle; each having assigned to it its peculiar province, the government being divided between the two. They are, however, unanimous generals ; for one does not proceed faster than the other; but both proceed at the same rate as the cerebrum itself, because they all act, or are compelled to act, from one and the same beginning or origin of motion" (i. nos. 494, 495).

"In respect to *sensation*: The corpora striata are placed over the sense of smell, but the optic thalami over that of sight, wherefore they are also called thalami nervorum opticorum; and both together minister to the senses of hearing, taste, and touch" (i. no. 496).

4. Dr. Ferrier strenuously opposes this view; for he holds that the corpora striata are exclusively subservient to the motor tract, and the optic thalami to the sensory tract. Dr. Althaus does not seem to be so sure of this distinction, since he evidently claims the power over habitual and automatic action for both "central ganglia."

Dr. Ferrier states the results at which he has arrived in the following words: "We know that by constant and habitual repetition, modes of action which were acquired by long and painful education and conscious effort ultimately become so easy as to be performed without attention, if not absolutely without consciousness. We have reason, from the facts of comparative physiology, to regard the corpora striata as the centres in which these habitual or automatic movements become organized. The optic thalami play the same subordinate *rôle* to the sensory centres which the corpora striata play to the motor centres of the hemispheres. That they are not the centres of true conscious activity is clearly proved by the facts already advanced, which show that the regions of true sensation are above these ganglia. But though the consciousness of sensory impressions must precede any true volitional act in response thereto, we find that by education and frequent repetition, the action becomes so easy as to follow impression without conscious discrimination or attention, the nexus between impression and action becoming so organically welded in the sensory and motor centres as to assume the character of reflex reaction below the domain of consciousness. In this case we may suppose that impressions made on the organs of sense travel up to the optic thalami, and thence pass directly to the corpora striata, instead of taking the larger or conscious circle through the sensory and motor centres of the hemispheres. That this shorter or automatic circle is sufficient for purposes of locomotion in the dog is shown by the fact that notwithstanding the interruption of the larger circle by excision of the cortical motor centres in this animal, movements in response to immediate impressions, or (when the sensory centres of the cortex remain) in response to ideal impressions, are still capable of being effected with tolerable precision and steadiness. The destruction of the corpora striata annihilates the centres of organization of these motor activities, and the animal lies helpless and completely paralyzed" ("Functions of the Brain," pp. 252, 253).

5. This summing up by Dr. Ferrier of the functions of the corpora striata and the optic thalami strongly recalls to our mind a statement of Swedenborg's which we quoted in our preface, and which on account of its appositeness we repeat here: "I found when intently occupied in exploring the secrets of the human body, that as soon as I discovered anything that had not been observed before, I began (probably seduced by self-love) to grow blind to the most acute researches of others, and to originate the whole series of inductive arguments from my particular discovery alone. . . . Nay, when I essayed to form principles from my discoveries, I thought I could detect in various other phenomena much to confirm their truth, although in reality they were fairly susceptible of no construction of the kind." This seems to represent Dr. Ferrier's position in analyzing the functions of the corpora striata and of the optic thalami. He had made some new discoveries respecting these functions by vivisection, and dazzled by their brilliancy, he grew blind to all the results which anatomy obtained by following up carefully, by means of the microscope, the course of the fibres of the cerebrum. On the basis of vivisection alone therefore he denies that the corpora striata are subservient to sensation, although modern anatomical researches confirm Swedenborg's statement, that "these corpora are placed over the sense of smell, but the optic thalami over that of sight."

Again his assumption that the corpora striata are subservient only to motion, and the optic thalami to sensation, compels Dr. Ferrier in the case of the excision of the two cerebral hemispheres to assume "that impressions made on the organs of sense travel up to the optic thalami, and thence pass directly to the corpora striata," when yet anatomy shows that there are no fibres which pass directly from the corpora striata to the optic thalami, and *vice versa* (see Meynert, etc., p. 681-695); so that in the case of excision of the hemispheres, the reflex actions excited by the afferent or sensory fibres of the corpora striata and optic thalami must be carried out by the efferent or motory fibres in each of these organs.

6. But let us examine the results of the anatomists in respect to the origin of the olfactory nerves.

Cruveilhier states that "Vieussens, Winslow, and Monro describe these nerves as arising from the corpora striata." He also says that "Herbert Mayo, in his beautiful plates, has represented the deep roots of these nerves as coming from the corpora striata."

Meynert[1] says, "The caput nuclei caudati [of the corpora striata]. extending beyond that part of its body which is visible in the lateral ventricle, curves downwards to the base of the brain, where its inferior

[1] In Stricker's "Manual of Histology," New York, 1872, p. 681.

portion constitutes the grey matter which lies just above the anterior perforated space. Gratiolet gave to this inferior region the name *olfactory district.* I am able to bear witness to the justice of this designation by confirming the fact that this inferior district of the corpus striatum is invested by a thin layer of cortical substance, whose continuity with the cortex of the olfactory lobe may be easily demonstrated both as regards the neuroglia and the nerve-cell stratum of the latter" (see above, p. 553).

In another place he says,[1] "The first member of the projection system [the medullary fibres springing from the cortex cerebri] enters the corpus striatum, . . . *thirdly,* under the form of fibres which connect the cortical substance of the olfactory lobe with the corpus striatum, whether it be the superficial fibres which take their rise in the bulbus, or the deeper laid medullary substance of the olfactory lobe. That portion of the olfactory medullary substance, however, that enters the anterior commissure, seems merely to traverse, without interruption, the substance of the corpus striatum" (see above, p. 553).

Again he says,[2] "The relative increase in the size of the ganglia of the caudex in man affects the nucleus lenticularis far more than the nucleus caudatus, which is probably due to the fact that *the development of the latter is dependent upon* that of a region of the brain which is but poorly represented in man, namely, *the olfactory lobe*" (see above, p. 558).

7. As to the other declaration of Swedenborg, "that the optic thalami are placed over the sense of sight," this is scarcely doubted by any one. Quain says on this subject, "Each optic tract may be traced backwards from the commissure, across the crus, to the under surface of the optic thalamus, at the posterior extremity of which it ends by blending with the corpora geniculata. Its fibres may be traced into the corpora geniculata, the *optic thalamus,* and the anterior of the corpora quadrigemina. Those which enter the thalamus, pass, some through the corpora geniculata, some beneath the inner corpus geniculatum, between it and the crus (as the middle root of some authors), to reach the cells of the lower stratum of the thalamus" ("Elements of Anatomy," ii. p. 567).

Meynert[3] confirms this, for he says, "In this region the thalamus may be separated into an upper and a lower division. . . . The radiating fibres of the *lower* division come evidently from the tractus opticus, *i.e.* from the retina, forming the so-called 'middle root' of the tractus. *The latter set of fibres pass from the medullary substance of the optic tract,* between the external corpus geniculatum, and the crusta

[1] In Stricker's "Manual of Histology," New York, 1872, p. 682.

[2] *Ibid.*, p. 687.

[3] *Ibid.*, p. 695.

cruris, about twelve mm. in front of the posterior border of the tuberculum posterius, *into the substance of the thalamus*" (see above, p. 580).

Again he says,[1] " In fact the stratum zonale of the thalamus is made up of those fasciculi which come through the tractus from the retina" etc. (see above, p. 582).

These anatomical facts which bear out completely Swedenborg's theory of the corpora striata and the optic thalami, are totally ignored by Dr. Ferrier in his summing up of the functions of these bodies.

[1] In Stricker's "Manual of Histology," New York, 1872, p. 697.

NOTE V.

The Lungs and their Motion.[1]

1. The organic forms or living structures, determined by their essentials, that is to say, by the vessels and fibres, and bounded and covered in by their common bonds or sheaths, require to be excited at intervals to their natural exercitation and play of motion, in order that their powers may become active forces, that the inherent nature of each may declare itself, that their labours may be prosperous, and that they may return perennially to their primitive state, and thus perpetuate life. This play of motion consists in the alternate expansion or swelling of the whole and all its parts: it is termed respiration and animation in living subjects; oscillation, vibration, and tremulation in inanimate subjects; and modification in the atmospheric world: and the latter of these coincide with the former: and it is as well common, or a condition of the whole, as singular, or a condition of the parts; so that it receives its name from its subjects, offices, and internal relations. Precisely as the least forms oscillate, vibrate, and perform modification, so also do the larger and the largest; so, for instance, does the universal machine of the organic body. The production of this effect is the end of those pneumonic bellows, the lungs, the alternate respirations of which call all things into activity, and infuse into them new and living powers of action. The breath of life that was breathed into the nostrils of the first parent of the human race was no other than the respiratory breath of the lungs; for it is this that opens the scene of bodily life, as well as in a certain image represents the higher life.

2. It is perfectly manifest that the most general use of the lungs consists in respiration; but we must go farther than this, and inquire what respiration has to do with life; nor must we rest here, but must push the matter still onwards into ulterior purposes, investigating the use of use: finally, we must discover what is the last use of the series, or the use that brings up the rear, which last use, like a gem in a

[1] From Swedenborg's "Animal Kingdom (*Regnum Animale*) considered anatomically, physically, and philosophically," vol. ii. nos. 392 to 410. Translated by Dr. J. J. Garth Wilkinson.

diadem, or in the circle of a crown, will also become the first use, and will lead the van; for there is a perpetual chain of uses, as of effects and causes, every cause and every effect involving a use.

3. The office imposed upon the lungs by their nature and structure consists in admitting the contiguous air through the larynx, the trachea, the bronchia, and the bronchial ramifications, into the vesicles of the lobules, and in immediately driving it back again through the same line of passages : thus by inflating their bags at intervals the lungs expand and contract; they draw breath or take in air; in a word, breath or respire. *Inspiration* is brought about by the force of the incumbent air, when opportunity is allowed it of passing into the given apertures. The force of the air is ascertained by multiplying the height of its column, and the consequent gravity, with the area of the given orifice ; and according thereto it presses equally against the sides in every direction. Proportioned to this is its effort or endeavour; and furthermore, its actual power as soon as it obtains the opportunity of rushing into the void spaces through the given orifice. By this force and gravity, then, the air opens all the bronchial locks that it comes against, separates the parietes, smooths out the corrugated passages, extends the very foldings of the interstices, and finally expands the vesicles—empty, collapsed, and united to each other in the way of pyramids by plane surfaces—into aërial bullæ and pyriform spheres, and thus raises a number of them into a distinct lobule. At the same time the intercostal muscles, the triangulares sterni, the muscles of the diaphragm, and several others that are supplied by the trunks and branches of the twelve dorsal nerves, contract and raise the ribs, extrude the vertebræ, expand the diaphragm, and thus enlarge the thorax : by virtue of which circumstances there is nothing from the inmost parts to the outmost to resist the advance of the air and the intumescence of the lungs. *Expiration*, on the other hand, is brought about by a general contractile effort on the part of all the internal constituents of both the lungs, that is to say, of the fibres, nervous, ligamentary, motive, and tendinous, and of the vessels that support and construct the ramifications of the bronchia, or their cartilaginous pieces, delicate circles, and membranous integuments. Simultaneously with this effort the before-mentioned muscles relax, the ribs are retracted into their natural situation, the diaphragm is relaxed and hollowed, the concave surfaces of the lungs adapt themselves to the hollow, and the thorax is contracted in its whole circumference ; thus there is nothing but drives the retreating air, and applies itself to the subsiding lung. Hence the internal forces of the lungs, which are natural, and the external forces, which in the daytime and during the waking state are voluntary, concur to each alternate movement of the respiration.

The internal forces or parts yield to the pressure of the air, while the external contract, raise their levers, and provide the requisite space; and *vice versa.* Thus the contraction of the voluntary muscles, united with the action of the atmosphere, gives the air the power of inflating the lungs and of overcoming nature; and the contractile action of the lungs, in conjunction with a similar action on the part of the levers of the thorax—the will the meanwhile being in a state of repose—gives nature the power of throwing out the encroaching Æolus; hence the province of the will is confined to admitting, and during good pleasure retaining, the aërial guest; but driving it out is left to nature. The above circumstances clearly show the nature of the equilibrium that exists in ordinary respiration, between the gravitating powers of the circumambient atmosphere and the singular or internal powers of the lungs in conjunction with the common or external powers of the thorax.

4. Not only do the lungs themselves respire, but they also cause the whole of the organic system to respire along with them; namely, both the middle region, in which they themselves are situated; the superior region, which is that of the head and the cerebrum; and the inferior region, or that of the abdomen; and, in fact, even the appendages of the trunk—the arms and hands, the legs and feet, down to the tips of the fingers in the one case, and to the ends of the toes in the other: so that there is not a corner in any province of the kingdom whither the pulmonic breath does not penetrate with active power; and this, by the mediation and instrumentality of a number of general appliances,—for instance, of the mediastinum, the pleura, the diaphragm, the peritonæum, the ribs, and the vertebræ; speaking generally, by the mediation of the nerves, vessels, membranes, muscles, tendons, ligaments, cartilages, and bones, that is to say, of all the constituents that make up the compages of the whole. We shall clearly perceive this to be the case if we consider the continuity, relation, and circling course of the above substances; nay, we may have sensible experience of it in our own persons in the respective acts of sneezing, coughing, shouting, vociferating, evacuating the fæces, wrestling, and other similar operations, during which we distend the lungs and augment the breathing to the greatest degree; that is to say, provided we fix our mental vision attentively upon all the circumstances of the case. And again, the fact is brought completely home to our senses, and placed in clear light, in the simpler and less elaborate forms of the animal creation—in worms, nymphs, caterpillars, butterflies, flies, and other little living machines of a similar kind; in which the pulmonic breath flows in, not as in animals of larger dimension, through so many mediations and instrumental appliances of ligaments, membranes, and muscles,

and through so many cartilaginous and osseous balances, but immediately, by air-vessels or bronchial pipes, dividing and ramifying in the form of fibres through all the organic powers of the body; and this flowing in by manifest co-operation expands their chain of uses.

5. The lungs not only effuse their moving breath or breathing motion into the general connecting media of the body, as the tunics, the muscles, and the septa,—and thence into the viscera enclosed thereby, as the stomach, the liver, the mesentery, the pancreas, the spleen, the kidneys, the bladder, the testicles, the vesiculæ seminales, the uterus, the ovaries, and the rest; but they also infuse it into the distinct particular congeries and simple forms of those viscera, that is to say, into their lobules, glands, and follicles, down to the very intimate recesses of each: and thus the lungs excite them, every one, in their general form as well as in all their parts, to operate in accordance to their nature and structure, inspiring force into potency, and thereby giving birth to natural effects or actions. Thus respiration calls forth the intimate lives of the determinations[1] into actions, or into their ultimate lives; so that the lungs are the very gymnasia of the exercises, effects, and uses corresponding to the ends or intuitions of the soul. Hence the numerous ligaments and fræna put forth by the diaphragm and peritonæum, thrown over all the viscera, connected by continuity with their external coverings, and produced into capsules or little sheaths that enswathe their several essential determinations, proper vessels, blood-vessels and nerves, surround them with a fibrous tissue, affect them perpetually, and in fine penetrate to all their intimate organic principles, whether vesicular or glandular. This is most clearly seen in insects; in which the pulmonic breath pervades the occult recesses of all these viscera, and mounts into them, not by the above substantial bridges and extrinsic reins, bonds and capsules, but by an uninterrupted machinery of air-pipes, and so assigns to each viscus its particular lung, and inspires it with its own pulmonic breath.

6. This pulmonico-atmospheric air or spirit penetrates not only into the organic works enclosed in the peritonæum, but it even invades the heart itself, the much venerated and worshipped co-regent with the lungs of this living world, and the illustrious partner of their bed. From it the lungs derive their corporeal life and soul, namely, all its blood and venous constituents, as well as its tunics, proper and common; for its præcordia or particular pleura, termed the pericardium, passes in the form of a cellular and fibrous sheath round the bronchial ramifications, the arteries, veins, and nerves, to the intimate follicular clusters of the lungs, and there, as in so many centres, meets the terminations of the trachea, and enters into close and intimate union

[1] See the definition of determinations, p. 40, footnote 2.—EDITOR.

with them. The lungs, in their turn, foster in their embrace this ruler of the kingdom, press him to their breasts, and reciprocate the act of love; for they likewise enter his pericardium with their common coat, by means of the mediastinum and the diaphragm; and they enter the sinus of his left auricle, with all their blood, venous constitution, marrow, and life: nay, they even surround his great arteries and veins, the aorta and the vena cava, with the pleura, with the diaphragm, and finally with the peritonæum; and more than this, they enswathe his bifurcations, I mean, the ischiadic, spermatic, and many other vessels, with a similar covering. Thus the lungs extend their action to these parts as well as to their head, the heart; so that wherever the heart penetrates by means of the arteries—whithersoever it carries the circulatory motion—thither also it brings with it the spirit of the lungs. The heart by means of the arteries diffuses the blood, or the corporeal soul, in all directions, while the lungs affuse the spirit of this world, the ultimate and corporeal spirit. Hence the ultimate or corporeal life is the result of the union of these two principles, the preliminary scene of its drama being opened and commenced by the lungs at birth, when we make our first entrance upon the theatre of this world's life.

7. The respiration of the lungs flows not only into the trunk of the body, but also into the head, and into its organs of motion and sensation; and, in fact, to the cerebrum, the very fountain of its motion, to which it rises in infinite streams, as it were in meanders and circles, and associates itself with the reciprocal respirations, or, as we term them, the animations of the cerebrum. Thus the lungs and the brains with the medulla oblongata and spinalis are synchronous in their respective animations and spirations; and this, in order that causes may act harmonically and conspire in operation with effects, things prior with things posterior, and the spirit of the soul with the spirit of the body, and in order that there may be an influx and reflux of the one into the other. On these accounts the pulmonic engines or bellows rise precisely at the same moments that the cerebrum inspires its costal, and the cerebellum its sympathetic nerves.

8. From these premises it follows that the lungs are the organs which open the scene of corporeal life and constitute the gymnasium of its exercises; for by wonderful influx they conspire in the way of general assistance to all its motions, effects, and actions, common and particular, natural and voluntary. For this end the universal fabric of the body and all its organic works are so mutually connected and coherent that there is no point whither the pulmonic respiration does not penetrate; nor is there a single fibre of a nerve which the lungs do not by a general assistance excite to action: most manifestly does

this apply to the nerves and twigs of the par vagum and of the great sympathetic nerve, which are the principles of the natural operations; likewise to the nerves of the medulla oblongata and spinalis, which although determined by the cerebrum, yet in the body are themselves determinant of the actions of the will. When the cerebrum and cerebellum by their rising and constriction, that is to say, by their animation, inspire all these nerves with living spirit, then the lungs for their part, by an analogous and consociate rising and constriction, that is to say, by their respiration, inspire them with an active and co-operating spirit, and carry on the causes to the effect: thus the lungs, in a secondary manner, incite and drive into circulation the very spirit of the nerves, or, as it is termed, the animal spirit. In order to enable the lungs to perform these ministrations a peculiar organic form is bestowed upon them, and a natural faculty implanted in the form, whereby they have a free power of admitting any given quantity of the wind or atmosphere, and of opening in any direction, and any door they please, and thus disposing themselves, by means of the muscles of the thorax, abdomen, and neck, that is to say, by means of all the muscles of the body, to every possible angle of direction and mode of formation; and therefore of accommodating themselves by infinitely varying states to what is done, and to what is to be done. For this end the pulmonary air-pump is divided through the middle into two lungs, which are parted and separated by the mediastinum; these lungs are divided into lobes by deep notches and fissures; these lobes again into lobules, which hang like clusters from the branches of the pulmonic vein; and these lobules, in fine, into vesicles representing single grapes, which are the chambers and receiving-rooms of the air that has been permitted to enter. For the same end also each bronchial passage is capable of being opened and shut *ad libitum*, particularly in its subordinate branches and ramifications, and in the doors leading to the lobules and vesicles, by an adaptation of external forces, and through the intervention and influence of the ligament upon the common coat of the lungs. Furthermore, every lobule and vesicle has the power of transmitting its own gentle zephyr through convenient anastomoses into the adjoining vesicles, and thereby into the remote vesicles; and thus of dispensing the air to every form of action, and to every use resulting therefrom, as may be seen still more plainly in the universal lungs of the insect tribes.

9. The lungs also associate and marry the voluntary motive life which originates from the cerebrum with the natural motive life which flows from the cerebellum; that is to say, during the waking state, when the will is dominant, and nature lies as it were asleep. At this

time the bronchial pipes are half opened, the air vesicles half distended, the common ways or peduncles open, the doors unlocked, and the vessels and membranes so intent upon the commands and wishes of their ruler, that at the first intimation they turn their hinges, and promptly rush into obedience. Such is the waking state of the lungs, and there is a similar state of all the muscles and sinews of the body, because there is a corresponding state of the cerebrum in the daytime, when it holds the reins of the will. Nevertheless, nature shares the empire with the will, for the latter only constringes the nerves and reins of the body, and keeps them constricted and drawn up so long as it pleases; but as soon as it relaxes its hold, then nature takes up the government and performs the contrary operation; as when we draw a bow, and then releasing it, shoot off the arrow, in which case the first act belongs to the will, the second to nature, for the loosened string bounds back spontaneously, and the arrow flies to its aim. Inasmuch as this drawing and straining of the fibres continues in various degrees during the day, according as the will commands, it follows that the costal nerves and muscles, being in a corresponding state, keep the lungs semi-expanded and raised, and consequently perfectly ready to afford any desired co-operation, and thus render the voluntary actions alternate with the natural actions.

10. Although during ordinary, tranquil, and spontaneous respiration, the government is shared between nature and the will, yet in the concurrence of the respirations with actions originating from the mind, the will engrosses nearly the whole of the power, and pushes nature from her throne to a low and humble seat; for besides the intercostal and other muscles, which minister to the lungs in respiration both by day and night, the will also calls into action several others, belonging to the breast, the neck, the head, the abdomen, and the back, and marshals them in battle array against the forces and efforts of nature. The muscles to which I allude are the pectorales, serrati, rhomboideus, cucullaris, abdominales, and many others, which, equally with those before mentioned, raise, depress, extrude, slant, and twist the ribs, the vertebræ, and the diaphragm, according to the simultaneous or successive determination of the fibres, more or less numerous, which are called into action by the command of the will. By these auxiliaries the will not only inspires and keeps up the lungs, but also empties and compresses them; and according to the degree of wakefulness, intensity, and presence of mind in the actions, seizes the department and province of nature and prostrates her authority.

11. In addition to their concurrence to the voluntary actions of the cerebrum, the lungs also superadd something from their own powers and properties, namely, a certain hardness, strength, softness, gentle-

ness, or some other similar endowment; and, moreover, all that the animal mind communicates to the will, the will communicates to the pulmonic breath, and this to the actions. Thus the lungs not only enter the forms of actions in the way of provisional and corporeal principles, but also inspire them with a kind of fire; and thereby represent them in ultimate effects precisely such as they are intended to be in first principles; as in all the affections of the animal mind, to which the qualities of motions or actions correspond—in anger, fury, heroic valour, frenzy, fear, mercy, pride;—that is, when our breasts are swelling, drooping, sinking in, or trembling. This is more clear from the diminutive actions of the larynx, namely, from sounds and speech, than from any of the other actions of the body.

12. The lungs extend the power of their breathing-apparatus not only around and below themselves into the viscera and masses of the body, but also in an especial manner above themselves into the trachea, the larynx, and the palate, with which they concur to produce, exalt, and regulate the sounds of singing and speech, in the same manner as the uterus concurs to conceive, nourish, and give birth to the offspring; and this by so wonderful a power, that they can cunningly apply themselves to the actions of the body at the same time as to the little actions of the larynx; like those who cultivate the player's art, and combine the voice harmoniously with the instrument, and the word with the action. When the will by education has become imitative or mimetic, it causes the lungs to produce the notes of sound much in the same manner as the blast of the mouth causes the trumpet, or as the finger causes the flute, to bring forth musical or melodious notes. Just so the will, governing the muscles, awakens its pulmonic lyres; these, the tracheal pipes and strings; and these, again, the laryngeal harp, from which the melody issues forth. The continuously successive series of causes down to the ultimate sonorous actions appears to be as follows. The muscles of the thorax, together with the true respiratory muscles, keep the two pulmonary bellows inflated, balanced, and raised up, the air being invited and driven into the last vesicles, that is, into those nearest to the surface. The diaphragm adapts itself closely to the concave surface of the lungs. The abdominal muscles, the sacrolumbalis, and many of the subpectoral muscles gradually drive up this septum from beneath, and by means of the ligaments, the pleura, and the common coat of the lungs, press the vesicles, and squeeze out the air. The air, driven from the cells by these external or voluntary forces in conjunction with the internal or natural forces, rushes with a strong impulse against the opposite parietes of each bronchial ramification, and from these again in like manner in a contrary direction against the parietes of the bronchial trunk, and

ultimately against those of the trachea, and thus against the membranes, tense as they are throughout, the squamous pieces and little cartilaginous circles, consequently against elastic vibratory objects, which will never suffer a stroke without returning as much as they receive. The air thus stricken and perpetually reverberated, encompassed wherever it goes with the trembles of the membranes, and accompanied by trembles of its own, is rolled through the trachea into the larynx, where, in the mouth of the glottis, by the educated vibration of the arytænoid cartilages, it is moulded into the form of sound, that is, into either singing or speech. The lungs do no more than supply a quantity of sonorous wind; but the larynx, the palate, the tongue, and the lips set forth and dispense the same—inflect, draw out, and divide it; in a word, reduce it into measured quantities and periods.

13. The consequence or conclusion from the foregoing premises is, that the brains and the lungs concur with unanimous spirit to produce every effect in the body; and they are moreover so absolutely united by nerves, membranes, and organic powers, like two balances or scales containing exactly equal weights, that the one moves when the other moves, and the one stands still when the other stands still: hence if the breath of the one be suspended, that of the other stops; no matter whether the suspension originate from a cause in the cerebrum—in its nature or its will; or from a cause in the lungs, the larynx, the palate, or the mouth; that is to say, whether it originate from an internal or from an external cause. Thus the lungs open the motive, but voluntary, life of the body, and at the same time enable the will to reign in conjunction with nature; and if they open the motive life, then they also initiate the sensual life of the body: for wherever there is action, there is also will; wherever there is will, there is also perception; and wherever there is perception, there is also sensation. Wherefore, inasmuch as the will is the beginning of actions, and is the end of sensations, therefore the lungs in instituting the one life also institute the other.

14. But we must now pass from the consideration of the spirit or breath wherewith the lungs animate the universal kingdom to the consideration of the blood which the lungs drink from the mouth of the heart, and return into its other chamber. For the blood, collected from innumerable venous streams into the right auricular cavity and ventricle of the heart, swollen and adulterated with chyle and vapour, fresh and obsolete—with chyle and vapour that has not yet been triturated and refined, but is undigested, vaporous, and flatulent;—this blood—mixed and confused, as in a rude chaos, in mutual implication and entanglement, with the pure, spirituous, florid, and youthful blood—the lungs eagerly and thirstily snatch and

swallow through the venous or pulmonary artery, and convey along the bronchial passages to their intimate chambers and secret cells; and on the way they divide the disorderly mass by continual acts of severation, in their branches, capillaries, and tufts, and ultimately down to its unities, which they lustrate or purify singly or particularly in their little reticulations. After this, whatever is sanguineous, or kindred thereto and consanguineous, they transmit into continuous veins; but whatever is discordant and heterogeneous, whatever is merely a dead weight and a useless burden, hostile to the marriage of the chyle with the spirit, and windy or flatulent, they expunge and banish out of the bronchial and vesicular lobules into the cells of the interstices, and there work and knead by reciprocal powers of constriction, and express its liquid from its thicker parts. But the lungs do not throw out the whole of this impure humour, for the veins select and reabsorb the part available for the blood; the lymphatics imbibe the spirituous part when sublimed to the surface, while the cellular tissue carries off the spume that is left, and extrudes it through foramina, leading uninterruptedly from the vesicles to the larynx, into the bronchia and trachea. Thus the lungs clear away the dross and impurities of the blood, and purify and correct the undigested contents of the heart, divided, according to nature's wonted manner, into their individual parts; at the same time that they eructate and banish the air, the mortal enemy of the blood, in the form of effete and vapid halitus and vapours. In this manner they are the prime and general strainers or Colatories of the blood, and the Evaporatories of its sweats. The foregoing statements are corroborated by the concurrent testimony of many circumstances; as, 1. The reticulations of blood-vessels in the intimate recesses of the lungs, and in the external parts of the pulmonary bladders of those animals which have no proper lungs. 2. The uninterrupted interstices and cellular tissue surrounding the arteries, veins, and air-tubes, and continuous and permeable on the one hand all the way to the trachea, on the other hand all the way to the surface. 3. The numerous lymphatics and veins opening with their little mouths in these hollow recesses. 4. The multitudinous foramina pervious and open from this tissue into the bronchial ramifications, the bronchia, and the trachea. 5. The experimental evidence furnished by the inflation of air into the bronchial vessels, and by the injection of coloured fluids into the arteries. 6. The quantity of viscid humour occupying the follicular spaces of the lungs, and causing various morbid affections. 7. The viscid humour of a similar kind covering the bronchiæ of fishes, in which an analogous process of percolation is carried on. 8. The fœtor that strikes the olfactory papillæ in the expirations, being not completely sheathed or concealed by the vapoury halitus. 9. The blood itself pronounces and declares the same thing on its own behalf; for all that is venous in the blood is poured by the heart into the lungs; and all that is arterial is poured back, changed in nature, appearance, and condition, that is to say, become florid, lively, and brisk, by the lungs into the heart. 10. And indeed, when poured back, it is found to have been reduced in quantity in the filters and strainers of the lungs; for the vein which goes into the left auricle of the heart is less than the vein which goes up into the lungs from the right ventricle of the heart, contrary to the usual habit of nature in other parts of this kingdom.

15. As the lungs load the air thrown out by expiration, with the adulterations and impurities cleared away from the blood, so they thoroughly examine the air attracted by inspiration, and alternately a welcome guest: and should it have brought any rich or choice presents in its vaporiferous bosom—any members of the volatile families of salts, sulphurs, and nitres—the lungs suck them in delightedly by their veins: although as soon as ever they have enjoyed the banquet, they throw out the air as the most deadly enemy of the blood, and, as we said before, load it like a mule with a baggage and burden of adulterations, and force it to carry them out. Let us now consider more minutely the successive stages of its immigration and arrival. The atmosphere, impregnated with effluvia exhaled abundantly from the three kingdoms of nature, and filled with odours, fragrant or the reverse, is attracted in volumes by the spiracles of the nares. The olfactory papillæ exquisitely anticipate whatever is concealed in these volumes, whether favourable or unfavourable to the pulmonic blood; if favourable, they imbibe it with open lips, and carry it home, as consisting of nectareous dainties and preserves, into the very depths of the vesicles of the lungs; but if hostile, they keep it out of doors by the compression of the alæ or pinnæ, and dread its approach, and chase it away. But the nares carefully supervise and examine whatever they admit for the sake of breathing, and invite for the sake of refecting the blood; all heavy and inert particles, sooty flakes, saline spiculæ, miasmata, and the like, which are of great weight and no value, they ensnare in their viscid mucus, and bury in their moist lacunæ. Those matters which go past the nares are similarly purified by the trachea. The bronchia likewise assist in the work, and finally their subordinate branches and ramifications, upon all points of which the intruding air impinges. Thus the air, closely examined at every corner of the way, and emunged of its impure accompaniments, at length comes to the lungs in their smallest form, namely, to the vesicles, and now warm and bathed in vapours, it has nothing in its bosom but what is friendly to the blood—nothing but delicate and welcome presents, which the

veins, omnipresent in their little atmospheric world of the vesicle, and hungry after all their losses, must eagerly seek out, select, and imbibe. Thus the blood, fed and feasted with occult, ethereal, and heavenly food, and no longer turbid and cloudy, but serene, florid, purple, joyous, lively, and worthy of marriage with the spirit, has already put on the arterial robe. But the air, which is only the ministering attendant for bringing and proffering these gifts to the blood—lest it should insolently rush, as it attempts to do, into the bed of the blood, and pollute its marriage—is driven out headlong and loaded with fines and burdens. Thus the lungs, by virtue of their office, are not only the *Colatories* and *Emunctories*, but the *Refectories* of the blood, the *Preparatories* also of the blood from venous to arterial, and the *Lustratories* of the air. This view is confirmed by a multitude of facts, which by their clear bearing upon the point convert what were before opinions into natural inferences. For, 1. The atmosphere conveys and carries about in its bosom, not a mere wave, but a whole ocean and cloudland of effluvia, by which the smell is affected, the state of the animal mind changed immediately from confusion to serenity, or from serenity to confusion; the blood suddenly awakened, or benumbed with torpor; and the life raised up as by a breath from heaven, or withered by contagion. 2. Sleep, cataphora, carus, and even ecstasis and catalepsy, nourish the blood with a kind of mystic food. 3. Many persons have prolonged life for months, years, and ages without taking any ordinary [terrestrial] sustenance. 4. And not a few species of animals, and those of the most voracious kind,—for instance, bears—live for a very considerable time in a state of natural asitia, and are actually fattened when they come from their winter dens; to say nothing of vipers, chameleons, and a number of other creatures, which if they do not feed upon effluvia, nevertheless, in the act of inspiration, enjoy a foretaste and perception of what is suitable to the blood in their daily food. 5. We may also gather confirmations from anatomy, for the parietes of the bronchia and vesicles are beset with congeries of veins, which greedily snatch all those things that will appease the hunger of the blood, and after taking what will be beneficial, reject all those things that are inimical to the blood. 6. Moreover, the blood returned into the arterial or left auricle and ventricle, is visibly changed in character, just as it would be by exposure to the air, or by mixture with a saturated nitrous solution. Nor must we omit to notice the proof derived from, 7. The bronchiæ of fishes, by which the blood is brought into contact with the air, to go back into the system, refected with atmospheric food. By these means it is ordained that whatever exists in the world or universe of nature—whatever is laid up in the great bosom of things

—shall minister and yield compliance to the subjects of the animal kingdom, and pre-eminently to their blood. This, then, is the ultimate function—the final office of the air.

16. When this sanguineous chaos—this crude and undigested volume—has been driven through the filters of the lungs, purged of its discordant parts, and skimmed of its impure phlegm; when furthermore it has been saluted with atmospheric kisses, enriched with occult, celestial aliment, and raised thereby to a higher power of radiance, then the portion of it that flows into the veins, and passes into the left chamber of the heart, is arterial; and its very serum is so virgin and marriageable, that wherever it finds the spirit unmarried or single, and comes into relation with it, there it forms a speedy alliance; the issue of which is a ruddy, flaming, and refulgent blood, a parent so prolific that the universal body is its offspring and its common progeny. Now since the blood constantly maintains its venous character and mixed indiscriminate condition all the way from the right cavern of the heart to the rete mirabile and intimate villi of the lungs, therefore it seems proper that the pulmonary artery, as it is usual to term it, should rather be considered as a *vein;* yet, again, since it has one distinguishing mark of an artery, in that it diminishes in calibre and increases in the number of its ramifications, in the direction of the sanguineous current, and in its ultimate capillaries separates and excretes various essences from the blood, therefore it would appear that it may deservedly and *ex officio* be termed an *artery.* And if we put these circumstances together, and think fit to denominate this vessel at once from its peculiar blood, and from its function, then we shall find that we cannot bestow upon it any term more appropriate than its ancient name of *venous artery* or *arterial vein.*

17. Two points now demand exploration, namely, with what systole and diastole do the pulmonary arteries and veins pulsate, and under what government do they act, under the government of the heart, or under that of the lungs; for thus much is certain, that the heart pours its blood with spontaneous readiness into the pulmonic channel and its pipes, and that the lungs drink it with eager mouths and veins. According to the facts revealed by anatomy, and confirmed and attested by the phenomena of respiration, the following appears to be the progression. The blood, sent from the heart into the lungs, as its grand capsules or appendages, never stops until it arrives in the last meshes and reticulations, that is, in the field of leasts, or in the parietes of the interlobular cells, where it flows round and round in a perfectly free arena. In these intimate goals and centres reside the essential pneumonic power and nature, as well as the circulatory power that propels the blood in the lungs. In other words, from these centres

the lungs govern their circumferences to the farthest limits in all directions; namely, to their external covering, to the beginning of the trachea, and to the two entrances of the heart, where the venous artery flows in, and the arterial vein flows out. It is evident from the reciprocal stretching and relaxation of the cells, while the lungs are inhaling and exhaling the breath, that these reticulations constantly thirst for the blood, and demand it from its branches and trunks, and from the cardiac bed, and that they as constantly send away and refund it into the other bed or cavity of the heart; but not alternately, that is to say, not during the intervals of inspiration and expiration. For the reticular meshes of blood-vessels that form the parietes of the cells are half extended and half relaxed during every act of breathing; thus while they are increased in length they are diminished in breadth, and *vice versa*. These meshes govern the large arterial and venous branches and stems proceeding along the sides of the bronchia; and the fibres of the pneumonic plexus, alternately elongated and shortened by the breathing of the lungs, institute this everlasting play. Thus the lungs hold the reins of their blood-vessels, and leave the heart no power over them, excepting with respect to the importation of the blood; and by the very condition of their nature and structure they continually thirst for a fresh supply, and continually reject the old supply. The truth of these statements is corroborated by a number of circumstances; as, 1. The ready reception and as it were invitation of the blood from the right chamber of the heart; and its ready ejection, and as it were spontaneous return to the left cavity of the heart; that is to say, after the lungs have once been opened or filled with air. 2. The course of the blood-vessels, within a capsule put forth by the heart, and along both sides of the ramifications of the trachea. 3. Their foldings and doublings during the contraction of the lungs. And, 4. Their reticular division and ramification in the cells of the interlobular tissue. 5. The similar division and ramification of the fibres of the pulmonary plexus. 6. The evident harmony subsisting between the circulation of the pulmonary and the circulation of the cardiac blood. And many other circumstances to be found in medico-anatomical records will furnish fresh points of corroboration.

18. But besides the pulmonary arteries and veins—as it were, the mistresses—there are also certain handmaids and domestics, termed the bronchial arteries, which (arising either from the great artery, at the beginning of its descent, or from one or more of the intercostals, or from the œsophageal, or from some other root connected with the intercostals, in some cases as a single vessel, in others by two trunks, one answering to each lung, in others again by almost as many trunks as there are lobules), take the same course as the former vessels, skirting

along the bronchia, all the way to the ultimate stadia and plexiform reticulations of the lungs. In fact, the bronchial arteries not only keep step with the pulmonary arteries, and accompany them to the very end of their walk, but even by frequent anastomoses join footsteps with them, and form a general alliance, and either retrace the way in common with them, to the left auricle of the heart, or else go out by particular passages, in the form of veins, to some branch of the intercostal veins, or of the vena azygos. The blood, running back through the bronchial vessels, but lately was blood in the pulmonary vessels, which now reascends, clothed in its own proper coat, to take the same course again and again, and serve the pulmonary vessel as a daughter and handmaid; for it follows their track, step for step, and as we said before, associates and interweaves its branches with theirs. This artery, I. In conjunction with the twigs of the par vagum and great sympathetic nerves, was what conceived, engendered, and constructed the embryonic lung, and all its vessels, aëriferous, arterial, and venous; and laid down and formed those direct passages along which the atmospheric air and the cardiac blood are to pass and glide in the second period of life: thus this artery was once the parent, but now the change in its fortunes has made it the daughter and the slave. II. It still performs a sort of parental office, for it in a manner runs before, and points out the way that is to be followed, as far as the reticular goals of the lungs, where it receives the pulmonary artery in the guest-chamber which it (the bronchial artery) formerly prepared; and teaches the former to play the artery, although it carries venous blood. III. The bronchial artery regulates, balances, and equalizes the respective quantities of the cardiac blood rushing into the lungs, and of the pulmonic blood returning into the heart; that is to say, whenever either organ labours under superabundance or deficiency of blood: for where there are two quantities actuated by different currents of motion, there must be some regulation, level, and equation; so that if either too much or too little, relatively to the desire of the lungs, be poured in by the right cavity of the heart, and consequently too much or too little be poured back into the left cavity, the deficiency may be supplied from the common channel of the aorta, or the superabundance be thrown out into the common channel of the intercostals or into the vena azygos. IV. The bronchial artery serves to equalize the quality as well as quantity of the venous blood, or that of the right ventricle of the heart, just as the hepatic artery serves to equalize the quality of the venous blood in the liver; for it besprinkles this thick and squalid blood, scraped together, as it is, from so many muddy streams, with blood that has been once lustrated by the lungs, and dilutes and vivifies it, so that it is no longer slow and lazy, but performs its functions with rapidity. V. By means of this artery and vein the lungs concur with the organic machine of the thorax, and produce therewith unanimous actions; for the intercostal arteries and veins, as also the vena azygos, from which these bronchial vessels arise, are the vessels that excite all the respiratory muscles of the body, to forces and actions correspondent and alternate with the internal breathings of the lungs.

19. But we must now draw to a conclusion, and in fine contemplate not the details, but the sum and amount of the matter. Respiration is threefold—natural, voluntary, and mixed. *Natural* respiration prevails when the lungs from internal causes, and the thorax from external causes, perform a prolonged series of unanimous reciprocations; and it prevails in one manner during the day, in another manner during the night. *Voluntary* respiration is various according to the degree of wakefulness enjoyed by the senses and the animal and rational minds, and according to the forces brought into action in the body, that is to say, according to the bodily exercises; and it may be either pure, or alternating with natural respiration: in which latter case it constitutes *mixed* respiration. The respirations are irregular, the irregularity depending upon the state of the lungs, or of the palate, the larynx, the trachea, the bronchia, the vesicles, the interlobular cellular tissue, the pedicles, the rete mirabile, or the air; of the arteries and veins, pulmonary and bronchial, and of the blood and other humours; of the fibres of the pneumonic plexus, and of the animal spirits: depending also upon the state of the thoracic cavity, of the pleura, the mediastinum, the ligament [ligamentum latum pulmonis], the diaphragm, the pericardium, the heart, the sternum, the vertebræ, and the ribs; upon the state of the breast, the pectoral muscles, tendons, aponeuroses, blood-vessels, and nerves; upon the state of the cerebrum, cerebellum, medulla oblongata, and medulla spinalis, with the animations of which the respirations of the lungs accord in their details and stages; and lastly, upon the general condition of the muscular, membranous, sanguineous, and nervous systems. Hence we may have respirations, either even, slow, deep, laborious, weak, harsh, compressed, sharp, hissing, hoarse, stertorous, painful, attended with fits of choking; or uneven, quick, tacit, full, easy, gentle, etc.; and the same [differences] in action, voice, and sound. These are so many diagnostic and pathognomic signs, revealing in a general manner the ailments and diseases of the body and animal mind; signs which are applicable whether the disease be asthma, continued or periodical, dry or moist, idiopathic or sympathetic, attended with dyspnœa or orthopnœa: or whether it be angina [quinsey], watery, œdematous, catarrhal, schirrous, inflammatory, suppurative, gangrenous, or convulsive: or phthisis, proceeding from

ulceration, empyema, abscess, vomica, or crude tubercles: or whether it be peripneumonia, pleuritis, catarrhus suffocans, hectic fever, vertigo, swooning, or phrenitis, etc. In fine, these signs are equally important, whether the disease come by defluxion from the brain and animal mind, or proceed by influxion into the brain and animal mind; for the lungs manifest what the brains conceal.

END OF VOL. I.

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