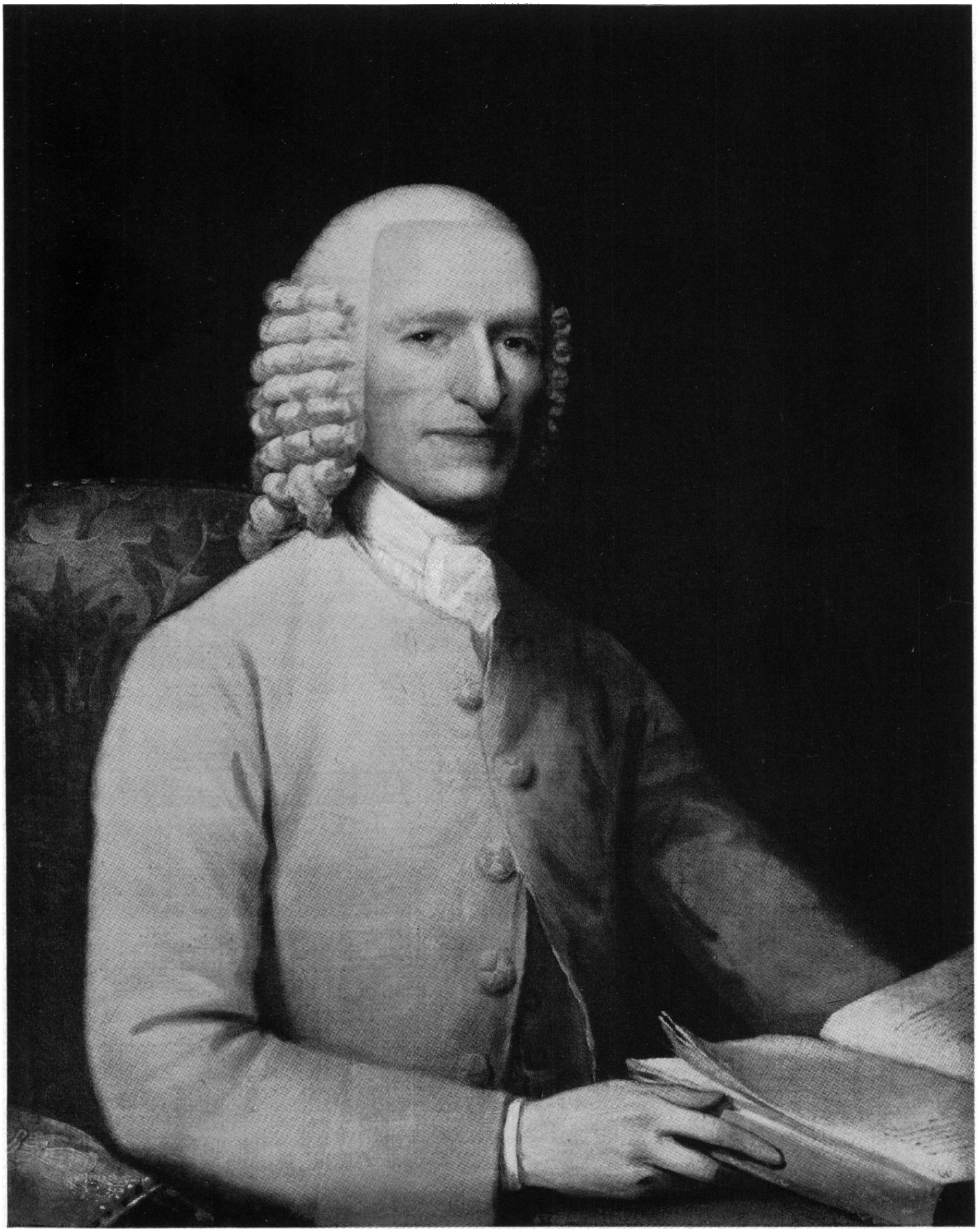

JOHN FOTHERGILL, M.D.
(From the painting by Gilbert Stuart in the Pennsylvania Academy of Fine Arts.)

THE HISTORICAL SIGNIFICANCE OF THE CEREBROSPINAL FLUID

BY

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THE neurophysiological advances of the nineteenth century, culminating in the enunciation of the neuron doctrine, excluded the meninges, the cavities of the brain and the cerebrospinal fluid from any major role in the economy of the nervous system. The phenomena of sensation and motion are explained today without reference to any other cell but the neuron, and it is confidently expected that, in the near or distant future, the neurological basis of behaviour will be elucidated on similar principles. With such an approach to the central nervous system any attempt at the understanding of the historical attitude to the circulation of the cerebrospinal fluid and its channels must be severely handicapped. In the calendar of human knowledge the neuron is as old as the internal combustion engine, the meninges are coeval with the Pyramids. Men have known the meninges for five thousand years and the ventricles for fully half that time, and for all those years save for a single century they have believed that the mainspring of human activity and thought was closely identified with these structures.

1. *How the ventricles came to assume supreme significance in ancient and medieval neurophysiology and psychology*

Hippocrates described hydrocephalus in both man and the domestic animals and knew that water inside the head was the cause of the swelling. He gave no indication, however, that he knew where this water was situated. The author of the treatise on 'Ancient Medicine' in the *Hippocratic Corpus* thought that the head was expressly designed to attract water from elsewhere inside the body, for its shape, 'a broad hollow that tapers', was comparable to that of other organs, the bladder and uterus, which possessed the power of collecting fluid. In another place Hippocrates described the brain as a gland which attracted water from the body. This concept was further developed by Aristotle, who, contrary to the views of Plato, Hippocrates and the medical opinion of his day, gave primacy to the heart and gave to the brain the secondary role of tempering the heat and seething of the heart.

https://doi.org/10.1017/S0025727300021025 Published online by Cambridge University Press

When the nutrient streams upwards through the blood vessels, its refuse part is chilled by the influence of this region, and forms defluxions of phlegm and serum. We must suppose, to compare small things with great, that the like happens here as occurs in the production of showers. For when vapour steams up from the earth under the influence of heat and is carried into the upper regions, so soon as it reaches the cold air that is above the earth, it condenses again into water owing to the refrigeration, and falls back to the earth as rain.[1]

The characteristic Aristotelian parallel between the microcosm and the macrocosm should be noted. It is the precursor of other similar comparisons which together formed the medieval conceptions of the ventricles.

Herophilus restored the brain to primacy as the seat of the intelligence. His writings give the first clear indication of familiarity with the ventricles of the brain. Erasistratus, who followed the 'pneumatic' rather than the 'humoral' school, evolved an ingenious theory of muscular contraction in which the ventricles of the brain played a leading part. As he described it, air became a *vital spirit* in the heart. This spirit was carried throughout the body by the arteries, and when it reached the ventricles of the brain it became an *animal spirit* which was transferred by the hollow nerves to the muscles of the body. It distended these muscles and produced contraction. In Erasistratus's description of the role of the ventricles is the first mention of the theory of their significance which was to be accepted for two thousand years. The anatomical description of the ventricles given by Herophilus and Erasistratus was propagated by Rufus of Ephesus,[2] a writer who, although strongly influencing Arabic medicine, was not read in the Western world until the middle of the sixteenth century.

If the views of Erasistratus had depended solely on Rufus of Ephesus for their dissemination, medieval psychology might have taken a very different form. Through Marinus of Tyre, whose master Marcus Aurelius was of course a Stoic, the pneumatic theory reached Galen. In the hands of Galen the simple concepts of Erasistratus were ingeniously and intricately woven into the framework of the detailed topographical anatomy of the ventricular system which Galen was the first to describe. The rise of the Christian Church was to a considerable extent responsible for the maintenance of Galen's supremacy, for as Singer[3] has suggested, interest in the structure of the body declined with the general focusing of attention upon the soul. Galen's system which was essentially monotheistic and his concept of the body as the instrument of the soul made his views acceptable alike to Christians, Jews and Arabs.

To comprehend fully the views of Galen on the function of the cerebral ventricles it is necessary first to grasp the essentials of his physiological system. Galen described three varieties of *pneuma*, which in their degree of separation and inter-relation might be compared to the Christian Trinity.

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Fig. 1. Decorated letters from the *De Humani Corporis Fabrica* of Vesalius, 1543.

Pneuma in the Pythagorean sense was drawn from the general world spirit in respiration and passed through the lungs and pulmonary veins to the left ventricle where it met the blood. At the same time, chyle reached the liver via the portal vein and became venous blood embued with the living essence of the body, the natural spirit or *pneuma physicon*. Some of this trickled through pores in the ventricular septum of the heart and passed from right to left ventricle. In the left ventricle it mingled with the externally derived pneuma and became the vital spirit or *pneuma zoticon*. In the rete mirabile at the base of the brain, this vital spirit was worked up into the *pneuma psychicon*, the animal spirit. The process of conversion of the vital to the animal spirit was accomplished by a 'boiling' and 'sieving' through the exquisitely fine mesh of the rete mirabile. Further 'boiling' and 'sieving' refinement occurred in the anterior ventricles. From these ventricles the pneuma pervaded the whole ventricular system. Thence it traversed the nerves 'as sunshine passes through air or water'[4] and so operated the muscles.

The rete mirabile which Galen described is of course a feature of the cerebral vascular system of the artiodactyla, but not of that of man. Galen remarked, 'Ox-brains totally prepared are to be had in all the large towns.'[5] This ready availability of the ox-brain was a bane to anatomical research even after human dissection was resumed at the Renaissance. In two of the decorated letters in the *Fabrica* of Vesalius *putti* or *amorini* can be seen dissecting the head of an old man and an ox respectively (Fig. 1), and Vesalius[6] remarks that he never dissected a human head in public without

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having a sheep or ox head at hand. According to Galen's theory, after the refinement of the pneuma in the rete mirabile and anterior (lateral) ventricles, a certain amount of refuse-matter was left over and had to be disposed of. This refuse-matter was of two consistencies, the gaseous and the liquid. The steamy detritus passed upwards to be dissipated through the air-sinuses of the skull and the cranial sutures. Because of its gaseous nature this was not perceptible to the senses. The liquid refuse followed two pathways. From the anterior ventricles it percolated through openings in the cribriform plate of the ethmoid bone, which were spiral in shape so that neither cold air nor solid bodies could penetrate upwards to damage the ventricles. From these canals it emerged into the posterior nares to be discharged as the nasal secretion. The other pathway of escape for the refuse was bifid and more complicated in its course.

The account of these two channels is in Galen accompanied by a typically acid attack on those who cannot see such things through their ignorance. It is curious that Galen in describing these channels uses words which have an ironic flavour in the light of our present knowledge:

> so that you would think that Nature, who apparently does nothing in vain, would have made this aperture to no purpose; but he, who dissects carelessly, commits crimes of this kind not only against anatomy itself, but against its natural maxims; for wonderful as is the use of certain anatomical facts when properly observed by dissecting, in the same manner those which have been wrongly observed, make the speech of use in vain.[7]

His commentator Oribasius,[8] softening Galen's asperities, remarked the most careful way in which Nature has provided these channels for the excretion of the waste products. He described the two conduits as leading, the one from the third ventricle, the other from the region of the mid-brain, to a common receptacle in the infundibulum. The pituitary acted as a reservoir for the waste products and discharged them into the naso-pharnyx as phlegm.

It is generally agreed that dissection was rarely if ever practised between the death of Galen and the rise of the school of Bologna in the early sixteenth century. For a period of over a thousand years Galen's anatomical descriptions were unquestioned and his writings in their original form were not available to the Western world until the twelfth century, or later. During the intervening period the Galenical inheritance passed into the hands of the Arabs. The distaste which they felt on religious grounds for the study of anatomy had its effects even on the transcriptions which they made of Galen. Thus if one compares the anatomy of Haly Abbas with that of Galen, as has been done for the brain by Wiberg,[5] one is struck most forcibly by the extreme differences in both quality and quantity. On all counts the description of the Arabian is vastly inferior and he makes it abundantly clear that he had little first-hand knowledge of the brain.

Between the Galenical and the medieval concept of the ventricles there is nevertheless one considerable difference. In the medieval accounts specific mental functions are attributed to the respective ventricles. In general to the anterior (lateral) ventricles are ascribed the powers of imagination, cogitation is assigned to the middle (third) ventricle, and memory to the posterior (fourth). How this concept originally came to be linked to the Galenical concept of the ventricles is something of a mystery, and the origins of the doctrine have been closely studied by Sudhoff.[9] Only the outlines will be given here.

The earliest protagonists of this theory were Poseidonius, Theophilus, Protospatharius and Nemesius. It has been suggested that the tripartite division of the brain as to mental functions might have had some basis in clinical observation of the effects of head injuries, that imagination was affected by a blow on the front of the head and memory by a blow on the back of the head. Again, it may be based on purely theoretical concepts, on the Aristotelian division of the soul or on a comparison with the architecture of the Greek temple. Galen held that the softer sensory nerves entered the anterior ventricle, and it is possible that from this belief arose the idea that imagination was located there.

Whatever its origins this doctrine of mental localization in the ventricles was absorbed together with Galen's anatomy into the vast compendia of Arabic medicine to return to Europe with the rise of the Salernitan school, and appears in many complex and obscure forms. Even when dissection was resumed in Europe in the late fifteenth century, this concept continued to gain acceptance and dominated every aspect of thought about the brain during the Renaissance. Its most fantastic variations arose through its interpolation into the theory which accounted for the removal of waste products from the brain after the elaboration of the *pneuma psychicon*. For example, Galen had held that the choroid plexus of the lateral and third ventricles acted as a valve regulating the flow of pneuma or of waste matter from the anterior to the middle ventricle. In a similar way he considered that the vermis of the cerebellum prevented the reflux of the pneuma from the fourth to the third ventricle. When this view of Galen's was combined with the notion that the ventricles are cells of imagination, thought and memory, it appeared in the following form in the *Anothomia* of Hieronymo Manfredi.[10]

To the side of this is another thing like a subterranean worm, red as blood, yet tethered by certain ligaments and nervelets (choroid plexus and taenia semicircularis). And this worm when it lengthens itself closes these passages, and thus blocks the path between the first ventricle and the second. Nature has wrought it thus, so that when a man wills he may cease from cogitation and thought; and similarly when, on the other hand, he would think and contemplate, this worm contracts itself again and opens these passages and thus frees the way between one ventricle and another.

In medieval manuscripts and early printed books there appear a range of representations of the human head with the position and mental attributes of the ventricles indicated. These range from mere scrawls by indifferent penmen in the margins of medieval documents to the stylized geometrical representation of Albertus Magnus. Sudhoff[9] has given a table (Fig. 2) which illustrates the manner in which the description of the ventricles was transferred from writer to writer. Where one writer differs from another it is not justifiable to draw the conclusion that this represents a difference of opinion. It is most likely to represent an error of transcription. The consensus of opinion appears to be that the anterior ventricle was the seat either of imagination alone, or of imagination together with that 'sensus communis' which was really the distilled essence of appreciation of the external world. There was considerable unanimity that the reasoning powers resided in the middle ventricle, and that memory together with possibly the power to activate the spinal cord resided in the posterior ventricle. When anatomical dissection began again, certain minor readjustments were made to fit the anatomical facts. So Leonardo da Vinci[11] originally followed the traditional allocation, but as a result of his anatomical researches came to place sensus communis in the middle ventricle. For similar reasons he came to place the sense of touch in the posterior ventricle,

since we have clearly seen that the ventricle (IVth ventricle) is at the end of the medulla where all the nerves which provide the sense of touch come together, we can then conclude that the sense of touch passes to this ventricle, in view of the fact that in all processes Nature operates in the shortest time and way possible and so would the sense, in the shortest time.[11]

The manner in which the ventricular system was related to the *pneumatic* theory and to medieval notions of psychology has been considered at some length. The ventricles also were involved in the humoral doctrine. As a manuscript in Trinity College, Cambridge (1410), put it:

The forthyr parte of ye brayne is hoot and drye
The medyl parte hoot and moyste
The hyndyr parte colde and moyste
The rygth syde hoot and dry
The leyft syde colde and drey.

In a drawing in this manuscript an anatomical subdivision of the mental faculties is indicated.

	I. cellula	II. cellula	III. cellula
POSIDONIOS	φανταστικόν	λογιστικόν	μνημονευτικόν
NEMESIOS	αἴσθησις	διανοητικόν	μνημονευτικόν
AUGUSTINUS	sensus communis phantastica [2]) imiginaria	rationalis	motus omnis
JOANNES DAMASKENOS	φανταστικόν	διανοητικόν	μνημονευτικόν
COSTA BEN LUCA	sensus, phantasia	intellectus cogitatio providentia cognitio	memoria motus
RAZES	imaginatio	cogitatio	memoria
HALY ABBAS	phantasia	cogitatio	memoria
Die lauteren Brüder	Vorstellungskraft (phantasia)	Denkkraft (cogitatio)	Gedächtnis (memoria)
AVICENNA	sensus communis phantasia	cogitativa imaginativa existimatio	conservativa memorialis
CONSTANTINUS AFRICANUS	sensus phantasia	intellectus ratio	motus memoria
COPHO	phantasia	ratio	memoria
ADELARD V. BATH	phantasia	ratio	memoria
AVENZOAR	imaginativa	cogitativa	memoria
AVERROËS	sensus communis imaginatio	cogitativa extimativa	reminiscibilis conservativa
ALGAZEL	sensus communis imaginativa	imaginativa cogitativa	aestimativa memoria
WILHELM VON CONCHES	cellula phantastica	cellula logistica sive rationalis	cellula memorialis
RICHARDUS SALERNITANUS	cellula phantastica, imaginatio	cellula logistica ratio	cellula memorialis memoria
ALBERT DER GROSSE [1])	sensus communis imaginatio phantasia et estimativa	existamativa (imaginativa) cogitativa formativa	memorativa virtus motiva
THOMAS VON AQUINO	sensus communis phantasia sive imaginatio	existimativa cogitativa	memorativa
RICARDUS ANGLICUS	operationes sensibiles	ymaginationes cogitationes	
WILHELM VON SALICETO	sensus communis phantasia imaginatio	cogitatio existimatio	memoria
LANFRANC	sensus communis ymaginativa phantasia	aestimativa	conservat sententias pronuntiatas (memoria)
HEINRICH VON MONDEVILLE	sensus communis ymaginativa	aestimativa	secreta thesaurizat (memoria)
MONDINO	fantasia sensus communis imaginativa	cogitativa et rationalis	motiva memorativa
GUY DE CHAULIAC	sensus communis imaginativa	cogitativa et rationalis	servativa memorativa

Fig. 2. The allocation of mental functions to the ventricles according to various authorities. From K. Sudhoff: *Arch. Gesch. Med.*, 1914, VII, 149.

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A grand synthesis of humoral and pneumatic physiology with the psychological ideas of Poseidonius, Theophilus and Nemesius was achieved in the *Anatomia Nicolai physici*, compiled in the twelfth century, an English translation of which is given by Corner.[12] This anatomical text is clearly derivative from the *Pantegni* of Constantinus Africanus, which itself derives from the Arabian school. As such it represents the return to Europe of Galenical anatomy after its long sojourn in the Mohammedan world. As Bertrand Russell[13] has pertinently remarked, 'The sixteenth century, with its absorption in theology, is more medieval than the world of Machiavelli. The modern world, so far as mental outlook is concerned, begins in the seventeenth century.' Even when accurate information about the anatomy of the brain and its cavities became available, the old ideas about the function of the ventricular system persisted even into the nineteenth century, for traces of the old materialistic philosophy of Albertus Magnus can be encountered in the phrenological teachings of Gall and Spurzheim. Nevertheless, after the re-introduction of dissection into Europe, and particularly with the publication of Vesalius's great book, the tower of speculation which the philosophers erected upon the anatomical teachings and pneumatic theory of Galen began to totter. The shell of the structure remains clearly recognizable in the eighteenth century, and odd bricks can be recognized in unorthodox religions and medical systems even at the present day. If we wish to see the building as it was when it was in constant use as a centre of medical thought we can do no better than consult the *Anatomy* of Master Nicholas (twelfth century), and a quotation from his writing on the functions of the brain and ventricles seems to be an appropriate place to end the consideration of the ancient and medieval views on the physiology of the central nervous system.

All agree that the brain is of moist complexion. In substance it is subtle because of its subtle operation; it is thin and soft in order that it may receive impressions and easily give up what it has received. It is white in colour, so that it may freely receive impressions of different colours, since white is the most sensitive of colours. In constitution it is hollow and spongy, that it may hold the wastes derived from condensation of vapours rising to the brain, for if they were not detained there they would impede the circulation of spirits destined to carry out the operations of the mind. In form the brain is oblong with a degree of rotundity; round that it may be as mobile as possible in performing its functions, and so that it will not give room for much waste material; oblong, that its motion may be slow and not impetuous. . . . It has much of spirits and much marrow; much spirits to provide sensation and motion in the members and to carry on the various activities of the mind; much marrow to permit the free perception of divers forms and shapes. It is mobile with a two-fold motion, namely, systole and diastole, so that these motions may create an upward flow of heat, which cleanses the substance of the brain and consumes wastes retained in the cavities. It is divided into three cells, the cellula phantistica in the anterior part of the head, the cellula logistica in the middle, the cellula memorialis in the posterior part. In the cellula phantistica imagination is said to have its seat, reason in the cellula logistica, memory in the cellula memorialis. The first cell is hot and dry, having much spirits and a little marrow; the second is hot and moist, having much spirits and much marrow; the third is cold and dry, having little spirits and much marrow. The cellula phantistica is hot and dry, having much spirits, for the following reason: Just as among the natural forces we find the attraction of nutriment by the appetitive force aided by heat and dryness, so among the animal forces there is an attraction brought about by similar qualities, namely, heat and dryness. This cell has much of spirits, to provide for the carrying on of its functions, and it has little marrow, in order not to impede the flow of spirits in apprehending the nature of things. The cellula logistica is hot and moist for the following reason: Just as among the natural forces there is a digestion of what has been received, and separation of the purities from impurities of the diet, by the action of heat and moisture, so also among the functions of the mind there is a property of discrimination brought about by heat and moisture, by which things received into the cellula phantistica are distinguished, for instance, the true from the false, the honest from the dishonest, merriment from sobriety, and other contrasting things. It has much of spirits, in order that the spirits depleted by these subtle operations may be replenished. The cellula memorialis is cold and dry, for the following reason: Just as among the natural functions, there is first an attraction of nutriment by heat and dryness, and digestion by heat and moisture, and then there must be retention by means of cold and dryness; so likewise among the functions of the mind, beside the attraction of ideas to the cellula phantistica by heat and dryness, and the separation of the true from the false, and so forth, in the cellula logistica, by heat and moisture, there must be also retention, and this is carried out in the cellula memorialis by the action of cold and dryness. For this reason that cell is called 'treasure house of the memory'. It has much marrow, that it may be easily stamped with the impression of diverse ideas, but not much spirits, which might flow about and remove the impressions of ideas. On account of the three divisions of the brain the ancient philosophers called it the temple of the spirit, for the ancients had three chambers in their temples: first the vestibulum, then the consistorium, finally the apotheca. In the first the declarations were made in law-cases; in the second the statements were sifted; in the third final sentence was laid down. The ancients said that the same processes occur in the temple of the spirit, that is, the brain. First we gather ideas into the cellula phantistica, in the second cell we think them over, in the third we lay down our thoughts, that is, we commit to memory.[12]

2. *The development of knowledge of the structure of the cavities of the brain*

In a passage of idiosyncratic asperity and with a truly Galenic impatience Vesalius castigated those philosophers who, without examining the cavities of the brain personally, had endowed the ventricles with psychological attributes. Describing the teaching on this subject which he had received at the University of Louvain, Vesalius said:

That we should follow up more in detail the items which we were thus taught, we were shown a figure from some Philosophic Pearl which presented to the eyes the

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ventricles so discussed.... It was suggested to us that this figure comprehended not merely the three ventricles but all relevant parts of the head, and especially the brain!

Such are the inventions of those who never look into our Maker's ingenuity in the building of the human body!...

But what impiety can such a description of the uses of the ventricles (as it concerns the powers of the Reigning Soul) produce in ignorant minds not yet confirmed in our Most Holy Religion!... the brains of quadrupeds... closely resemble those of men in all their parts. Should we on that account ascribe to these beasts every power of reason, and even a rational soul, on the basis of such doctrines of the theologians?[17]

Vesalius's very natural and justifiable anger at the lack of knowledge of anatomy of the scholars of his age should not blind us to the difficulties under which these men had laboured. Although Galen gives a very good description of the form and relations of the anterior ventricles, his description of the other ventricles is always very thin and at times quite inaccurate. In the absence of access to either dissected material or to illustrations made by those with personal experience of dissection, it is little wonder that the medieval concept of the ventricular system degenerated into a trinity of hollow spheres. Leonardo was the first to apply experimental methods in order to obtain an idea of the configuration of the cavities of the brain. It is illuminating to compare the drawings made by Leonardo before and after he made wax casts of the ventricles. The drawing which Clark[14] dated 1490 is little more than a diagram apparently based on an Arabian text, probably of Avicenna (Fig. 3a). The next two drawings attributed by Clark to 1504 show a completely different picture of the ventricles (Figs. 3b and c). This difference is obviously due to the influence of the wax casts of the ventricular cavities which Leonardo made, probably early in 1504. The presence of a rete mirabile at the base of the brain (Fig. 3b) suggests that an ox was the animal used, although since Leonardo gave a very poor description of the arteries, it may be that this drawing showing the rete mirabile is an illustration of Leonardo's ignorance of the arterial supply of the human brain. However, although McMurrich[15] has suggested that the sulci in the small drawing of the surface of the brain represent an attempt at a delineation of the general human pattern, they do suggest very strongly the typical pattern of the sulci on the surface of the brain of the ox.[11] Since there appear to be no descriptions in the modern literature of casts of the ventricle of the brain of the ox, we are not in a position to say whether Leonardo's drawing is an accurate representation or not. It is ironic, in the light of Vesalius's faith in anatomy as a correction to faulty philosophic speculation, to study Leonardo's series of pictures of the ventricles. When he came to dissect the base of the brain he found that the sensory nerves were distributed around the third rather than the anterior (lateral) ventricles. He therefore transferred the location of *sensus communis* from the anterior to the third

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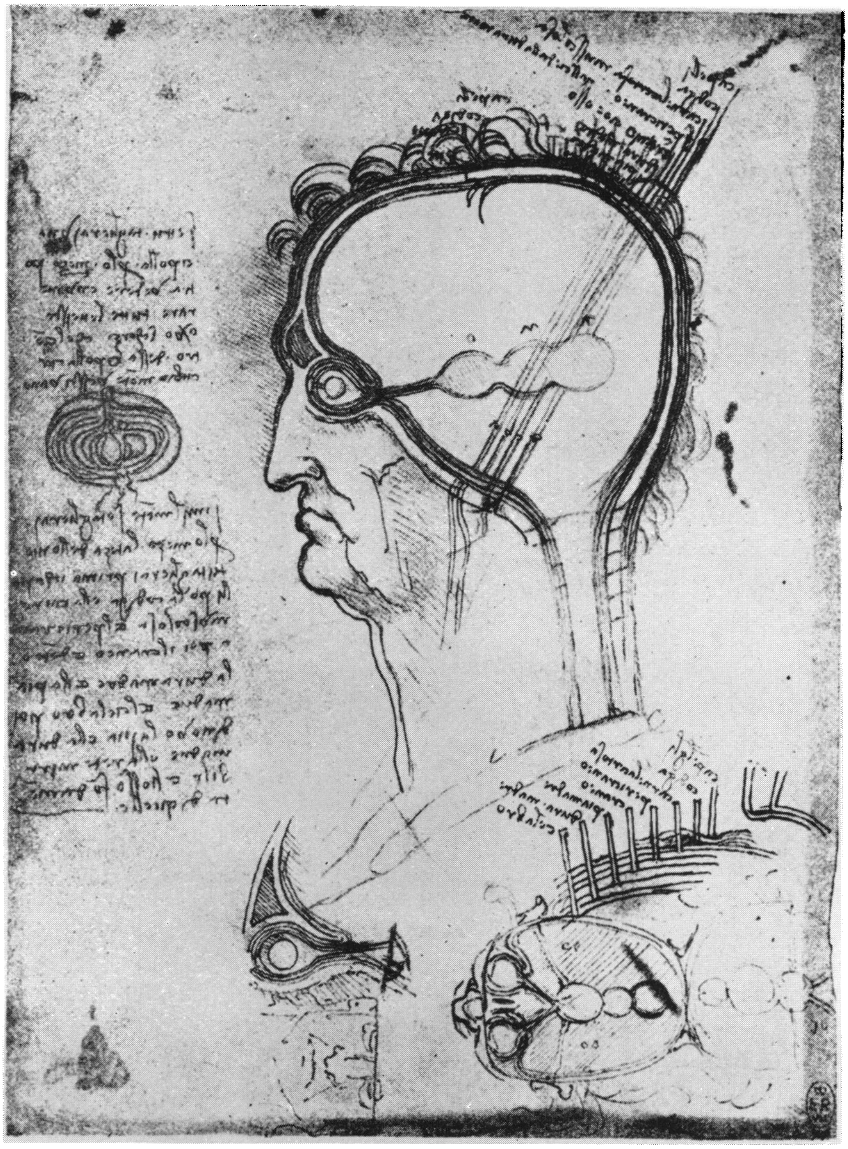

Fig. 3a

Fig. 3. Drawings by Leonardo da Vinci from the Royal Collection at Windsor Castle. (*a*) Dated by Clark 1490. A diagrammatic representation of the ventricles only. (*b* and *c*) Dated by Clark 1504. These drawings show the influence of the wax casts which Leonardo prepared, probably in the same year. (*Reproduced by gracious permission of H.M. The Queen.*)

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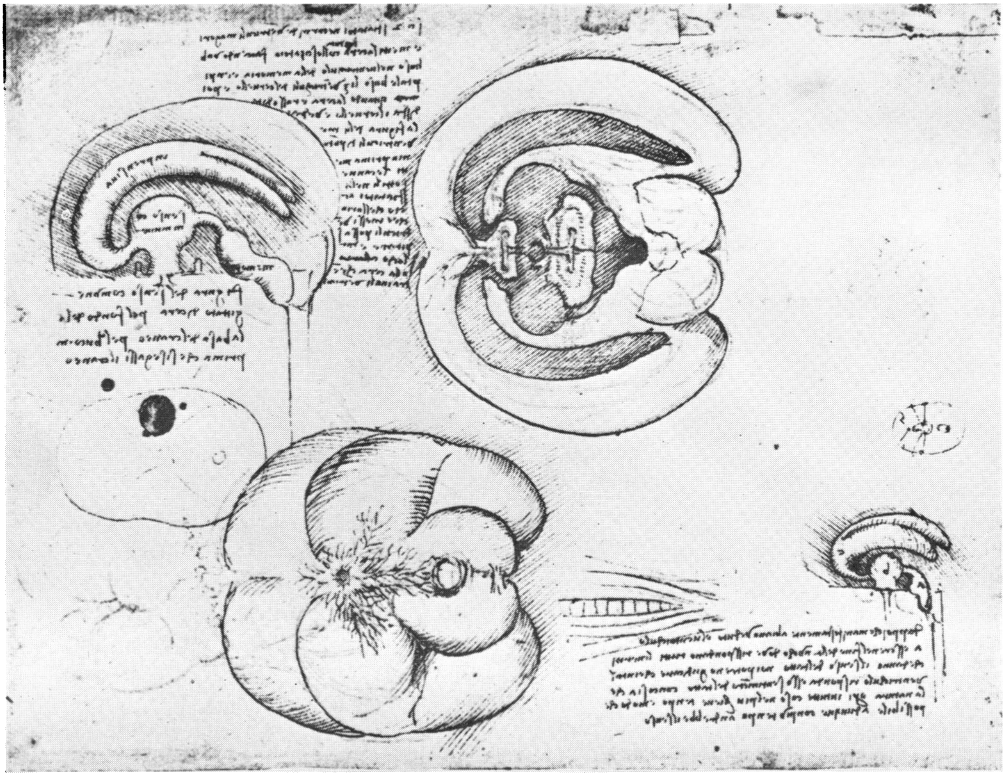

Fig. 3b

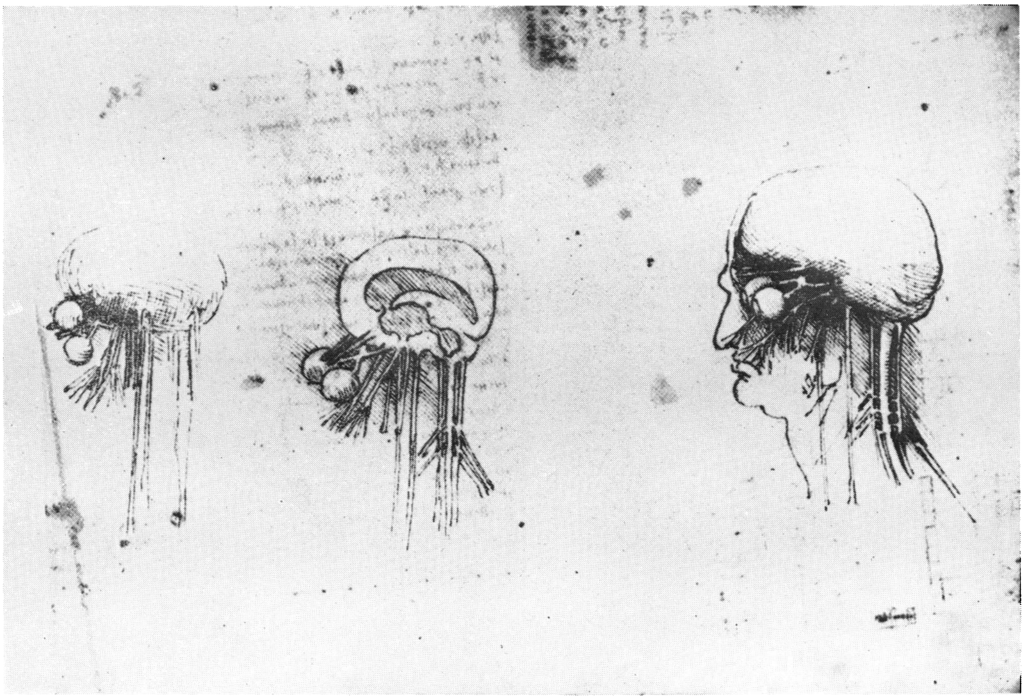

Fig. 3c

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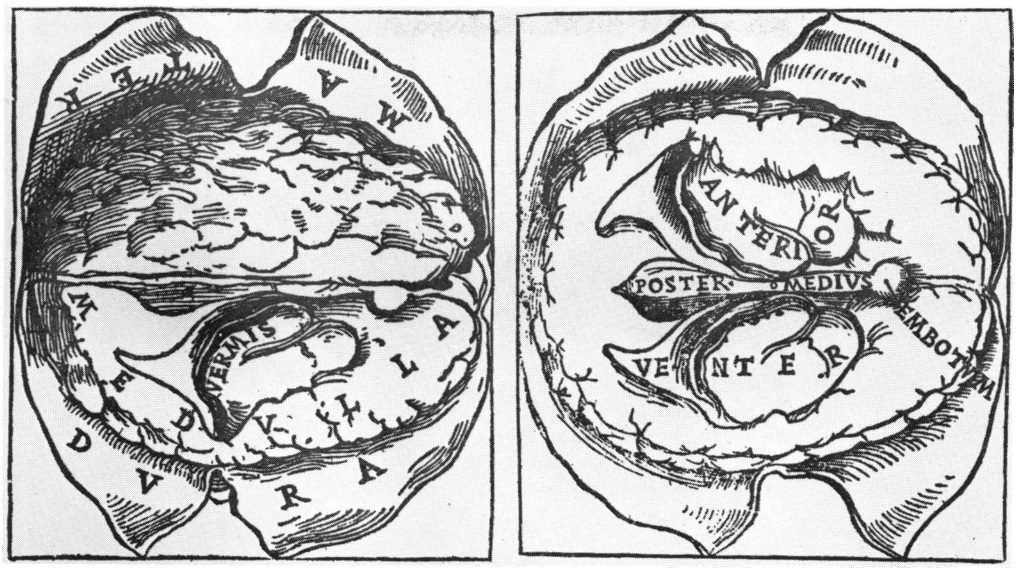

Fig. 4. Illustration of the brain from Berengario da Carpi's *Isagogae Breves*, 1523.

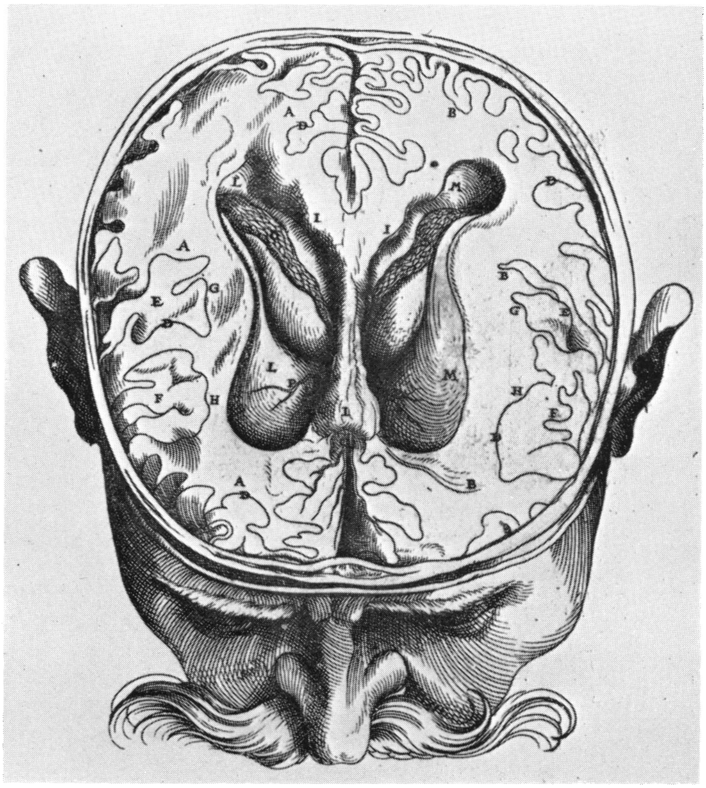

Fig. 5. Illustration of a dissection of the brain showing ventricles and choroid plexuses. From the *De Humani Corporis Fabrica* of Vesalius, 1543.

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ventricle. Vesalius obviously did not allow for the possibility that anatomy itself might be conscripted as the handmaid of philosophic speculation.

Since they were not made available for inspection for over two centuries, Leonardo's drawings were of course without influence on the development of thought in the years following his death. It is not indeed until the end of the eighteenth century that we hear of another great anatomist interesting himself in the anatomy of Leonardo. This was William Hunter. He had intended to publish the drawings but was prevented from doing so by his death in 1783.[11]

The first illustration of the ventricles with any pretensions to accuracy was given by Berengario da Carpi[16] (Fig. 4).

Berengario's account of the ventricles is a reasonably accurate one, but he was not as fortunate as Vesalius in his choice of a draughtsman. The comparison of the crude productions of Berengario with the exquisite quality of the illustration for the *Fabrica* underlines the accuracy of Singer's observation,[17] 'If he [Leonardo] be indeed the turning-point of the Renaissance, in the *Fabrica* we see its anatomical summit. We can but regret that Vesalius's literary skill did not equal the artistry of some, at least, of his draughtsmen.' If Vesalius's illustrations of the ventricles (Fig. 5) do not represent the apogee of knowledge of the ventricles, they do represent at least a major turning-point in the description of the cavities of the brain. Although subsequent accounts could not greatly improve on Vesalius's description of the gross topographical relations of the ventricles, on the question of the channels which interconnect this complex system, Vesalius was almost evasively vague. The main task of the anatomists who followed Vesalius was therefore to elucidate the problem of the inter-relationship of the cavities and the subsequent history of the ventricular system is, to a large extent, the history of their researches.

3. *The connections between the ventricular cavities*

(i) *The inter-ventricular foramina* (*foramina of Monro*). Galen[7] instructed the dissector to elevate the fornix by inserting the handle of a scalpel into the apertures whereby vessels entered the lateral ventricles through the communication between the lateral and third ventricles. This is the first description of the foramen of Monro. The opening was again mentioned by Berengario da Carpi,[18] but Vesalius admitted its existence only by implication: 'A common cavity of the ventricles is formed by descent and concurrence of the lower parts of the lateral ventricles below that body (fornix) which professors of dissection have likened to a tortoise.'[17] A curious description of the existence of two openings from the lateral ventricle to the third termed *vulva* and *anus* respectively gained considerable currency in the seventeenth century. The *vulva* as described by Marchetti[19] and Casserio[20] seems to correspond to the inter-ventricular foramen. Vieussens[21] described the *vulva* as a foramen near the anterior region of the lateral ventricle by the fornix. This foramen which was hollowed out near its roots served, in his view, for a means of communication between the lateral ventricles both with each other and with the third ventricle. This foramen was again well described by Vicq d'Azyr in 1781, although his description was not published until 1805. Haller,[22] however, maintained that, in the normal condition of the body, the velum interpositum closed off any possible opening between the lateral and third ventricles. Somewhat remarkably, Haller denied the existence of the foramen of Monro and maintained the authenticity of that of Magendie, whilst Monro in his description of his own foramen denied the existence of any foramina of exit whatsoever from the fourth ventricle.

It was the distinction of Alexander Monro *secundus*[23] to give the first clear, accurate and detailed description of the inter-ventricular foramen, and, at the same time, to indicate positively that there was no other point of communication between the two lateral ventricles either with each other or with the third ventricle.

> Let the gutter which is between the corpora striata and the thalami nervorum opticorum . . . 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' . . . which should rather be called 'iter ad tertium ventriculum'. . . .

(ii) *The cerebral aqueduct.* Galen's concept of the function of the ventricles demanded that they intercommunicate. Whilst it is clear that Galen knew of the inter-ventricular foramen, he does not seem to have been aware of the real nature of the communication between the third and fourth ventricles.[5] The description he gave was of a channel passing between the dorsal aspect of the corpora quadrigemina and their meningeal covering. This channel entered the roof of the fourth ventricle through an opening in the superior medullary velum ventral to the vermis of the cerebellum. Although Wiberg[5] suggested that Galen knew at least the lower portion of the aqueduct, it seems more probable that he was simply describing the sub-arachnoid space on the dorsal aspect of the mid-brain. Berengario da Carpi[18] gave an illustration in which the aqueduct is clearly shown but adhered to Galen in his text, describing a canal lying between the pia mater and the brain. Vesalius[6] gave a curiously elusive account of the aqueduct

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which suggests that he was familiar with both extremities of the canal, but not with its central portion. In the description of this portion he also followed Galen. According to Sprengel,[24] Servetus knew of the aqueduct in general terms, and regarded it as the seat of the soul. Jacobus Sylvius, the teacher of Vesalius, described the aqueduct in great detail, but followed Galen in placing the channel between the mid-brain and the vermis of the cerebellum. Although Arantius gave the name *aqueduct* to the passage, he was not, as might be thought, aware of the nature of the substance it transmitted, believing that it contained not water but the customary *pneuma psychicon*. Nevertheless Arantius seems to have recognized the true cerebral aqueduct, and Haller[22] drew attention to the impropriety of naming the aqueduct after Sylvius.

Even though it may be agreed that the aqueduct should have been named after Arantius rather than Sylvius, there remains a further problem which appears to have been successfully solved by Baker.[25] For many years it was believed that the aqueduct was named after the master of Vesalius, but Baker has conclusively shown that the Sylvius whose name is eponymously commemorated is Franciscus Sylvius (1614–72). His account of the cerebral aqueduct was as follows: 'From the third ventricle . . . there is a canal or aqueduct passing towards the fourth ventricle of the cerebellum under our bridge (pons) and the nates or testes (corpora quadrigemina) that are placed as four eminences at the extremity of the same.'[25] Anyone who has had the experience of examining the fresh mid-brain will realize that, until hardening solutions became available, this description could hardly have been improved upon. Although both Vesalius and Berengario may have known the true aqueduct, and Arantius almost certainly did, all three observers wrongly identified its situation. Franciscus Sylvius was therefore the first to locate the aqueduct unequivocally in the substance of the mid-brain; for this reason there seems to have been some justification for associating his name with the structure.

It is remarkable how many of the ancient and medieval theories of cerebral function demanded the existence of a valve to control the passage of spirits or humours in the aqueduct. Galen regarded the vermis of the cerebellum as serving to prevent the reflux of *pneuma psychicon* from the fourth ventricle. This view was ridiculed by Vesalius[6] on the grounds that the passage must necessarily remain ever open to allow the free transport of the animal spirits to the spinal marrow. According to Sprengel,[24] Servetus followed Galen in regarding the vermis as the 'janitor' of the aqueduct. Other ancient observers thought that the pineal gland acted as a ball-cock between the third ventricle and the aqueduct, but, as Vesalius said,[17] 'we agree with Galen that the pineal gland does not close the passage (from the third to fourth ventricle), for it is by no means in contact with that passage

https://doi.org/10.1017/S0025727300021025 Published online by Cambridge University Press

and could not shut its orifice'. In the view of Vieussens[21] the superior medullary velum was the true valve between the third and fourth ventricles. The theory that there was a valvular control in the aqueduct did not die easily. It survived into a more scientific age, and even Magendie[26] compared the course followed by the cerebrospinal fluid to a tunnel running under the Thames, and thought that he had discovered the significance of the pineal gland which was to act as a plug to the aqueduct. The age when such speculations could be made with impunity was, however, by then beginning to pass, and Magendie's thesis was subject to the most scathing criticism.[27] With the publication of the classic experiments of Key and Retzius[28] no further serious reference appeared to the existence of a valve between the third and fourth ventricles.

(iii) *The lateral and median apertures of the fourth ventricle (foramina of Luschka and Magendie)*. It was essential to Galen's physiological system to regard the fourth ventricle as a sac closed to the exterior. If the ventricle was in any way open, the psychic pneuma would escape and fail to reach the muscles which it served to activate. Moreover, the concept of a ball-valve in the aqueduct or of a 'valve of Vieussens' also demands a closed fourth ventricle. It is not therefore surprising that no reference to the foramina of exit from the fourth ventricle appears in the ancient or medieval authors and that such references do not appear on the scene until relatively modern times.

In the unpublished MSS. of Swedenborg[29] there is some suggestion of the existence of a median aperture in the roof of the fourth ventricle, but the first clear description in the literature is of the lateral foramina.[22] 'Where the choroid plexus passes out of the ventricle (lateral foramina) water easily makes a way for itself into the space which surrounds the spinal cord.' This observation was strenuously denied by Monro,[23] who said there was no question of there being a communication between the fourth ventricle and exterior as the roof was completely sealed off by the choroid plexus and the pia mater.

Bichat[30] described a fissure in the roof of the fourth ventricle which was clearly an artifact. In 1828, however, Magendie read a paper at the annual public session of the Paris Academy of Sciences in which he clearly established the communication of the fourth ventricle and the sub-arachnoid space through a median aperture. He presented to the Academy wax models of the ventricles which showed this relationship. Since Magendie described his foramen, it has been the subject of a continuous and fierce controversy comparable to that which the activities of Magendie aroused during his lifetime. Its existence was supported by Cruveilhier[31] and Luschka.[32] There were, however, distinguished names on the other side. Krause[33] supported the view of Monro[23] that the fourth ventricle was closed off from the sub-arachnoid space by pia mater, and both Reichert[34] and Kölliker[35] were convinced that the foramen was an artifact produced when the brain was removed from the cranium. The experimental studies of Key and Retzius,[28] however, led them to confirm the existence of the foramen. It was admitted even by the supporters of the foramen that it was absent in certain animals, notably the horse, and, perhaps for this reason, the controversy has continued uninterruptedly into modern times. Thus Bland-Sutton observed in 1923: 'This foramen has had such a charm for teachers that it maintains a place in text-books although sealed up by practical anatomists many years ago.'[36] To this Wood Jones (1923) characteristically replied: 'As a teacher I fully admit the charm of this foramen, and as a practical anatomist I also regard it with affection, for of its presence in the undisturbed condition of the roof-plate I have no doubt whatever.'[37]

No such stormy debate marks the history of the lateral apertures of the fourth ventricle. After the brief announcement of their existence by Haller and the subsequent attempt at refutation by Monro little attention was paid to the apertures until their classic description by Luschka.[32] Luschka described the foramina in these terms:

> On either side the outer angles of the fourth ventricle assume the form of a gutter leading outside, whereby the lateral portion of the choroid plexus passes outside of the fourth ventricle, whilst the arachnoid stretches freely over the place in question. The fourth ventricle therefore by its exterior angles lies in open communication with the subarachnoid space. This anatomical point is of considerable importance because in some animals, for instance the horse, the lower extremity of the fourth ventricle is closed up.

4. *The discovery of the cerebrospinal fluid*

It is extremely difficult to apportion credit for the discovery of a fluid which has no obviously distinguishing physical properties, being only, as Halliburton[38] termed it, 'a modified tap-water'. Hippocrates, for example, was probably aware of the existence of fluid in the brain, and certainly knew that there was a fluid under the cranial dura mater. Galen referred to a watery humour inside the ventricles, and, like many ancient authors, gave a general impression that there was a fluid medium covering the external surface of the brain. These descriptions are, however, so vague that it is difficult to give much credit to their authors. In the sixteenth and seventeenth centuries, when dissection and observation slowly replaced speculation as anatomical methods, the first germs of the notion that the cerebrospinal fluid existed as something more than a moist humour can be detected. For example, Vesalius said:[17] 'The entire surface of the ventricle is smooth and lubricated with a watery humour and is often found completely filled with it.' Varolio[39] drew attention to the fact that the ventricles were filled with *fluid*, not with the *pneuma* his contemporaries would have expected to find. Glisson[40] progressed further, noting the appearance 'between the Dura and Pia Mater and in the very Ventricles of the Brain of wheyish and waterish humours'. This appearance Glisson associated with the occurrence of hydrocephalus. On his observations he based his physiological theory that through the motion of the brain fluid was propelled along the nerves, this being the prime cause of sensation and motion. Haller[22] followed Glisson's concept of nervous action and identified the cerebrospinal fluid in the ventricles of the brain. According to Haller it belonged to a class of 'viscid fluids, coagulable by a heat of about 150 degrees, by alcohol and by strong acids; although generally in the living animal, they escape in the form of vapour and after death are compacted into a gelatinous substance'.[22] Haller went on to describe the vapour as passing through the ventricular system to the base of the skull and into the loose cavity of the 'spinal marrow'. Apart from the use of the word 'vapour' for 'fluid' this is a fair general description of the circulation of the cerebrospinal fluid. Exactly how and why this concept that the brain was covered by a vapour came into such prominence in the early eighteenth century is difficult to ascertain. Possibly, like the ancient idea that the pneuma escaped as steam from the corpse of a sacrifice, it was based on the study of anatomical material so fresh as to be still warm. Certainly this concept gained most currency in the cold climate of northern Europe.

There is an isolated brilliant and prophetic description of the cerebrospinal fluid which, although contemporaneous with Haller's, had no influence since it remained unpublished. This was the work of Swedenborg and was committed to manuscript in the middle of the eighteenth century. Photolithographed copies of the manuscript were printed in Stockholm in 1869. An extract from the English translation[41] gives an indication of the quality of the powers of observation displayed by Swedenborg.

> The arachnoid membrane may be separated from the subjacent pia mater by injection and a blow or air, and in dropsical brains it actually appeared separated; whence it follows that a humour flows between it and the pia mater, by which they are kept apart, and prevented from coalescing. . . . A subtle liquid is expressed from the little arteries of the cerebrum which pass through the cortical substance, or else from the pia mater which under pressure always yields some moisture. This fluid is kept under the arachnoid membrane and cannot rise upwards, but has to flow down between the cortical tori. . . .

The history of Swedenborg's manuscript shows curious parallels with that of Leonardo's drawings. Both lay unnoticed for many years and were without influence on the development of anatomical knowledge. Yet, although Swedenborg's physiological system was as absurd as that of the medieval Galenists, some of his anatomical observations are much in advance of his time. To take an example from the extract above: 'a subtle liquid is expressed from the little arteries of the cerebrum which pass through the cortical substance' is an obvious reference to the perivascular spaces of the brain, a century before their description by Virchow[42] and Robin.[43]

According to Bilancioni,[44] Valsalva obtained an ounce of liquid after cutting the membranes round the spinal cord of a dog and compared this fluid with the synovial fluid. This discovery, made by Valsalva in 1692, was the first recognition of the existence of a spinal fluid.

Notwithstanding the work of men like Glisson, Haller and Valsalva, in the days when eponymous nomenclature was the order of the day, the cerebrospinal fluid was, with considerable justification, termed the *liquor Cotugni*. For to Domenico Cotugno[45] was due the first adequate account of the cerebrospinal fluid which in itself drew together into a harmonious whole all accurate previous observations:

The whole space between the dura mater and the medulla is always filled; not by the medulla which is more turgescent in the living, nor by a water vapour (as this yet obscure substance is suspected of being by noted authors); but by water, similar to that about the heart which the pericardium holds, which fills the ventricles of the brain and the labyrinths of the ear, as well as the other cavities of the body inaccessible to air.

Cotugno's observations did not immediately revolutionize anatomical opinion, and Soemmerring[46] only referred to a phlegmy water between arachnoid and pia mater. Physiological attention at the close of the eighteenth century was closely attracted by the theory advanced by Bichat[30] that the arachnoid membrane formed a closed sac analogous to the pleural and pericardial cavities. This conception was obviously incompatible with Cotugno's observation, and the neglect of his work continued into the nineteenth century.

The story of the rediscovery of the cerebrospinal fluid is a well-known one,[26] and shows a much misunderstood figure in an attractive light. At an autopsy in 1824 Magendie discovered a liquid filling the spinal canal of the cadaver, and suggested that this fluid was a normal rather than a pathological phenomenon.[47] In a subsequent paper,[48] he generously accorded priority to Cotugno, going so far as to publish Cotugno's original Latin paper in full. In his classic paper of 1828[49] Magendie laid a firm foundation for all future work on the cerebrospinal fluid. He established the communication between the cavities of the brain and the sub-arachnoid space as well as the continuity of that space around both brain and spinal cord. He described the cisterna magna at the base of the brain. He claimed that the cerebrospinal fluid was under positive pressure and, in addition, noted the constant motion of the cerebrospinal fluid which accompanied respiration, thus unravelling the tangled story of the 'motion of the brain' upon which so many curious psychological theories had been based.

From the pioneer work of Magendie later generations of research workers established a body of physiological knowledge which was of the utmost significance to the development of the discipline of neuro-surgery. The introduction of lumbar puncture by Wynter[50] and Quincke[51] allowed the fluid to be obtained freely for examination and thus made possible the detailed study of the chemical pathology of the fluid[52] which itself came to have so many applications in the medicine of the twentieth century.

5. *The history of the meninges and their associated structures*

In *The Edwin Smith Surgical Papyrus*,[53] which is most probably a copy made in 1700 B.C. of a manuscript composed about 3000 B.C., there appears a clear reference to the meninges as coverings of the brain. In the *De Historia Animalium*, Aristotle[54] mentioned both outer and inner membranes; the outer meninx lying next to the bone, and thick and strong in texture; the inner consisting of a fine network of minute blood vessels, lying in close contact with the brain itself. In his *De Somno* Aristotle suggested that the small size and narrow bore of the pial vessels served both to prevent the easy access of the vapour of nutriment and to further the process of refrigeration, which was in his view the chief purpose of the brain.

According to Galen[7] the term 'meninx' was used by the older writers, Hippocrates, Marinus and Diocles, to describe any membrane in the body; by Galen's time, however, the description was reserved for the coverings of the brain. Singer[7] suggested that it is only in the 'de Carnibus' of Hippocrates that the writer used the term 'meninx' to denote membranes in general, and that elsewhere in the *Hippocratic Corpus* the word is used in its Galenic sense.

The first account of the detailed topography of the meninges was given by Herophilus, whose work is unknown save through its survival in Galen. The name of Herophilus is remembered today for the 'torcular Herophili' or 'confluence of the sinuses'. Herophilus likened the confluence of the sinuses to a wine-press because of the collection of fluid in that situation. He was the first to attempt the detailed study of the dural venous sinuses. Galen improved on the descriptions of Heraphilus from the results of his own researches, noting that there was no tunica adventitia or media surrounding the blood in the sinuses, only a 'venous membrane' or endothelial lining.[5]

The description of the dura and pia maters which Galen[7] put together from his own experiments and the books of Herophilus which were available to him was a most accurate one, notwithstanding the fact that he dissected the brains of monkeys, oxen and other animals, but not that of man. Although Galen described only two membranes, it would appear that the inner membrane in his account is really a pia-arachnoid, although the suggestion he makes of a fluid on the outer aspect of the pia does suggest the cerebrospinal fluid. He believed that the pia expanded to meet the dura when the brain expanded, and was thus clearly aware of the existence of a space between the two membranes. He recognized that the cranial dura mater was formed of two layers, now described as periosteal and meningeal. He was also aware of the processes of the dura mater, the falces cerebri and cerebelli, the tentorium cerebelli. Somewhat surprisingly he also knew that these processes were formed by reduplication of the dura mater.

Possibly because as a subject it offered less opportunity for misunderstanding than did the ventricular system, Galen's account of the meninges appeared in a fairly accurate form in the Arabian manuscripts.[7] When this description returned to Europe, the terms 'dura' and 'pia mater' were introduced in 1127 by the translator, Stephen of Antioch.[3] 'Mater' was taken as a translation of the Arabic word 'umm'. The sense in which the meninges were regarded as the 'mothers' of the brain is apparently the same as that in which 'mother-of-pearl' is used. In the Second Salernitan Demonstration dated by Corner,[12] 1100–50, a work which derives from the Arabic Galenists via the Pantegni of Constantinus Africanus, the pia mater is described as protecting the brain 'like a devoted mother' from the harshness of the dura mater; the dura mater in turn is regarded as protecting the brain and pia mater from the hard cranium. In that anatomical curiosity, Vicary's *Anatomy of Man*,[55] which, although supposedly put together by Henry VIII's personal medical attendant, is a garbled version of various Arabic texts, the maternal qualities of the pia are extended by attributing to it nutritional as well as protective functions: 'It nourisheth the brayne and feedeth it, as doth a loving mother unto her tender childe or babe.' The Arabian use of the term 'mater' to describe the meninges was accounted for on other grounds by different authorities. Thus in Kersey's *Phillips New World of Words* the purpose of the pia mater's close attachment to the brain was said to be to 'keep in the Spirits there bred'. The author went on to claim that 'These Skins are called Maters, i.e. Mothers, by the Arabians, as if all the other Membranes of the Body took their rise from or were propagated by them.'

Although Vesalius was well aware of the importance of the dura mater, 'the knowledge of which is of utmost necessity, by Hercules, in [treating] wounds of the head', and his illustrations of it are excellent, his description of the topography of the meninx is in many ways not as accurate as that of

Galen. Thus Vesalius erroneously contradicts Galen on the double nature of the dura, 'None of the processes or parts (of the dura) is double (as Galen wrongly taught, explaining the matter very little) but single, as is the dura which covers the brain or lines the calvaria.'[17]

Vesalius's account of the dura shows evidence of haste and lack of both interest and thought: 'if any ingenious device in the harmonious fitting of the dura has been omitted which should have been mentioned, I will include it in the ensuing (description) of the tenuis'.[17] He described the dura as a covering (involucrum), a hammock (fulcrum) and a storage flask (lagena) to the brain. He followed Galen in stressing the protective function of the meninges, regarding the pia as supporting the brain substance like a mould and protecting it from the dura, which in turn protected both brain and pia from the cranium.

Vesalius's account of the meninges was much improved by the great neuro-anatomists of the succeeding century, notably by Glisson, Ruysch, Willis and Vieussens. The most striking advance made in the seventeenth century was the introduction of a third membrane, the arachnoid. This membrane was discovered and named by Blasius or Blaes,[56] and its authenticity received the imprimatur of the Anatomical Society of Amsterdam. Vieussens[21] described the existence of two separate thin membranes over the surface of the spinal cord, and according to Haller,[22] Ruysch described the extension of the arachnoid over the cortex and base of the brain in 1692.

Today it is a commonplace to regard the function of the meninges solely as protective in nature. The germs of this idea may be found in the writings of Aristotle, and it has reached us through Galen and the Arabians. There is another concept of the function of the meninges which arises from the physiological theories of Galen and his followers.[7, 8] Galen commented on the pulsation of the brain and noted that it was synchronous with the pulse at the wrist. The motion of the brain came, however, to be regarded as an entity separate from the pulsation of the heart. Pacchioni[57] went so far as to regard the dura mater as composed to some extent of muscular tissue, and maintained that its contractions forced the nervous fluid towards the periphery. Baglivi[58] carried this line of argument even further. He described the dura as the 'heart of the brain', which, by virtue of its contractile tissue, exerted pressure on the brain. This theory accounted for the motion of the fluid through the ventricles, which Glisson's concept of nervous physiology demanded. The most important iatromechanist Fredrich Hoffman,[59] whose ideas first led to the implication of the brain in general disease, described the living organism as formed of fibres. These fibres had a quality (*tonus*) with the ability to contract and dilate. The normal tonus, on whose maintenance health depended, was regulated by the passage throughout the body of a nervous ether disseminated by the systole and diastole of the meninges.

Theoretical concepts such as Hoffman's survive today only in esoteric medical systems. The discovery of the cerebrospinal fluid and the introduction of the neuron concept finally destroyed the myths associated with 'the motion of the brain'. As far as the meninges are concerned the modern age dates from the publication of the superbly illustrated monograph of Key and Retzius.[28]

6. *The arachnoid granulations and chorioid plexuses*

(i) *The arachnoid granulations*. The arachnoid granulations were illustrated by Vesalius.[6] He described them as interrupting the smoothness of the external surface of the dura where the sagittal suture joined the coronal. He also noted that they projected irregularly into recesses in the skull to which they adhered.

The classic description of these structures was given by Pacchioni,[57] whose name was for many years associated with the granulations. He described the granulations with that wealth of simile which characterized his literary style:

> 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.

Luschka[32] showed that the granulations were only the result of the enlargement of arachnoidal villi which normally existed as slender projections of the arachnoid. He also elucidated the relationship of the granulations to the lacunae of the sinuses. As so often in the history of the circulation of the cerebrospinal fluid, the modern age comes into view with an observation by Key and Retzius.[28] They showed that the villi and granulations could be found at all ages but were most common in old people. They regarded the granulations as junctional structures between the blood and cerebrospinal fluid. With their observations and those of Luschka a controversy as to the function of the arachnoid villi and granulations originated which has not yet been satisfactorily settled.

(ii) *The chorioid plexuses*. Both Rufus of Ephesus[2] and Galen[7] leave us in little doubt that Herophilus discovered the chorioid plexuses of the lateral ventricles. Galen observed that 'You will see in the ventricles what is called the "chorioid plexuses". The followers of Herophilus call it a "chorioid concatenation", of course taking the name from the outer membrane of the

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foetus. It is a plexus of veins and arteries held together by delicate membranes.'[7] Rufus of Ephesus,[2] writing before the time of Galen, described the membrane covering the interior of the ventricles as the chorioid tunic, noting that Herophilus called it the chorioid meninx. This concept of the ventricular lining as being formed by pia mater was also adopted by Galen, and since Rufus of Ephesus apparently drew his description from Herophilus or Erasistratus independently, it is probable that Vesalius was right when he said:[17] 'I believe therefore that Galen, when writing that work (*De usu partium*), has read in Herophilus or Andreas or Marinus or Lykus or some other of the leading Alexandrian anatomists who described the membranes of the brain, that process or parts of the tenuis (pia mater) extend into the (first) three ventricles but not into the fourth.' Although the illustration given of the chorioid plexuses in the *Fabrica* (Fig. 5) is a superb piece of artistic anatomy, Vesalius's account of the chorioid plexuses is extremely poor. It is not clear whether he is describing the plexus or merely the chorioidal arteries in some parts. Sometimes it appears that he used 'arteria' to refer to the plexus as a whole. Although Galen knew the chorioidal vein and its entry into the great cerebral vein which bears his name, Vesalius believed that this vein was an artery. His description of the plexus is scanty in the extreme, and he, like Galen, showed himself quite unaware of the existence of plexuses in ventricles other than the lateral ventricles.

Willis[60] gave a description of the chorioid plexuses which indicates how rapidly knowledge of cerebral anatomy had advanced in the century following the publication of the *Fabrica*. Willis described 'glands' interspersed in the chorioid plexus; these appear to be the villous processes of the plexus. He also suggested that a serous liquid was 'distilled into the ventricles from the glands'. Willis further described the chorioid plexus of the fourth ventricle. It is possible, however, that by 'glands' Willis meant the small cysts or hydatids described in detail by Vieussens,[21] which are frequently encountered in the plexuses, often in association with hyaline concentric bodies or 'brain-sand'. Ridley[61] gave the first clear account of the separate nature of the plexuses of the third ventricle. With this description the distribution of the chorioid plexuses as it is known today became familiar.

The function of the chorioid plexuses has been a subject of debate since the revival of interest in anatomy at the Renaissance; it would be presumptuous to suggest that that debate is now ended. To the medieval anatomists the function of the chorioid plexus was intimately related to the concepts of cerebral physiology current in those times. Leonardo followed the conventional view in regarding the chorioid plexus of the lateral ventricles as a ball-valve preventing the flow of fluid from one ventricle to another. With the concept of Willis[60] that a fluid was produced by the plexuses there dawned the germ of the theory, first established by Luschka,[32]

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that they played the major role in the production of the cerebrospinal fluid. This theory, although constantly under attack until the present day, has nevertheless held firm, and the chorioid plexuses are today generally held to play an important part in the production of the cerebrospinal fluid.

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