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Brief Review

Ventricular anatomy: illustrations and concepts from antiquity to Renaissance

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ABSTRACT

In this article we have tried to narrate ventricular anatomy from its start in antiquity to the transitionalists of the Renaissance. The crude drawings of the Alexandrian series can hardly be called "anatomical". The accompanying texts consisted mostly of concepts unrelated to sketches. With the Renaissance there came an era where true knowledge, through dissections, revealed the actual structures of the ventricles and ended the unfounded arguments of ventricular function. ***Neuroanatomy; 2005; 4: 57–63.***

Key words [brain ventricles] [anatomy] [antiquity] [Renaissance] [history]

Introduction

The localization of motor and sensory activities, the *"rete mirabile"* and the localization of the mental processes – the seat of the soul – in the ventricles or *"cells"* of the brain were ancient Greek concepts which were handed down to the middle ages. Although this last concept had not fully matured during classical antiquity its basic elements can be traced to Galen's works.

Even though there were dissections (mostly animal) and enough visual material, the concepts were passed through writings with rare medical illustrations.

With the death of Galen in 199 anatomical dissection of either scientific or medical reasons was absent in both Europe and Islam for over a thousand years. It began again in thirteenth century Italy, first for forensic purposes and then as a way of illustrating Galen's anatomical works for medical students [1]. As the Renaissance men began doing their own dissections, medieval physiology, passed through translations of Arab scholars, confronted with their anatomical dissections. Being not able to totally rid themselves from medieval learning there became a transitional period in which medieval physiology was superimposed upon Renaissance anatomy [2].

In this article we shall narrate ventricular anatomy from *"the Alexandrian series"* to the Renaissance transitional period; touching some other medieval concepts when relevant.

The functional role of the ventricles began with Herophilus of Alexandria (ca 270). The uniqueness of the Alexandrian anatomy nexus is revealed by the fact that not only was human dissection first practiced in that city, but this was the first and virtually the only place where human vivisection was systematically carried out for scientific purposes.

Both Herophilus and Erasistratus (ca 260) were particularly interested in the brain. They provided the first accurate and detailed description of the human brain including the ventricles [3–4]. Like Alcmaeon and the Hippocratic doctors before them, they had no question about the brain's dominant role in sensation, thought, and movement.

Herophilus claimed that the fourth ventricle was the *"command center"* and compared the cavity in the posterior floor of the fourth ventricle with the cavities in the pens that were in use in Alexandria at the time, and it is still called *calamus scriptorius* or sometimes *calamus Herophili* [5].

Anatomical illustrations were also first produced in Hellenistic Alexandria about 300 BC. The tradition, owing much to Herophilus and to Erasistratus has been traced by way of Byzantium to the medieval west.

Figure 1 is a unique drawing around 1250 AD which according to Sudhoff may have originated in Salerno [6]. It is most probably a copy of original Alexandrian series and depicts the venous system. The text written

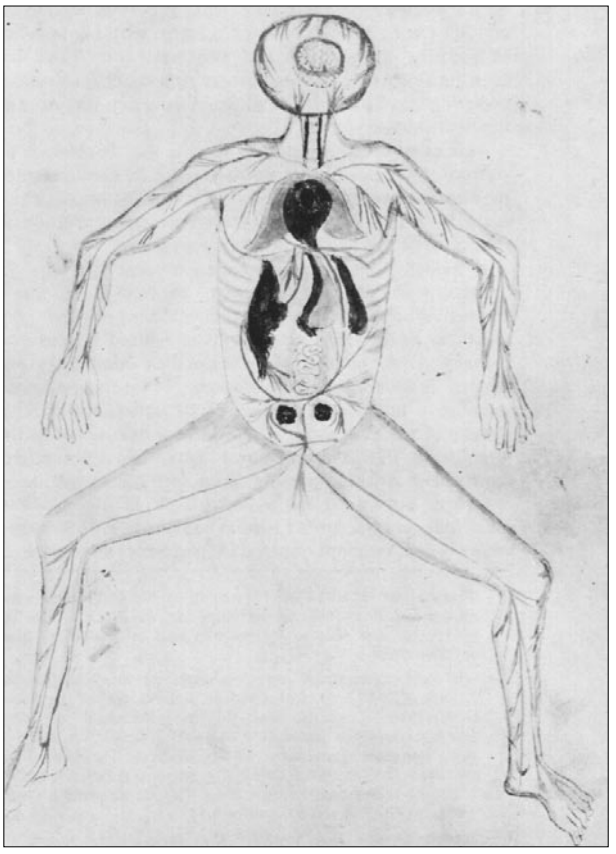

Figure 1. A unique drawing of around 1250. Salerno. Part of Alexandrian Series [12].

in Catalan describes three chambers in the brain thus referring to the *cell doctrine* of ventricular localization of mental functions although it is not apparent where these are sited other than possibly between the worm like structures. Since the figure is essentially of the venous system, the brain is most probably added at this later copy.

Galen (129–199 AD) was the most important figure in ancient medical science. He provided a detailed and accurate account of anatomy in general and anatomy of the brain in special. But, it was not until recently that historians realized his descriptions being remarkably accurate when applied to the monkey or ox (his usual subjects of dissection) but not on humans [7–8]. More curiously, Galen never mentioned that his anatomical descriptions were almost always based on non humans.

He described the ventricles in considerable detail as four cavities and their connections. He described the two lateral (anterior), the third and the fourth ventricle and addressed them as crucial in his physiological system where the ventricles were the site of storage of *psychic pneuma*. The psychic pneuma (animal spirit) was the active principle of both sensory and motor nerves and the central nervous system. Although the ventricles, particularly the anterior ventricle, were important as a source of psychic pneuma he located the soul and higher cognitive functions not in the ventricles but in the solid portions of the brain around the ventricles. For that, he argued on the basis of his extensive clinical experience as a doctor at the gladiatorial school in Pergamon. He claimed that when brain lesions penetrated to the ventricles, death did not invariably result even if both sensation and movement were lost. Imagination, reason and memory were the three constituents of intellect and they could be affected separately.

Being the greatest anatomist of antiquity, he did not, however, encourage his students to rely on illustrations, believing that direct visualization and handling of the structures was the only way to appreciate their form and relationship.

Cell Doctrine

The cell doctrine developed out of a curious amalgam of Greek medical theory and practice and ideological concerns of early Christian church authorities. In the fourth century Poseidonus of Byzantinum developed Galen's ideas of cerebral localization further [9]. He is, probably, the first to report in detail on the effects of localized brain damage in humans. He said that the lesions of the anterior brain substance impaired imagination, lesions of the posterior brain impaired memory, and damage to the middle ventricle produced deficit in reasoning.

The early church authorities, in particular Nemesius, Bishop of Emesia (ca 390) and St Augustine (350–430) were very much concerned with the nonmaterial nature of the soul. Therefore, rather than localise the soul, they localized Aristotle's classification of its functions such as sensation and memory. They believed that soul cannot be localized in the heart as Aristotle did, and placed it in a much higher place at the temple, to encephalon. Furthermore they believed that the brain tissue was too earthy, too dirty to act as an intermediary between the body and soul; so Nemesius put all the faculties of the soul into the ventricles following the same antero-posterior pattern as his contemporary Poseidonus [10]. Besides the desire for a suitable intermediary between the body and non corporeal soul another desire was to make it match to trinity, so they reduced the four ventricles of Galen to three.

The lateral ventricles were considered as one cavity, the first cell or the small room or the vestibulum of the temple. It received impulses from the special senses and from the rest of the body and thus accommodated *"sensus communis"* the common sense. Since images were created from these sensations so *"imaginativa"* imagination and *"fantasia"* fantasy were also in the posterior part of the first cell. The second cell (our third ventricle) or middle cell was the seat of the cognitive process: *"ratio"* reason, *"aestimativa"* judgement or *"cogitativa"* thought. For the posterior third cell (our fourth ventricle) Galen's original thought of motor function was changed to *"memorativa"* memory.

The three stages of processing postulated for the three cells were also rationalized by a comparison with the spatial division of function in classical law courts. The quotation from the Anatomia Nicolai Physici, a twelfth-century text of Nemesius and Poseidonus [11]:

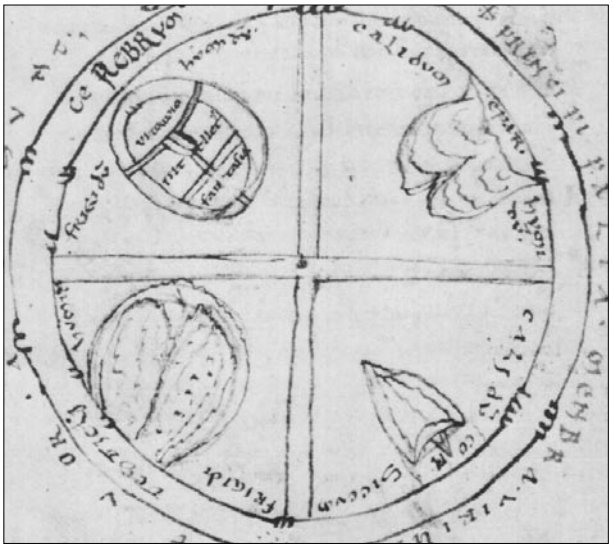

Figure 2. From an 11th century manuscript. The earliest known illustration of brain Function [12].

"*On the 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 process occur in the temple of the spirit, that is the brain. First, we gather ideas into the cellular phantisca, in the second cell We think them over, in the third, we lay down our thought, that We commit to memory*" [9].

The cell doctrine, though discussed a lot in the texts was not pictured in figures. As we see, there are no ventricles in figure 1. *Figure 2* is from eleventh-century and is the earliest known western illustration of brain function. The design is reminiscent of the Celtic stone cross found in Anglo-Saxon diagrams. The figure shows four principle human members, which are the liver, heart, testes, and cerebrum in a clockwise sequence from 12 o'clock. The last, in fact, is a drawing of skull facing inwards and seen from above. Coronal, sagittal, and lambdoid sutures are presented by double lines. The mental faculties fantasia, intellectus, and memoria are inscribed on it centrifugally. Around the circle *"there are present four principle human members"* is written. In the text, the brain is labelled cold and moist where as the heart is hot and dry in accordance with the ancient Greek theory of qualities. Since these designations were given great prominence by Aristotle and his followers, the illustration transmits traditional Greek ideas as well as the concept of ventricular localization of mental functions.

The initial form of cell doctrine was liable to variations and more complicated rearrangements. The first cell could have two separate parts (sensus communis and imaginativa) or the second might be doubled (aestimativa and cognitiva) or, occasionally the third cell can be in control of both motiva and memoria. Variations from the central theme was determined by the master teaching, whether it be Galen or Avicenna or the church fathers. For example, Avicenna, being a non Christian, did not feel obliged to stick to three cells and favoured a five cell scheme.

The diagram shown in *Figure 3* is at the end of a treatise by Avicenna copied in 1347 as *"De Generatione Embryonis"* [12]. There is no legend other than the statement *"this is the anatomy of the head for physicians"*. It is a crude profile of a human head. There are five cells in the brain. Five senses – *tactus* (touch), *gustus* (taste), *olfactus* (smell), *auditus* (hearing) and *visus* (vision) – are connected to the first cell sensus communis, and other cells fantasia, imaginativa, cogitativa, seu estimativa and memorativa are shown separately and interconnected. Besides this classification, the head is also divided to three cells from anterior to posterior as first, second, and third. This may be original or, more likely, a contribution of the copier.

Avicenna is neither the only nor the first of this variation of five compartments. About 100 years before this diagram Roger Bacon (1219–1292) prepared a similar manuscript *"De scientia perspectiva"*. *Figure 4* is a 1428 copy of this manuscript [12]. It is very similar to Avicenna's description showing five interconnected circles with much the same labelling. But in the accompanying text there is an interesting and unique discussion of brain function. The four humors of ancient Greek medicine, blood, phlegm, yellow bile and black bile are said to be excreted from cranial apertures: blood from the mouth, phlegm from the nose, yellow bile from the ears as ear wax and black bile from the eyes as tears. On the drawing these functions are recorded, close to each special sense organ.

Crude drawings similar to figure 3 later became the basis of Leonardo's first anatomical drawings of the brain about 140 years later.

Transitionists

With the advent of Renaissance learning, the medieval cell doctrine began to lose ground. This gradual transition was brought about by a group of men who stand between the medieval period and the Renaissance. Men who, having learned the old ways, had begun to assimilate and adopt the new.

Leonardo de Da Vinci (1472–1519) is the first of these pioneers. His powerful, insatiable, and extraordinary visual curiosity drove him to seek meaning in the structure and pattern of the body. Looking at the crude drawings before him it can easily be said that he was probably, the first great medical illustrator. His drawings are the earliest naturalistic drawings of the internal structure of the human body. He introduced a number of powerful techniques for potraying anatomical structures such as the use of transparencies, cross sections and three dimensional shading.

Leonardo's studies on anatomy can be roughly divided into an *early* (from 1478), *middle*, (1506–1510) and a *late* (after 1510) phase. As in other areas of his investigations, Leonardo's understanding of the brain showed a progression from unrefined images clouded

with medieval knowledge to the refined illustrations conveying first hand knowledge through dissections.

One of Leonardo's earliest anatomical drawings shows the visual input to the brain (*Figure 5*). Drawn in 1490 it is an uncritical amalgam of Arabic and medieval sources with minor discovery and some new techniques thrown in [2, 13–15]. At that stage Leonardo probably did not do much dissection of the brain and relies on Avicenna through Mondino's text.*

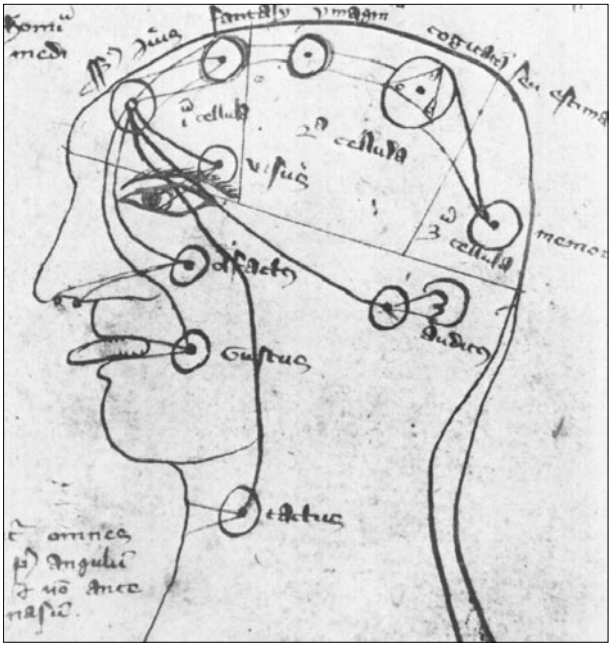

Figure 3. Avicenna's De Generatione Embryonis. Copied probably in 1347 [16].

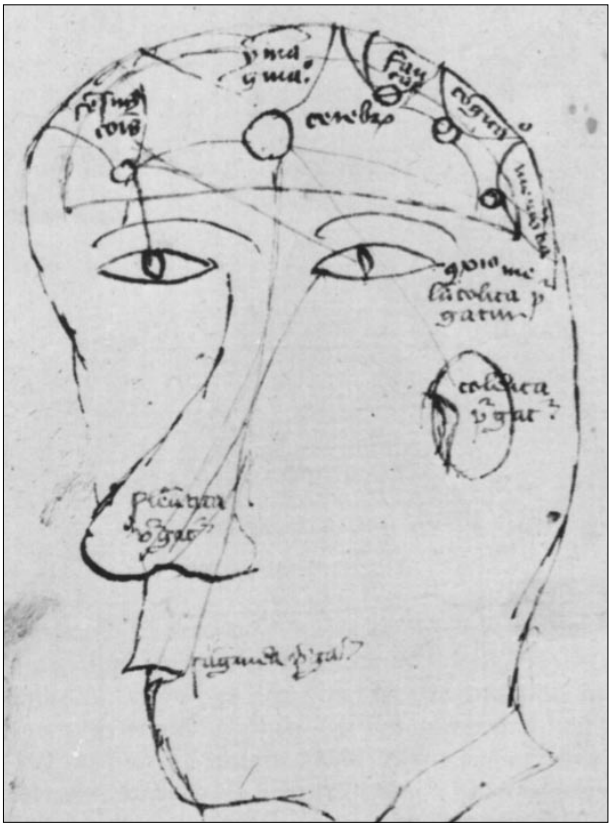

Figure 4. Manuscript copy of De scientia perspectiva by Roger Bacon, 1428 [16].

The terms for the layers from hair to brain are from Avicenna and portrayal of the ventricles as three connected spheres are from medieval cell doctrine. There, he did not even follow Galen, as the first (lateral) ventricles are not paired.

Drawn by red chalk and two shades of brown ink, the figure is more artistic than the previous ones. What Leonardo shows and discusses is the visual input, not the ventricles. At the bottom of the figure we can see an axial section at the eye level showing the visual and auditory inputs into the first cell.

For an artist like Leonardo who could draw the axial section of the brain, it is highly unlikely that he would miss the cross sectional anatomical structure of the ventricles. At this level of his drawings it was not clear whether Leonardo was drawing the brain observed, the brain remembered, the brain read about or the brain dissected. This is a typical figure of the early transition period artist, putting his art to half observed facts and half accepted false knowledge.

To stress this argument further, we can look at his later works. A few years later Leonardo turned to the ventricles with brilliant success. Using the sculptural technique of wax injection he revealed the shape of the ventricles. As he instructed: *"Make two vent-holes in the horns of great ventricles, and insert melted wax with a syringe, making a hole in the ventricle of memoria. Then when the wax has set, take away the brain and you will see the shape of the ventricles. But first put narrow tubes into the vents so that the air which is in the ventricles can escape and make room for the wax which enters into the ventricles".*

Wax injection is a technique Leonardo learned from his artistic craft. He was genius enough to apply it to the ventricles of the brain. This technique was not used again until Frederic Ruysch in the eighteenth century. French Academy of Science thought it to be an achievement equal to Newton's [9, 14].

The results of Leonardo's wax studies stands out in *Figure 6*. In the figure there is a sagittal and axial sectional anatomical drawing of the ventricles. In the axial view, posterior horns of the lateral ventricles cannot be seen. It was probably due to the absence of air vents in the posterior horns and the use of unpreserved brain. At this point we think that Leonardo deserves extra credit for his anatomical studies, for at his time corpses were not fixed and began to putrefy within hours and especially organs like the brain lost shape and consistency. It took fast, meticulous and uninterrupted work of several

* *Anatomia* of Mordino de Luzzi (Mondinus) written in 1316 was the first European anatomy textbook. It was essentially a 40 page dissection guide for learning Arab accounts of Galen's words, not for learning about the actual body. Mondino's work went through many manuscripts editions before it was finally printed in 1478, but remained unillustrated until the 1521 edition [16–18]. It was known to Leonardo at the beginning of his dissections around 1490 and was an important source of anatomical nomenclature for him [15–17, 19].

corpses to reveal even one muscle leave alone the brain. Most probably these frustrations made Leonardo seek techniques like wax injection. At the top right of the figure there is a faint drawing of the cortex seen from above. This is the most accurate cortex drawing up to that time. The base of the brain at the bottom left shows the *"rete mirable"* and is probably drawn from an ox brain. Lastly at the middle right there is an axial section showing the senses and cells. Here Leonardo, typical of an early transitionist, is trying to adopt his old knowledge to his new findings, to see whether they match. At the text he is mentioning the horns of great ventricles, yet he is putting the ox brain and cell doctrine side by side with the human brain.

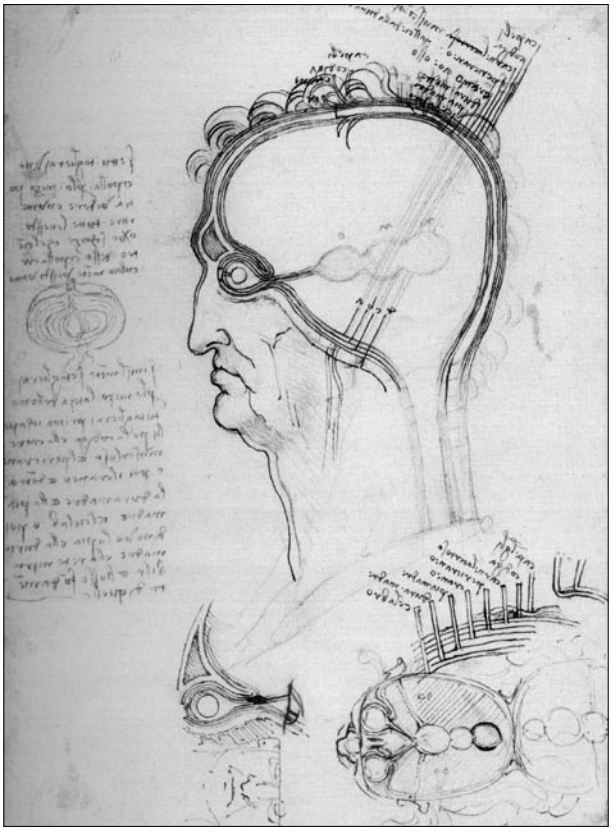

Figure 5. Leonardo da Vinci', sagittal section of head. The early drawings 1490 [22].

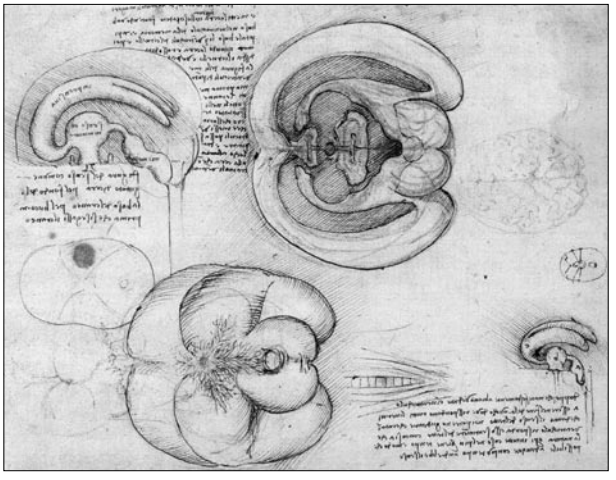

Figure 6. Leonardo da Vinci. Drawings after his wax injection studies 1504–1507 [22].

About 20 years after Leonardo's wax studies Berengario da Carpi (1460–1530) published his book *"Isagoge Breves"* in 1522. His anatomical illustrations were more like pictures and were much improved compared to Leonardo's. *Figure 7* is from the second edition of Isagore Breves published in 1523. It shows the brain from above with, at first one ventricle opened to show the vermis. In this figure vermis is shown as the sitting place of the choroid plexus where as in the dynamic cell doctrine it acted as a valve between cells one and two. The lower view reveals both lateral ventricles at their anterior venter, two veins in the midline and the *"embotum"*. Embotum may be, either the opening into the aqueduct of Sylvius or the hypothetical exit by way of the pituitary for ventricular wastes. With our present knowledge and due

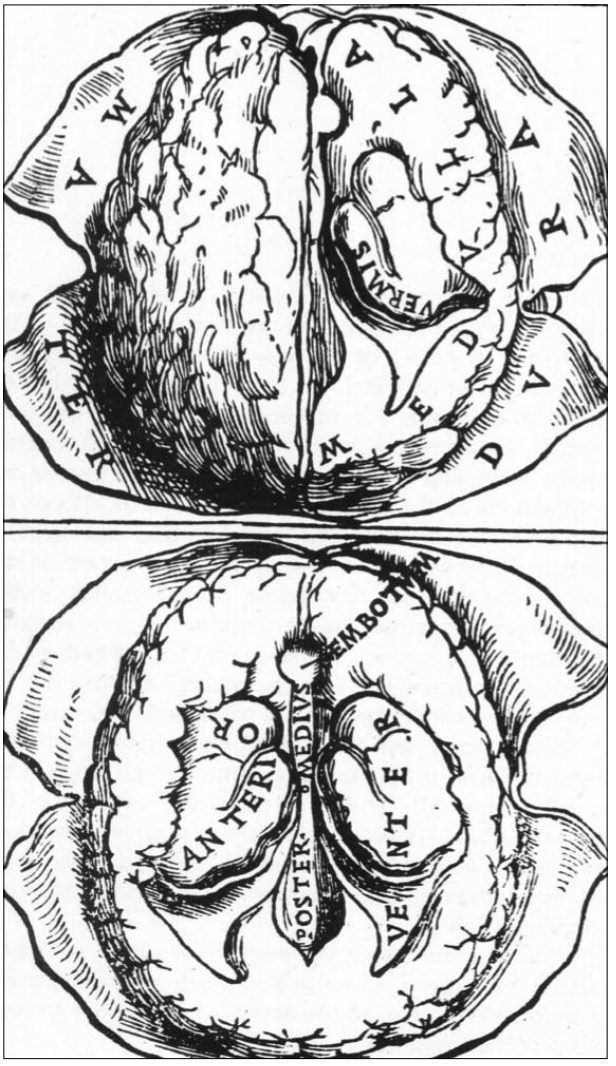

Figure 7. Berengario da Carpi. Anatomical illustration from Isagoge breves 1522 [12].

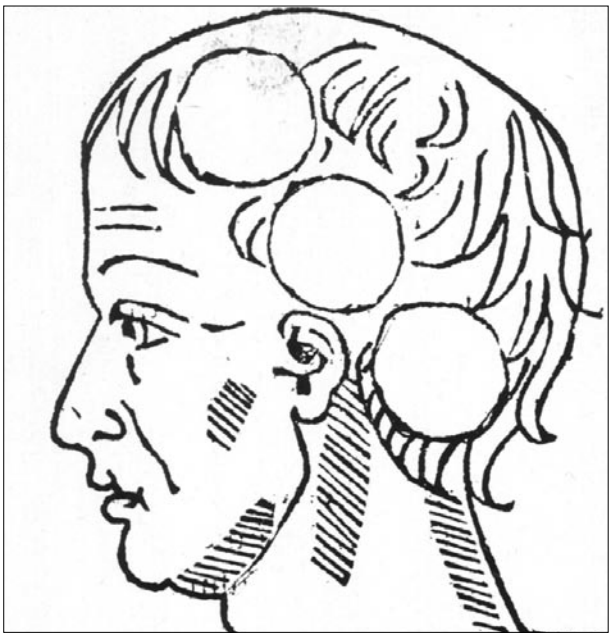

Figure 8. Berengario da Carpi. Cover of his famous book. Tractatus de fractura calve Sive cranei a carpo editus 1518 [12].

to its anterior localization the second hypothesis seems more plausible.

In a statement at the text Berengario discusses the aim of his anatomical studies and illustrations as *"… so that the matter discussed may be better understood I have accommodated below such figures of the brain as I was able in which some of the matters previously described can be understood as you see"*. Though his visuals were much removed from medieval cell doctrine, he was still a transition man under the influence of medieval knowledge. When it came to argument in the text of his Isagoge, he accepted some of the cell doctrine, for he located all the mental functions in the lateral ventricles.

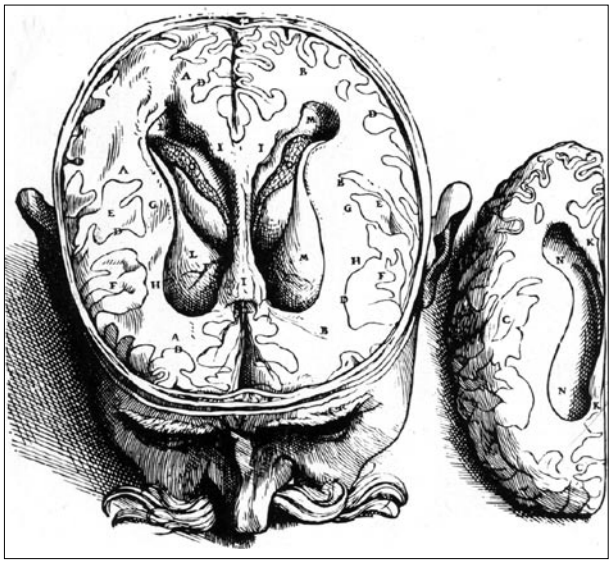

Figure 9. Andreas Vesalius. Brain ventricles from his famous book De Fabrica 1543 [21].

He argued that the other ventricles dealt with excretion, motion and sensation.

His most famous book *"Tractatus ed Fractua Calve Sive Cranei"* is a surgical text on cranial fractures. On the cover of his book there is a head in profile showing the three cells. This cover figure (*Figure 8*) is a reproduction of another famous Renaissance anatomist of Bologna, Alessandro Achilini (1460–1512) without the namings of the ventricles.

Andreas Vesalius of Pauda (1514–1564), is known as the greatest of the Renaissance Anatomists and also, maybe, the last man of transition with regard to brain function. He rekindled anatomical science and virtually broke Galen's stranglehold on the field. In his remarkable book *"De Humani Corporis Fabrica"* 1543 [20], he tells how he was taught the cell doctrine and although he describes its basic tenets, referring to one of the most popular portrayals of cell doctrine by Gregor Reich (1467–1525) – a Carthusian prior of Freiburg and Confessor to Emperor Maximillian I – he implicates his rejection for church sanctified authority for knowledge and casts doubt upon its veracity.

Figure 9 is from the seventh book of the De Humani Corporis Fabrica VIII. Vesalius says: *"We have resected all the portions of the dural and the thin membranes which occurred in previous figures. Then we have removed in the sequence of dissection the right and left portions of the brain so that the cerebral ventricles now begin to come into view. First, we made a long incision along the right side of corpus callosum where the sinus denoted by one of the M's exists, which was led into the right cerebral ventricle. Next we removed the right part of the brain lying above the section where we cut the skull in circular fashion with a saw. When we have finished the same on the left side, we placed here the left part of the brain so as to show to some extent the upper aspect of the left ventricle, while the corpus callosum still remains in the head"* [21].

This is a clear scientific description of brain dissection that requires no more comment. As to their function, Vesalius argued against placing the functions of the soul in the ventricles. He argued that many animals have ventricles similar to those of humans and yet they were denied a reigning soul. He said that he believed nothing ought to be said of the locations of the faculties, of the principal soul in the brain even though they are so assigned by those who today rejoice in the name of theologians.

Although cell doctrine persisted into the seventeenth century by transmission through the writings of certain authors, with the work of Renaissance artists and, mainly, Vesalius, the true anatomy of the ventricular system was established. The crude medieval conceptual sketches were no longer accepted. It was shown that the ventricles contained a fluid, a what is now called *"cerebrospinal"* fluid and it was highly unlikely that mental functions took place within it.

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