ON THE PACCHIONIAN BODIES

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THE villous outgrowths of the arachnoid membrane in the neighbourhood of the intracranial venous sinuses, which were originally described in detail by Pacchioni (1) in 1721, have for a long time attracted the curiosity of anatomists and physiologists. Investigations of these granulations have almost always been approached from the experimental point of view, and there are surprisingly few observations recorded on their anatomical structure and relations.

Originally referred to as "glandulae" by the old anatomists, the Pacchionian bodies were later regarded as passive filters through which the cerebrospinal fluid drained from the subarachnoid space into the intracranial venous sinuses. This view was strongly supported by the classic work of Key and Retzius (2), and received further corroboration from a number of investigators (3), (4) who approached the problem by different methods of experimental injection.

Latterly, the observations made by Weed (5) enable one to accept, though in a somewhat modified form, the filtration hypothesis as being fully confirmed.

Luschka (6) first pointed out that the Pacchionian bodies are hypertrophied arachnoid villi which are normally present in all brains, but which are microscopic in character. If this is so, then what is the significance of the hypertrophy?

Some authors, among whom are Weed and Rokitansky, regard the granulations as definitely pathological formations. This view appears untenable when consideration is given to the constant presence of the granulations in human brains above a certain age, and to their presence in the brains of certain lower mammals. Weed says that "undoubtedly the Pacchionian granule must be considered as a large hypertrophic villus becoming evident on macroscopic examination in *most*[1] adults." I have never seen an adult in which they were absent.

In order to arrive at a satisfactory solution of the question, it is necessary to enquire more closely into the morphological features of the Pacchionian bodies, and to this aspect of the subject I shall confine myself in the present communication.

The intimate relation—physiological and anatomical—between the development of the arachnoid outgrowths and the venous system is well known, and it is clear that the two must be studied in conjunction.

[1] Italics mine.

During the course of my investigations, I have found that the arrangement of the meningeal venous sinuses and the cerebral veins differs fundamentally in several points from the orthodox description as given in current text-books of anatomy. I propose first to deal with these points, and subsequently to give an account of the macroscopic and microscopic features of the Pacchionian bodies.

A. THE VENOUS SYSTEM IN RELATION TO THE PACCHIONIAN BODIES

1. *The Superior Cortical Veins*

The general course and distribution of these veins have lately been described in some detail by Sargent (7). In common with modern text-books, he describes these veins as sometimes opening into the sagittal sinus directly, and sometimes opening into the lacunae laterales. This statement, I believe, is incorrect, and is based on a misconception of the true nature of the lacunae laterales, as I shall indicate.

If the cortical veins are carefully dissected out, either in injected or uninjected specimens, they will be found always to open directly into the sinus, and never into the cavities of the lacunae. Where they come into relation with the lacunae, the cortical veins pass beneath them. Such at least is the result of my observations which are based on the examination of over 40 brains. It is evident, therefore, that a cerebral vein opening into a lacuna lateralis is a very rare and abnormal occurrence.

In many cases the vein, immediately before opening into the sinus, undergoes a dilatation, and this may be mistaken for a lacuna lateralis. These two structures are, however, situated in different planes, and, moreover, differ in their naked-eye appearance and in their mode of formation.

The floor of the vein is throughout lined by a smooth endothelial membrane which is only very exceptionally perforated by an isolated Pacchionian body near its termination.

The floor of a lacuna, on the other hand, presents a fasciculated appearance, and is usually perforated by numerous arachnoid protrusions, while the cavity is crossed by innumerable fine dural strands. The membrane separating the lumen of the vein from the lacuna may be extremely thin, and is thus readily torn.

2. *The Lacunae Laterales*

These structures develope pari passu with the growth of the Pacchionian bodies, but it is impossible to say precisely when these lacunae—as such—appear in the human brain.

If the intracranial venous system of a new-born child be injected with coloured gelatine, and if the dura mater be then removed, dehydrated with alcohol and cleared in xylol, the following arrangement will be well seen.

Alongside the sagittal sinus is a coarse plexus formed by the anastomosis of the terminal arborizations of the meningeal veins, the diploic veins which run from the parietal bones to the dura in this region, and the small lateral tributaries of the sagittal sinus.

This plexus occupies precisely the position of, and is formed in exactly the same way as, the lacunae laterales of the adult. As growth proceeds, the venous network becomes more complex, and by the attenuation of the dural meshes and the corresponding widening and coalescence of the venous channels, "lacunae" of variable number and extent are formed.

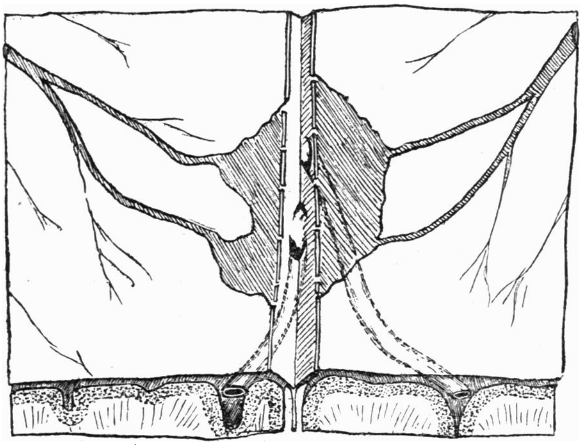

Fig. 1. Diagram illustrating the relations of the cortical and meningeal veins to the lacunae laterales.

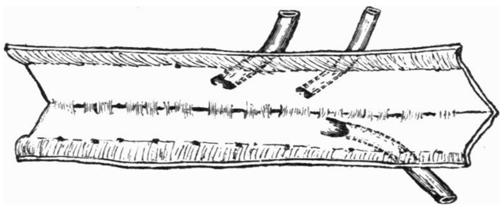

Fig. 2. Diagram illustrating the sagittal sinus laid open from above, to show the openings of the cortical veins and the dural venous plexus.

These lacunae should not be described as well-defined single cavities—diverticula of the sagittal sinus—but rather as a complicated meshwork of veins. If they are studied by dissection, or, better still, microscopically by means of serial sections, it will be seen that the superior terminations of the meningeal veins drain into the outer border of this meshwork, while the diploic veins enter it on its upper aspect. Internally, the meshwork opens by a series of small foramina into the sagittal sinus, i.e. through the venous tributaries of the sinus mentioned in connection with the venous plexus found at birth. The position of these openings is shown with diagrammatic clearness in the sinus of a new-born child, and the accompanying illustration shows their relation to the openings of the cortical veins.

A glance at the calvarium of an adult will show the very numerous diploic foramina scattered alongside the groove for the sagittal sinus, indicating the extent to which the diploic veins enter into the formation of the lacunae laterales.

Faivre (13), indeed, appears to have regarded the lacunae as being formed wholly in association with the diploic veins, for he speaks of "les lacunes, des sinus secondaires qui reçoivent le sang des veines diploïques."

Incidentally, it is perhaps worth while drawing attention to the inadequate description of the openings of the diploic channels as given in anatomy text-books. These descriptions lead the student to suppose that the diploic veins leave the diploë at very few and limited points.

The lacunae, as they increase in size, form small smooth depressions in the frontal and parietal bones on either side of the groove for the sagittal sinus. These are commonly described as "depressions for the Pacchionian bodies." They are more correctly regarded as depressions for the lacunae laterales, for they are frequently well-developed before the Pacchionian bodies are large enough to make an impression on the bone. As the Pacchionian bodies grow, however, they may become lodged in well-defined and sharp-edged pits which can be easily recognised and distinguished by their characteristic appearance. The arrangement of the other cerebral veins and dural sinuses accord well with the usual description. Sargent has recorded the presence of a dilatation at the commencement of the straight sinus, i.e. at the junction of the great vein of Galen and the inferior longitudinal sinus. This dilatation he terms a lacuna, but it is clear that it differs fundamentally in its anatomical relations and mode of formation from the lacunae laterales. This dilatation is especially well marked at birth, when it forms a relatively very large cavity.

B. MACROSCOPIC ANATOMY OF THE PACCHIONIAN BODIES

1. *Development*

The Pacchionian bodies appear at a much earlier age than is generally supposed. At birth they are imperceptible even on examination with a hand lens. At the age of six months they are still invisible, but by 18 months they are quite obvious on close inspection. They appear in the first instance in the regions where the parieto-occipital and central veins open into the sagittal sinus. From these nuclei they spread forwards and backwards along the superior margin of the cerebral hemispheres, and at the age of three they are disseminated over a considerable area. By this time they are often to be seen along the lateral sinuses, on the margin of the cerebellum. At four they project well into the sagittal sinus, forming conspicuous nodules in the lumen of the sinus[1].

[1] Faivre (13) states: "c'est vers la dixième année que ces produits (Pacch. bodies) commencent à se montrer, bien qu'on en puisse trouver avant cette époque." I cannot explain this discrepancy.

2. *Distribution of Pacchionian bodies in Adult*

According to Key and Retzius, the Pacchionian bodies occur in the following situations in order of frequency: sup. longitudinal sinus, transverse sinus, cavernous sinus, sup. petrosal sinus, and venae meningiae mediae. I have also found them in connection with the sphenoparietal and straight sinuses. In all these situations, they tend to congregate in the regions where the cerebral veins open into the sinuses.

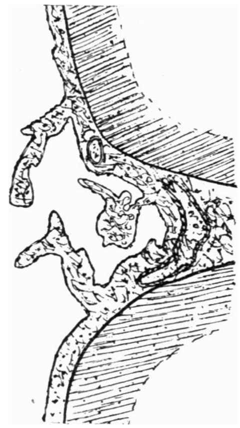

Fig. 3. Section showing Pacchionian bodies in the region of the parieto-occipital fissure in a child aet. 2½.

In the neighbourhood of the sagittal sinus, the granulations are most numerous in the floor of the lacunae laterales. As these latter increase in extent, the granulations also spread, and, with advancing age, they tend to crawl down the middle meningeal veins. Elliot Smith (8) has recorded an extreme instance of this latter arrangement.

The bodies that project into the lumen of the sinus are found in the floor and lateral walls. Quite frequently, a small clump of granulations is found on the floor of the sinus at the mouth of one of the cerebral veins, so that they are bathed by the blood as it is poured from this vein into the sinus.

The Pacchionian bodies in relation to the lateral sinus are practically always confined to the surface of the cerebellum—that is to say, they project into the sinus from below. Very rarely are they found on the surface of the cerebrum in this situation. They are most numerous at the point where the inf. cerebellar veins open into the lateral sinuses on either side of the Torcular Herophili, and from this point they gradually fade away laterally.

The Pacchionian bodies are much less frequently seen in relation to the other venous sinuses, and these become conspicuous only in certain conditions, such as senility.

The precise relation of the Pacchionian bodies to the venous spaces with which they are associated is of some interest. The impression is gained from most descriptions that the Pacchionian bodies are formed by a pouching out of the arachnoid membrane, which eventually finds its way into a venous sinus, i.e. that the body, when it first appears, is not connected with a venous space in the dura. This idea can be readily demonstrated to be erroneous. If the brain, either of an adult or a child, be examined, and if the dura mater be lifted up from the underlying arachnoid with the utmost care, it will be found that every granulation of the arachnoid—even the most minute—is directly attached to the under surface of the dura mater. If this adhesion be broken down and the dura inspected, it will be seen that the point of attachment at the dura is marked by a minute aperture, and with appropriate pressure, blood can be squeezed out through this aperture from the dural sinuses. This observation—in conjunction with histological evidence to be presently produced—indicates that the arachnoid granulations come into direct contact with the blood of the venous spaces from their first appearance. Poirier (9) wonders "comment functionnent celles qui ne sont pas dans une cavité veineuse." The answer is that they all reach a venous cavity.

Other points in the naked-eye anatomy of the granulations are well-known, and need not be detailed here.

C. MICROSCOPIC ANATOMY OF THE PACCHIONIAN BODIES

Histologically, a Pacchionian body or arachnoid granulation (Arachnoidealzotte of German authors) appears as a diverticulum of the subarachnoid space penetrating into the interstices of the dura mater. It is thus covered by a layer of arachnoid mesothelium, and contains a prolongation of the subarachnoid space.

The arachnoid mesothelium consists of a single layer of flattened cells, with lightly staining cytoplasm and large oval nuclei. The subarachnoid space consists of a reticulum of fine fibrous tissue in which are scattered a number of connective-tissue cells. These cells are most numerous, and the fibrous stroma more dense, immediately beneath the arachnoid mesothelium, and on the surface of the brain. Between these two areas, bundles of fine fibrous tissue predominate and the cellular element is very scanty. In children, these connective-tissue cells are found in very much larger numbers, and inter-trabecular spaces are very much less marked than in adults.

Incidentally, it may be noted that the pia mater is merely a condensation of the subarachnoid trabecular tissue, and is not a definite membrane comparable to the arachnoid. The density of the subarachnoid tissue in the Pacchionian bodies as a rule is greater at the periphery than at the centre of the structure, and this difference is more marked in the larger granulations.

Although not usual, it is by no means uncommon to find a small capillary blood-vessel in the cavity of a granulation, and in some cases a capillary may be observed to leave the granulation by passing through the arachnoid mesothelium and subdural space to reach the surrounding dura mater. In the Pacchionian bodies of adults, and more so in advanced age, there are frequently found small calcareous nodules. These may be either spherical or cylindrical in shape. They appear to arise by the calcification of small collections of endothelial cells arranged in a concentric formation. My sections show these latter structures undergoing various degrees of hyaline and calcareous changes to form ultimately calcareous nodules. The origin of the primary endothelial formation is, however, not clear. Some sections would appear to indicate their origin in connection with capillary blood-vessels by a proliferation of the endothelium. In other sections they are found in the epithelial cap on the summit of the Pacchionian body, as described below. Their interest lies in the close resemblance of their structure to that of endotheliomatous tumours in this region, and this fact lends support to the suggestion—originally put forward by Schmidt (11) with detailed evidence—that the so-called endotheliomata of the dura mater are really arachnoidal tumours. The calcareous changes in these endotheliomata leading to the formation of psammomata are well-known.

If the arachnoid mesothelium of a Pacchionian body be followed throughout the structure by means of serial sections, it will be found that at the summit of the granulations the mesothelial cells proliferate to form a multi-layered cellular cap, and this cellular formation penetrates the surrounding dura mater to come into direct continuity with the endothelial lining of the

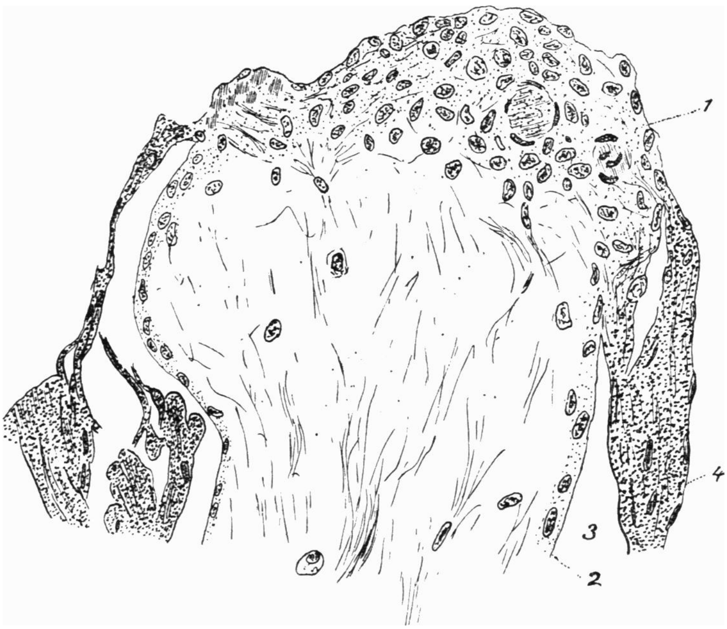

Fig. 4. Section 49, showing tip of Pacchionian body projecting into a venous sinus. The arachnoid has completely blended with the vascular endothelium, and the subdural space is obliterated. 1. Epithelial cap. 2. Arachnoid mesothelium. 3. Subdural space. 4. Dura mater.

intradural venous sinuses. At this point, that is to say, there is no subdural space or layer of dura mater intervening between the arachnoid and the venous sinus.

This mesothelial cap is evidently identical in structure with the cellular tuft described by Weed in connection with the microscopic arachnoid villi of lower animals, and corresponds to the "Epithelzapfen" of German authors (10, 11). Moreover, Weed (5) has demonstrated that it is through this structure that the cerebro-spinal fluid passes from the subarachnoid space into the venous sinuses.

Except for this point of fusion between the arachnoid and the vascular endothelium (which can be demonstrated by serial sections), the arachnoid covering the Pacchionian bodies is surrounded by the subdural space and the dura mater. The latter—covered on its cerebral aspect by a layer of endothelium—is invaginated into the venous sinus by the protrusion of the arachnoid granulation. In most sections of a Pacchionian body it appears to be completely surrounded by the subdural space, but, as pointed out above, this is not so.

Histological evidence indicates that the Pacchionian bodies are developed in the following way. Opposite the point where an intradural venous sinus approaches the cerebral surface of the dura mater, the arachnoid cells proliferate to form a cell cluster (Epithelknoten of German authors). The cellular tuft thus formed finds its way through the interstices of the thin layer of dura mater separating it from the sinus, and fuses with the endothelial lining of the latter. In so doing, it pulls out a stalk of arachnoid membrane con-

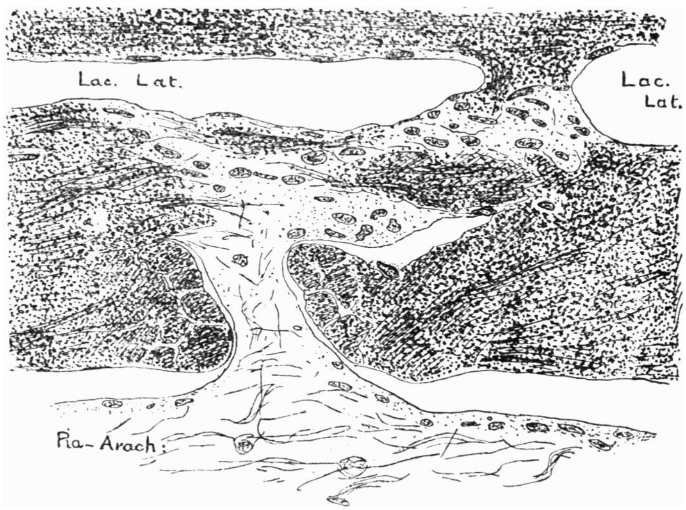

Fig. 5. Section 102, showing the first formation of an arachnoid villus.

taining a diverticulum of the subarachnoid space. This early stage is shown in the accompanying illustration.

Thus is formed the microscopic arachnoid villus normally present in all brains. Subsequent growth, leading to the formation of the macroscopic arachnoid granulation, appears to take place almost entirely by the dilatation of the subarachnoid space in the pedicle of the microscopic villus.

D. SIGNIFICANCE OF THE PACCHIONIAN BODIES

The assumption that the Pacchionian bodies constitute the essential mechanism of filtration of the cerebro-spinal fluid is nullified by Weed's researches. He has shown that the cerebro-spinal fluid reaches the venous channels by means of the microscopic arachnoid villi. It therefore remains to ascertain the precise relation of the Pacchionian bodies to the villi.

Microscopic examination gives the Pacchionian bodies the appearance of arachnoid villi which have been distended and herniated into the cavity of the venous sinuses by the pressure of the cerebro-spinal fluid. And it is, in fact, suggested that the size and number of the Pacchionian bodies are an indication of the cerebro-spinal fluid pressure. If this is the case, then an examination of the brain of an individual who has died with an abnormally high cerebro-spinal fluid pressure should reveal an unusual development of the Pacchionian bodies. This indeed appears to be the case. It is well known that an autopsy of a case of Dementia Paralytica reveals an increase in the number and size of the Pacchionian bodies (Stoddart(16)). This is correlated with an increased pressure of the cerebro-spinal fluid, for an examination of the brain also shows that "the sulci are distended with fluid" (Mott(14)).

Similar changes are to be found in cases where the intracranial pressure is raised by the presence of tumours. I have lately seen the post-mortem examination of a case of cerebral tumour in which there was evidence of increased intracranial pressure of two years standing. In this case, the Pacchionian bodies were very clearly larger and more numerous than in a normal person of the same age and sex.

Again, the Pacchionian bodies are always found to be very well developed —sometimes to an extraordinary degree—in patients suffering from chronic nephritis and arterio-sclerosis. In these cases, the arterial blood-pressure is abnormally high, and it has been shown that the cerebro-spinal fluid pressure is dependent to a certain extent upon the blood-pressure (Becht(15)). If the development of the Pacchionian bodies is indeed an expression of the cerebro-spinal fluid pressure, then the increase in number and size of these bodies with advancing age receives a satisfactory explanation. For the blood-pressure increases with age, and presumably therefore the pressure of the cerebro-spinal fluid also rises.

It is thus seen that the Pacchionian granule is not so much an hypertrophy as a distension of the arachnoid villus, and it appears that Pacchioni was correct in his implication: "In senibus vero glandulae albescentes et magis turgidae cernuntur."

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