CEYLON J. MED. SCI. (D) VOL. VIII, PT. IV (April, 1954)

The Dura Mater and its Relation to Blood Vessels*

BY

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The dura mater is usually described as consisting of two layers, an outer periosteal and an inner supporting, but the criteria adapted by different investigators for this subdivision into two lamellae have varied.

Vieussens (1685) and current textbooks of anatomy have indicated the plane of cleavage by the presence of venous sinuses and meningeal arteries between them. Slevogt and Xylander (1690), Arnold (1893), Poirier and Charpy (1921) and many others have maintained that the dura mater is easily separated into two layers in the new born. Todd (1839-47) has described an apparent lamellar disposition due to its fibres being arranged in different planes. Weed (1932) and Penfield and McNaughton (1940) found no indication of cleavage except at the sinuses. Hewer (1937) and Maximow and Bloom (1948) have differentiated the two layers by the relative increase in vascularity and cellularity of the outer layer and the fineness of the fibres in the inner layer.

The available literature also shows differences of opinion with regard to the vascular system of the dura mater, hence it was thought profitable to reinvestigate the structure of the dura mater and its relation to blood vessels.

Material and Methods

This study was made on human material. The brain and meninges were removed entirely from still-born infants and fixed in 10 per cent. formalin for two weeks. The whole specimen was then dehydrated through repeated changes of ascending grades of alcohol, the process taking another two weeks. The dura mater was then cut off in blocks, some in relation to the greater parts of the superior sagittal and transverse sinuses and others from the side walls adjacent to the main vessels. They were all cleared in xylol prior to embedding. In addition frozen sections of the transverse sinus were prepared, each 100 microns in thickness.

The connective tissue stains used were haematoxylin and eosin, Van Gieson's and Mallory's triple stain. Verhoeff's and Van Gieson's techniques were used as selective stains for elastic fibres. Cajal's silver impregnation method and the haematoxylin-eosin combination were employed for the purpose of demonstrating epithelial tissues.

The internal vascular architecture was studied by employing a slight modification of the technique described by Pickworth (1934). Large areas from the lateral parts of the dura mater were removed with a fine pair of scissors and promptly transferred

*Adapted from the Thesis on ' The Blood Supply of the Meninges ' accepted for the degree of Doctor of Philosophy of the University of Manchester.

with the minimum loss of blood from the vessels, to petri dishes containing formol-saline (10 per cent. formalin with 2 per cent. normal saline). They were held flat with the aid of lead weights and after two days fixation the material was treated as follows :—

1. Washed in running water for 3-4 hours ;
2. immersed in nitroprusside benzidine and constantly shaken for one hour ;
3. placed in weak hydrogen peroxide for one hour ;
4. dehydrated in ascending grades of alcohol, and
5. cleared in xylol.

When cleared the material was examined under a dissecting microscope.

A study of the vascular patterns in the thickness of the dura mater was made by adopting a modification of Pickworth's method described by Doherty, Suh and Alexander (1938). 200 micron sections, which had been fixed in formalin, were stained consecutively in two solutions :

1. A mixture of benzidine and sodium nitroprusside in 50 per cent. alcohol (solution A) and,
2. a mixture of sodium nitroprusside and hydrogen peroxide in 50 per cent. alcohol, acidulated with 2 per cent. glacial acetic acid (solution B).

Findings

The division of the dura mater into an outer periosteal layer and an inner supporting layer was apparently determined, primarily by the position of the dural venous sinuses which lie between the two layers. Microscopic examination provides evidence that it is really more complex and reveals differences in the size and arrangement of the constituent fibres. Although fibrous tissue bundles interlace in diverse directions, it is possible to distinguish three main layers in the dura mater outside the large venous sinuses (Pl. I, fig. 1). They are from without inwards :—

(1) A superficial layer consisting of coarse bundles of fibrous tissue disposed transversely to the long axis of the superior sagittal sinus.
(2) An intermediate layer of thinner fibres running in the long axis of the sinus.
(3) A delicate layer of still finer fibres resembling areolar tissue, containing several venous channels.

The large bundles of transversely running fibres correspond to the layer commonly described as the outer or periosteal layer, whereas the intermediate longitudinally arranged thinner fibres along with the inner reticular zone represent the inner meningeal or supporting layer. Nuclei were present in all these, being most numerous in the external lamina. The dura mater is almost devoid of elastic tissue except for a small number of fibres present in the internal elastic lamina of the arteries.

Artificial separation into two layers is most readily produced around the main vascular bundles, which lie ensheathed by loosely arranged tissue, between the superficial and intermediate layers (Pl. I, fig. 2). In other areas there is no sharp demarcation between the periosteal and the meningeal layers. Here the compactly arranged coarse bundles of the superficial set, when followed inwards, separate out into a loose network and the strands get smaller, and longitudinally directed fibres increase to become the intermediate layer (inner layer).

When these laminae, described above are traced towards the superior sagittal sinus, the spongy tissue gradually diminishes whilst the longitudinally running fibres increase in number and separate out to enclose the sinus (Pl. I, figs. 3 and 4).

It is evident, therefore, that the superior longitudinal sinus runs through the inner layer (intermediate layer) and not between the periosteal and meningeal layers, which is the accepted view. The outer layer also becomes thicker but without any change in the direction of its fibres.

The arrangement of the layers of the dura mater in relation to the transverse sinus, however, is completely different from that around the longitudinal sinus. Two sets of fibres can still be distinguished, the outer being coarse and the inner fine. All the fibres of the inner layer pass inwards to become a superficial layer of the tentorium cerebelli, but the innermost bundles of the outer layer separate to enclose the sinus; below the level of the sinus only the coarse bundles of the outer layer are still evident (Pl. II, figs. 5, 6 and 7). Thus if the comparative fibre size and direction are used as criteria for distinguishing the two layers of the dura mater, the superior sagittal sinus lies within the inner layer and the transverse within the outer layer.

The main meningeal vessels which run between the superficial and intermediate laminae alter their course on reaching the superior longitudinal sinus. Some of the arteries and their branches enter the superficial layer to be distributed to the dura mater forming the roof of the sinus, while others pass inwards in the intermediate layer (inner layer) to supply the falx cerebri. Their companion veins pass through the intermediate lamina to enter the sinus. The veins which are carried in the spongy tissue also pass into the layer commonly described as inner or meningeal to enter the sinus. Immediately around the sinus, however, the spongy tissue is absent.

The middle meningeal arteries and their branches are almost always accompanied by two veins one on each side (Pl. III, fig. 8). The cross-section of these venae comites vary in shape between triangular and semilunar and they are lined only by endothelium. The three tunics of the arteries are all thin and show almost complete absence of elastic tissue in the outer and middle coats. The fibres in the inner elastic lamina are arranged in a circular manner and the tunica media contains a few smooth muscle cells, similarly disposed.

Some sections showed arteries lying suspended in venous channels. A large number of serial sections was studied to ascertain whether this appearance was an artefact and due to a close venous network around the artery or arteries, or whether they were in fact embedded in the sinuses. This arrangement was commonest in regions just distal to an arterial bifurcation. The companion veins divide prior to the artery, the larger branches remaining lateral to it, whereas the other two divisions run under the dividing artery (in some cases one is disposed superficially and the other deeply) to gain the medial aspects of its daughter branches. These two veins, as they enter the fork of the divided artery, communicate with each other and isolated sections taken through this area give the false appearance of an artery lying within a venous channel, whereas serial sections prove that the artery is in fact outside (Pl. IV, figs. 12-21). This artefact is produced by anastomosis of the branching venae comites around the artery. In the particular sections illustrated the artefact could only be traced for very short distances.

There are two venous plexuses in the dura mater; superficial and deep. The former consists of fine vessels superficial to the main vascular bundle (Pl. III, fig. 9). The latter is made up of larger vessels lying deep to the main vascular bundle (Pl. III, fig. 10). Obliquely running vessels connect the two plexuses (Pl. III, fig. 11). The tributaries from the superficial net open into the venae comites and also into the deep plexus, and its contained blood can therefore drain into the dural venous sinuses by two routes, i.e. (*a*) through the venae comites and (*b*) via the deep network. The venae comites often communicate with the veins of the deep plexus as these pass under the main vascular bundle. Sections passing through these sites of anastomosis can also give the false impression of an artery lying within a vein, but in the many sections examined no arteries were ever noticed to be completely surrounded by venous channels. The deep plexus of veins by virtue of its communications with the superficial network and the venae comites, is the most important route for the venous return to the sinus. In addition cerebral veins open into this network.

Discussion

Slevogt and Xylander (1690), Arnold (1838), Todd (1839-47), Poirier and Charpy (1921) and many others have maintained that the dura mater is easily separable into two layers in the new born, but Boehm (1869) contested this view. Todd further indicated that the fibres of the two layers were arranged in different axes. Vieussens (1685) and the current English text-books of anatomy have indicated the plane of cleavage by the presence of both venous sinuses and meningeal arteries between the two but Boehm and Poirier and Charpy state that the meningeal arteries run exclusively in the outer layer. Knox (1839) regarded the meningeal vessels and the lining mesothelium on the inner aspect of the dura mater as two separate layers, and thus accounted for four layers. Weed (1932) mentioned that the two closely adherent layers separate to enclose the sinuses. The majority of investigators have agreed that the dura mater is composed of fibrous tissue but Elliot (1947) has claimed elastic tissue is present in the two layers.

The results of this investigation do not substantiate the findings of Slevogt and Xylander and others that the dura mater is easily split into two layers in the new born. Artificial separation is difficult as interlacing fibres run in different directions and it is hardly possible to separate any two layers in the same plane, except around the main vascular bundle. This supports the observation made by Boehm that the dura mater in man cannot be artificially separated into two layers.

The dura mater can, however, be separated into layers histologically. In fact three layers can be demonstrated in the cerebral dura mater outside the large dural venous sinuses. The presence of the reticular layer, however, is not indicated by any investigator. It is undoubtedly a part of the dura mater and cannot be mistaken for the arachnoid in that its fibres are continuous with those of the intermediate layer and is different in structure and arrangement. This spongy layer, however, was not discernible around the large venous sinuses and in this respect it may be considered as a part of the intermediate layer present only in regions outside the sinuses.

The elastic fibres claimed by Elliott to be present in the two layers were far from conspicuous in preparations taken from six different subjects, although specific

elastic stains were used; indeed, they were easily distinguishable only in the elastic lamina of the arteries.

The main meningeal arteries with their venae comites always run between the outer and intermediate layers. As these two sets of fibres differ in size and run in opposite directions the position of the main vascular bundles is readily established and this bears out the findings of Vieussens and the descriptions given in the standard text-books of anatomy. Others who hold the view that arteries run in the outer layer perhaps included them to be in this layer in view of its endosteal function. But microscopical examination shows that the main vessels really occupy a position between the two layers.

As stated above, the reticular layer was not discernible in the region of the large sinuses. It seems to provide a suitable medium for the passage of numerous thin-walled venous channels on their way to the sinuses. The arrangement of the other two layers differs around the superior sagittal and transverse sinuses. The superior sagittal sinus is enclosed by the longitudinally running fibres of the intermediate layer, (now the inner layer in the absence of the reticular layer) while the outer set of fibres pass transversely over the roof of the sinus. The position of the transverse sinus differs entirely from the above. Here the whole set of inner fibres passes inwards to become a superficial layer of the tentorium cerebelli and the fibres of the outer layer separate to enclose the sinus. The different arrangements in the two sinuses are conclusively demonstrated in Plate I, figures 3 and 4 and in Plate II, figures 5, 6 and 7, and they differ individually and severally from the opinions expressed in all monographs and modern text-books which are based on the findings of earlier workers and so are supported by the weight of tradition. In this matter tradition is erroneous.

Wood Jones (1912) observed that the meningeal arteries sometimes ran within venous channels. This was noted earlier by Boehm who suggested that this appearance was due to a close network of veins crossing the arteries. None of the sections examined showed an artery completely surrounded by a vein, as stated by Wood Jones; some did show an artery apparently lying embedded in a vein. But this is certainly an artefact, seen only in isolated sections and commonly in regions distal to an arterial bifurcation. It is caused by the communication of the daughter veins of the venae comites in the fork of a divided artery. This artefact is seldom visible beyond very short distances. Anastomoses between venae comites and veins passing deep to the vascular bundle are also present and cross-sections at sites of such union also give rise to the appearance of an artery lying embedded in a vein.

The presence of two venous systems in the two surfaces of the dura mater, with communicating vessels between them has been reported by Michel (1877). Key and Retzius (1875) described an outer 'venous' and an inner capillary system with communicating channels between them. They observed 'peculiar dilatations' at the junction of these connecting vessels with the inner net and regarded the vessels distal to the dilatations as the venous route which passed obliquely upward to the outer system.

Two venous plexuses exist, one superficial to the main vascular bundles and formed of fine channels and the other deep and composed of large veins. Communications exist between the two systems and some of these, detected only in frozen sections

stained by the benzidine reaction are certainly venules. The inner net of large veins cannot in any way be mistaken for the capillary system described by Key and Retzius. The ' peculiar dilatations ' observed by them were not demonstrable in any of the preparations examined and no attempt is made to distinguish as they did between ' arterial ' and ' venous ' capillaries.

Summary

(1) A reinvestigation was made of the following :—
  (*a*) The structure of the dura mater ;
  (*b*) The position of the large venous sinuses and arteries in relation to the different layers of the dura mater ; and
  (*c*) The vascular system of the dura mater.

(2) The material used was entirely human.

(3) The methods employed were histological.

(4) A histological survey of the cerebral dura mater revealed that it was divisible into three layers outside the large dural venous sinuses.
  (*a*) A superficial layer of coarse bundles of fibrous tissue disposed transversely to the long axis of the superior sagittal sinus ;
  (*b*) An intermediate layer of thinner fibres running in the long axis of the sinus ;
  (*c*) A delicate layer of still finer fibres resembling areolar tissue which contained several veins.

(5) The arteries with their venae comites run between the outer and intermediate layer.

(6) When these layers are followed to the superior sagittal and transverse sinuses, it is found that,
  (*a*) The inner areolar layer is absent around the sinuses ;
  (*b*) The superior sagittal sinus lies within the intermediate layer which because of the absence of (*a*) now becomes the inner layer :
  (*c*) The transverse sinus runs within the outer layer.

(7) Intra-vascular staining shews the presence of two venous plexuses in the dura mater, one situated superficial to the main vessels and formed of fine tributaries and the other deep and composed of large channels.

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Plate I

Figure 1.—Photomicrograph of dura mater, sectioned parallel to the superior sagittal sinus. ×102.

(*a*) The outer or periosteal layer showing coarse fibres running transverse to the long axis.

(*b*) The intermediate layer of fine fibres running longitudinally.

(*c*) The inner layer consisting of very fine fibres, resembling areolar tissue and containing several venous channels.

Figure 2.—Photomicrograph of dura mater, sectioned parallel to the superior sagittal sinus ×46. This shows the main vascular bundle lying between the outer and intermediate layers of the dura mater.

Figure 3.—Transverse section of the superior sagittal sinus ×28.

(*a*) outer layer of dura mater,

(*b*) intermediate layer of dura mater dividing to enclose the superior sagittal sinus—S.

Figure 4.—Area marked A in fig. 3 ×102.

(*a*) outer layer of dura mater,

(*b*) intermediate layer of dura mater dividing to enclose the superior sagittal sinus—S.

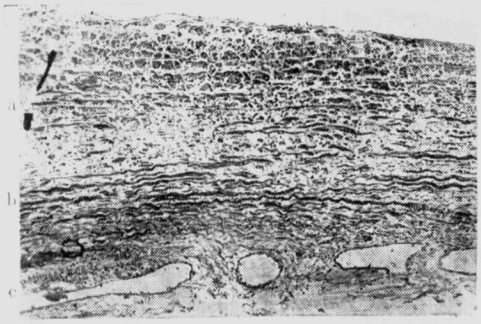

Fig. 1

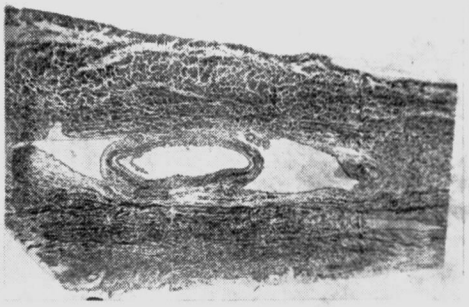

Fig. 2

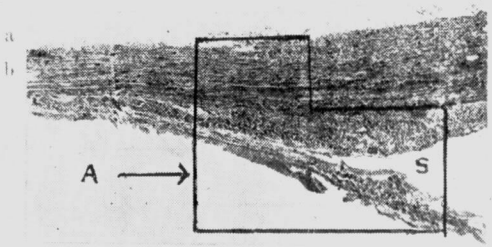

Fig. 3

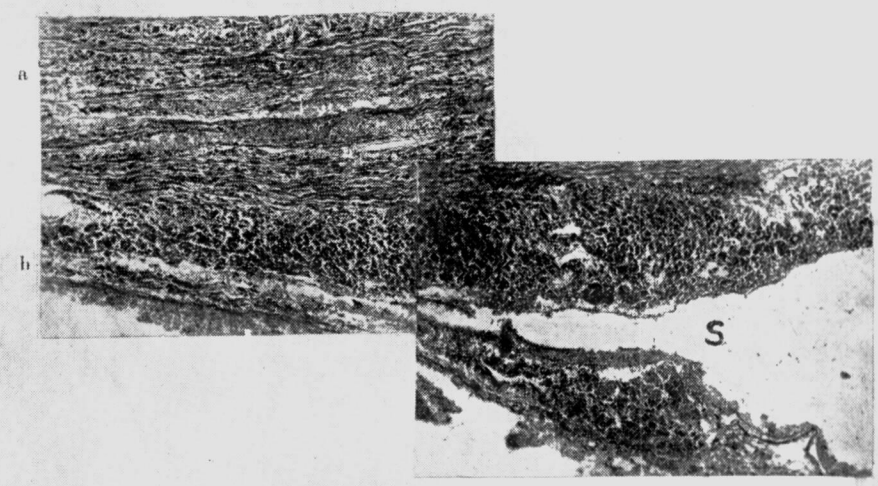

Fig. 4

PLATE I

Plate 11

Figure 5.—Transverse section of the Transverse Sinus ×5.

1. outer layer of the dura mater,
2. inner layer of the dura mater.

Figure 6.—Area A in fig. 5 ×42.

This shows the whole set of inner fibres (2) passing inwards to form a superficial layer of the tentorium cerebelli, while the outer layer (1) separates to enclose the transverse sinus—S.

Figure 7.—Area B in fig. 5 ×42.

This shows the complete absence of the inner layer of the dura mater below the level of the sinus—S.

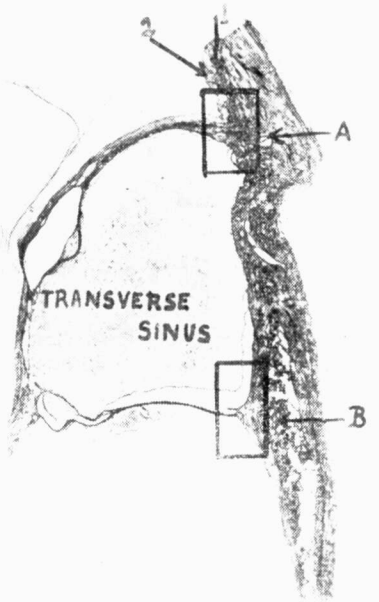

Fig. 5

Fig. 6

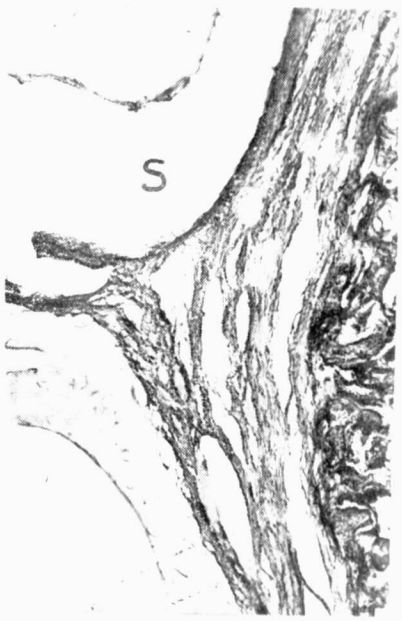

Fig. 7

Plate III

Figure 8.—Photomicrograph of the dura mater ×5.

This shows the branches of the middle meningeal artery, with the constant venae comites.

Figure 9.—Photomicrograph of the dura mater ×12.

A—Artery. V—Venae comites.

This illustrates the fine plexus of veins lying superficial to the meningeal vascular bundle.

Figure 10.—Photomicrograph of dura mater ×5.

This illustrates the large veins of the deep plexus lying deep to the meningeal vascular bundle.

Figure 11.—Photomicrograph of dura mater ×102.

This shows obliquely running vessels which connect the superficial and deep plexuses of veins.

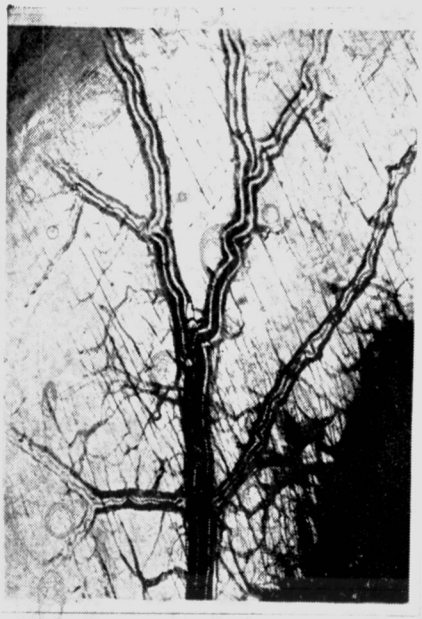

Fig. 8

Fig. 9

Fig. 10

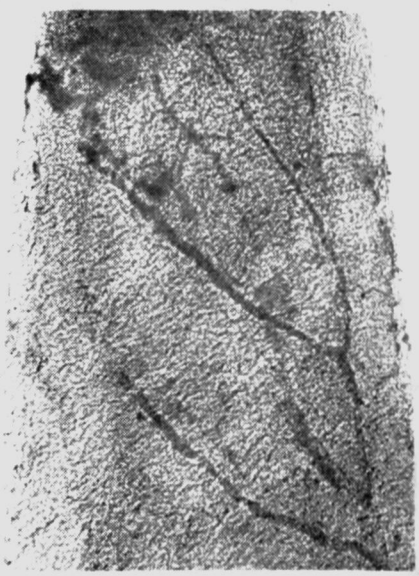

Fig. 11

PLATE III

PLATE IV

Figures 12-21—Serial sections of the dura mater parallel to the superior sagittal sinus.

The branching of the venae comites prior to the division of the artery and the subsequent communication between the daughter veins after the arterial bifurcation could be followed in these sections. Any section in the region of this venous communication (figs. 20, 21) gives the appearance of an artery embedded in a venous channel.

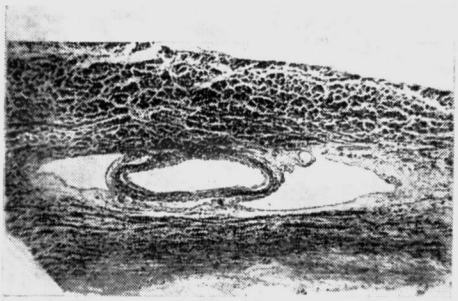

Fig. 12

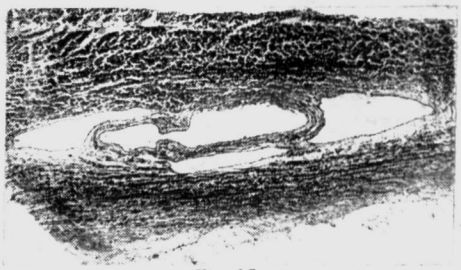

Fig. 17

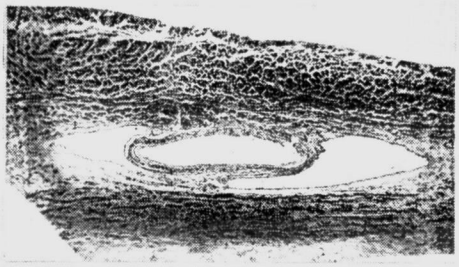

Fig. 13

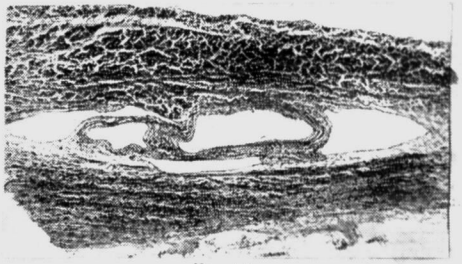

Fig. 18

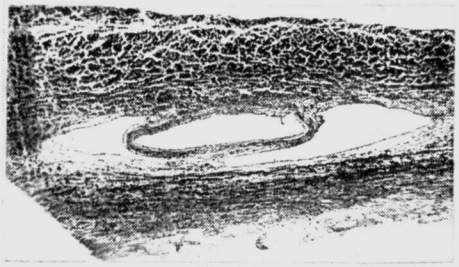

Fig. 14

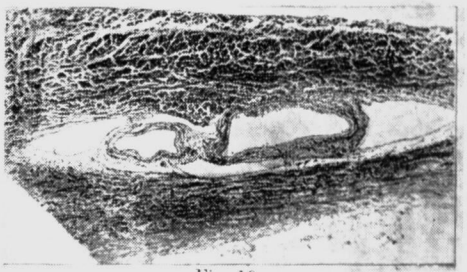

Fig. 19

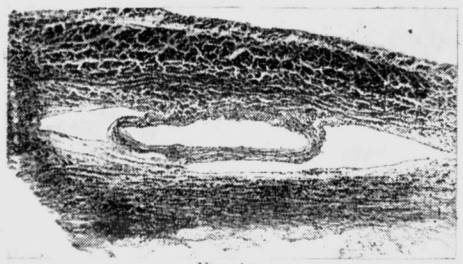

Fig. 15

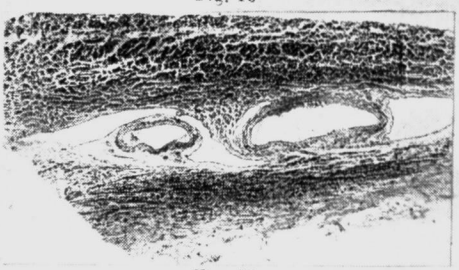

Fig. 20

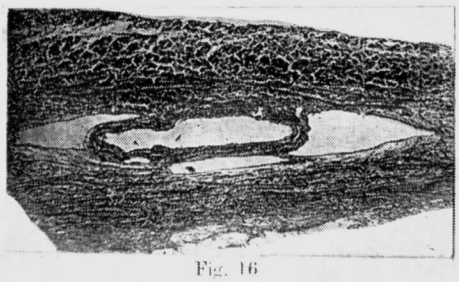

Fig. 16

Fig. 21

PLATE IV