MULTIPLE HERNIAS OF THE CEREBRUM AND CEREBELLUM, DUE TO INTRACRANIAL PRESSURE.*

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Multiple hernias of the brain following increased intracranial pressure are small masses of brain tissue which are forced into and through the dura. They may enter the large sinuses of the cranium or they may cause the formation of pits in the bones of the skull. In extreme cases these hernias have perforated the bones of the vault.

Multiple hernias of the cerebrum have been described by von Recklinghausen and by Beneke. The former demonstrated a single case in 1870, the latter reported two cases in 1898, and these three cases are the only ones recorded. The increased pressure in these cases was due to intracranial tumors. Similarly produced hernias of the cerebellum have not been described.

This paper is based upon the study of nine cases of increased intracranial pressure: six were due to tumors, two to acquired internal hydrocephalus, and one to massive cerebral hemorrhage. These cases, with the exception of one (number nine, for which I am indebted to Professor E. E. Southard), represent autopsies by myself upon consecutive cases of increased intracranial pressure. It is evident, then, that multiple hernias of the brain in cases of increased pressure are common and, in my experience, constant. The absence of mention of these hernias in autopsy protocols and in reports of brain tumor cases is certainly due to the failure of pathologists to examine carefully the sinuses and both surfaces of the dura. It is also probable that these hernias have been mistaken for arachnoid villi of unusual size. "In cases of brain tumor — glioma, sarcoma, gummata of dura (case of Lancereaux), carcinoma, etc., — one often finds an excessive development of the Pacchionian granulations

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noted." (Browning, the relations and pathology of the Pacchionian formations, and the spaces beside the sinuses of the dura mater. Amer. Jour. of the Medical Sciences, 1882, p. 370.)

In addition to the statistical study, the histology, and the mechanism of formation of these multiple hernias there are several interesting features. By their location they illustrate the direction of transmission of pressure by the brain and give additional proof to the fact, determined by experimentation upon animals, that the brain does not transmit pressure equally in all directions. Practically, the character of the contents of the hernias, and their size, should enable the pathologist to make deductions as to the amount and duration of pressure. And finally, some observations regarding the behavior of the neuroglia are of general significance.

Sarcoma of the brain. — Von Recklinghausen's case was demonstrated before the Würtzburger physikalisch-medicinische Gessellschaft in 1870, and the only published account is a very imperfect one in the proceedings of this society for March 12, 1870. The hernias were found on different parts of the surface of the brain, entering into and perforating the dura. There were corresponding pits in the bone. The hernias were most numerous close to the vessels of the dura, and there were several projecting into the basilar sinus. Von Recklinghausen believed that fissures were first formed in the dura as a result of the increased tension and that the brain substance was gradually forced into these fissures. He was able to demonstrate a covering of pia over the smaller hernias.

Beneke's descriptions of his two cases are full and accurate, and upon many points cannot be improved. His first case, in which there were pressure symptoms lasting six years, was due to a large glioma of the parietal region which had caused complete absorption in places of the overlying bone. The hernias into the floor of the skull were very numerous, and chiefly in the anterior fossa. The largest were pea size, and each hernia occupied a pit in the bone. The

hernias were especially numerous on both sides of the crista galli. The cribriform plates were entirely destroyed. Other hernias pitted the orbital plates, the middle fossæ, and the squamous portions of the temporal bones. The anterior edges of the petrous bones and the orbital plates were deeply and extensively pitted; the latter were generally thinned, so that the right orbital plate was of parchment-like flexibility. The larger hernias possessed only a very thin covering of dura. The smallest were entirely intradural. Beneke's second case was a papilloma of ependymal origin arising from the choroid plexus. There were symptoms for about one year before death. There was a large tumor filling the fourth ventricle and another similar tumor, the size of a pea, over the infundibulum. There was marked internal hydrocephalus. The hernias were particularly numerous in the regions of the arachnoid villi along the superior longitudinal sinus. A number had completely perforated the bone. The largest were one centimeter in diameter.

The histological characteristics and the locations of the tumors in these two cases were so dissimilar that Beneke concluded that the one common feature — the increased intracranial pressure — must have caused the hernias. He believed the hernias to be purely mechanical in origin. The following features were determined by Beneke: The hernias consisted of brain tissue in various stages of disorganization, some containing vessels of considerable size, which were carried along from their original positions. Where the bone was pitted the process had been gradual but, probably, rapidly formed intradural hernias were found, which consisted of cylindrical plugs of brain tissue. The smaller hernias are covered with dura and pia; the larger may lack both, though nests of endothelial cells are always found somewhere upon the surface. The entrance of the hernias into the dura takes place through endothelial lined fissures, which Beneke states normally contain processes of arachnoid tissue. These arachnoid processes, he goes on to say, are the smallest "Anlagen" of the Pacchionian granulations, and as Key and Retzius have shown do not necessarily reach dural veins.

Entrance may also take place into the large granulations in the neighborhood of the superior longitudinal sinus. After entrance, the hernias extend along the lymph spaces and Beneke found a similarity between the spaces thus filled with brain tissue and the pictures obtained by Key and Retzius by injection. The correspondence of the hernias with the locations of the arachnoid villi, namely, along the superior longitudinal sinus, and in the anterior portions of the middle fossæ, is emphasized. The pits in the bone, Beneke believes, are largely performed by the arachnoid villi and the hernias enlarge them through pressure atrophy. He does not, however, exclude the possibility of a new formation of pits. No microscopic examinations of the pitted bone were made. As a factor in the causation of the hernias, Beneke suggests the possibility of an increased lymph flow through the arachnoid villi, which softens the underlying tissue. A momentary further increase in pressure is supposed to cause rupture of the pia and the escape of brain tissue into the granulations from whence it spreads. Beneke finally states that these hernias are excessively rare.

In the presentation of the cases which have furnished the material for this paper, only those facts are included from the clinical histories and autopsy records that are of direct interest in the consideration of multiple hernias of the cerebrum and cerebellum. Three cases of tumor are complicated because of the formation of cysts after decompression operations. In two cases, numbers I. and VI., these cysts were of very large size and unquestionably produced some of the hernias found at autopsy. And in these two cases, the localization of the hernias is dependent upon two independent sources of pressure.

Case I. (L. I. H. 06: 22) is that of a man twenty-nine years old, who had symptoms of intracranial pressure for more than one year. Fourteen weeks before death a decompression operation was done, in which a large portion of the skull, involving the left parietal and temporal bones, was removed. A large hernia of the brain took place through this opening and the pressure symptoms became worse. Death followed immediately after a second decompression operation upon the right side. At

autopsy a glioma in the right half of the cerebellum was found. The dimensions of the tumor were 3.5 x 2 x 2 centimeters. Beneath the soft tissues covering the field of operation on the left side there were many cysts, one to two centimeters in diameter, containing clear liquid. Fifty cubic centimeters of liquid were obtained from these cysts. Hernias of the cerebrum were found in the left middle fossa, distributed along the middle meningeal vessels. The largest hernias were one to five millimeters in diameter and one to four millimeters deep, and occupied pits in the bone. Many small elevations of the dura, which were just visible, proved on microscopic examination to be hernias. There was general thinning of the bones of the skull. An occluding thrombus was found in the right lateral sinus just external to the torcular. There was acute inflammation of the right middle ear.

Case II. (L. I. H. 06:23) is one of hemiplegia in a woman thirty-nine years old. Death occurred thirteen days after the stroke. A massive hemorrhage into the right basal ganglia was found at autopsy. There were many firm white villus-like bodies in the right lateral sinus, midway between the torcular and jugular foramen. These bodies projected from the inferior surface of the sinus; the largest were two millimeters in diameter. Microscopic examination showed large arachnoid villi containing, at their bases, small masses of distorted cerebellar tissue.

Case III. (H. M. S. 2618. Reported by E. W. Taylor, Boston Med. and Surg. Journal, clvi, No. 6) began six months before death to have symptoms of pressure upon the spinal cord. Three months before death there were symptoms of increased intracranial pressure. The autopsy revealed a diffuse sub-pial, small round cell sarcoma of the spinal cord and marked internal hydrocephalus. The amount of liquid in the lateral ventricles was estimated at eighty cubic centimeters. There was marked flattening of the convolutions. Small hernias with corresponding pits in the bone were found in the anterior portion of the left middle fossa.

Case IV. (H. M. S. 2666) is that of a middle-aged woman who had symptoms indicating increased intracranial pressure for about one year. A decompression operation was done several months before death, in which large portions of the occipital bone were removed on each side of the median line, below the level of the lateral sinuses. The autopsy revealed chronic basal leptomeningitis and marked internal hydrocephalus. The flattening of the cerebral convolutions was extreme. Small hernias of the cerebrum, one-half to three millimeters in diameter, were found in both middle fossæ. The left Gasserian ganglion was cystic, and in the microscopic examination of the overlying dura a small hernia was found. The arachnoid villi along the superior longitudinal sinus and the sinuses in general contained no hernias.

Case V. (H. M. S. 3416) is that of a powerfully built man of thirty-nine years, who had pressure symptoms for several years, and bitemporal hemianopsia for two years before death. At autopsy a large tumor was found in the median line in the position of the pituitary body. The optic

tracts were flattened and separated by the tumor which projected upwards into the third ventricle, forming there a smooth rounded eminence. The tumor was connected below with a large extradural tumor mass which had destroyed portions of the basilar processes of the occipital and sphenoid bones and adjacent portions of the middle fossæ. The sphenoidal sinuses and the superior nares were invaded. There was no acromegaly. Microscopically, the tumor is an adeno-carcinoma. Hernias of the cerebellum were found into the left lateral sinus. These hernias consisted of two hemispherical masses of soft white tissue, each about four millimeters in diameter and situated midway between the torcular and the jugular foramen.

Case VI. (H. M. S. 3851) is that of a man thirty-seven years old, who had symptoms of increased intracranial pressure for five years. Seven months before death a decompression operation was done in which a large opening six by nine centimeters was made on the left side, involving the parietal and frontal bones. At the time of the autopsy there were a large hernia of the brain through the opening in the skull and many small cysts in the meninges beneath the scalp at the edges of the opening. With the scalp removed, the hernia appeared as a translucent walled cyst overlapping the opening in the skull for a distance of one to two centimeters. This cyst contained remains of brain tissue consisting of delicate strands and a thin lining layer of soft brownish yellow material. The floor of the cyst was crater-like and composed of necrotic brain tissue; it communicated with the left ventricle through two small openings. There was moderate internal hydrocephalus. The opening in the skull was surrounded by a sharp ridge of newly-formed bone. At the base of the brain to the left of the median line and anterior to the pons, was a large tumor, adherent to the brain, and connected with a large subdural tumor mass which extended through the floor of the left middle fossa into the neighboring sinuses and the nose. Microscopically, the tumor is composed of small round cells supported by a reticulum. The cells resemble those of the lymphocyte series and the tumor is one commonly called small round cell sarcoma. Multiple hernias of the cerebrum were found into the arachnoid villi on both sides of the superior longitudinal sinus, and into the floor of the right middle fossa. There were corresponding pits in the bone. There was a single hernia into the right lateral sinus, from the superior surface, in about the middle portion. The tip of the occipital lobe was adherent at this point. There were no hernias of the cerebellum.

Case VII. (H. M. S. 4495) is that of a man fifty years old, who had symptoms of increased intracranial pressure for about six months. At the autopsy a tumor 2.5 x 2 centimeters was found in the cerebellum, involving the left half and the superior worm. There were several small tumor masses in the posterior end of the left superior frontal gyrus. Microscopically, the tumor proves to be carcinoma, in type suggesting an origin from the alimentary tract. Multiple hernias of the cerebrum were found into the arachnoid villi upon the left superior frontal gyrus and in

both middle fossæ. These hernias were of minute size and there were no demonstrable pits in the bone. Multiple hernias of the cerebellum with corresponding pits in the bone were found in the left posterior fossa, along the external border of the occipital sinus. The largest of these hernias were two to four millimeters in diameter. The left lateral sinus was nearly completely filled with hernias of the cerebellum for a distance of three to four centimeters from the torcular. The largest of these hernias were five millimeters in diameter. The dura on the external surface presented a series of parallel white striæ between which were tags of cerebellar tissue.

Case VIII. (H. M. S. 4564) is that of a man fifty-two years old, with a history definitely indicative of increased intracranial pressure for six months preceding death. A decompression operation on the right side was done one month before death. A similar operation on the left side was done eleven days before death. The two openings in the skull were of large size and symmetrically placed, and each included the temporal and parietal bones. At autopsy there was a slight hernia of the brain through the operation opening on the right side. There were many small cysts between the brain and the tissues which covered the opening in the bone. The largest cysts were about one centimeter in diameter. On the left side there was no hernia and the brain was not adherent to the overlying tissues. The cause of the cerebral pressure was a large infiltrating glioma of the right temporal lobe, which projected into the posterior horn of the lateral ventricle, forming there a smooth rounded mass. The cornu ammonis was pushed upwards and inwards; the optic thalamus was pushed forwards and upwards. The tumor extended forward in the substance of the temporal lobe to within a few centimeters of its tip. The diameter of the infiltrated region in the middle portion of the temporal lobe was five centimeters.

Multiple hernias of the cerebrum were found in the arachnoid villi on the right side of the superior longitudinal sinus, in the floor of the right middle fossa, and in the right lateral sinus. There were deep pits in the middle fossa on both sides of ridges of bone which lay beneath the branches of the middle meningeal vessels. The pits for the arachnoid villi at the vertex were of unusual size and there were slight corresponding elevations of the external table. The hernias through the superior wall of the lateral sinus were small. Multiple hernias of the cerebellum were numerous into the right lateral sinus, and there were a few minute hernias into the left sinus. The right lateral sinus also contained an occluding thrombus filling the sinus for a distance of two centimeters external to the torcular. The middle ears were normal.

Case IX. (Danvers 1072) is that of a woman, age thirty-nine years, who had symptoms of cerebral pressure for several years. There was a history of apoplectiform seizures for eight years before death. The autopsy showed a large infiltrating glioma involving the median portions of both frontal lobes, but lying chiefly within the left frontal lobe. The dimensions

of the tumor roughly were, 6.5 centimeters in the vertical line, four centimeters horizontally, and 3.5 centimeters in the antero-posterior line. The flattening of the convulsions was extreme. Many multiple hernias of the cerebrum of large size were found. There were scores in both temporal and frontal regions with corresponding pits in the bone. The arachnoid villi along the superior longitudinal sinus were of unusual size and contained hernias. The hernias of the temporal lobes into the middle fossæ showed the usual distribution about the branches of the middle meningeal vessels.

The following table is inserted in order to give in compact form the data of greatest importance concerning duration and cause of pressure, together with the localization of the hernias. It is obvious that in the early cases many minute hernias must have been overlooked, and especially those into the sinuses and arachnoid villi along the sides of the superior longitudinal sinus. This is indicated by the greater range of distribution of hernias found in the later cases. The data, however, point clearly to a relationship between the location of the source of pressure and the distribution of the hernias.

Case.	Duration.	Location and Cause of Pressure.	Location of Hernias.
I.	1 year; decompression operation 2½ months.	Glioma of cerebellum; right side. Cysts from decompression operation; left side.	Left middle fossa.
II.	13 days.	Right basal hemorrhage.	Left lateral sinus (cerebellar).
III.	6 months.	Acquired internal hydrocephalus.	Left middle fossa.
IV.	1 year.	Acquired internal hydrocephalus.	Both middle fossæ; left Gasserian ganglion.
V.	2 years.	Base of brain. Adenocarcinoma of pituitary body.	Left lateral sinus (cerebellar).
VI.	Years. Decompression operation several months.	Base of brain, left side, small round cell sarcoma. Cysts after decompression operation in right temporal region.	Both sides of superior longitudinal sinus; right middle fossa; (left perforated by the tumor); right lateral sinus (cerebral).
VII.	6 months.	Metastatic carcinoma; left side of cerebellum.	Left superior frontal gyrus; left lateral sinus (cerebellar); left posterior fossa; both middle fossæ.
VIII.	6 months. Decompression operation 1 month.	Glioma of right temporal lobe. Cysts from decompression operation in right temporal region.	Right side of superior longitudinal sinus; right lateral sinus (cerebellar and cerebral); right middle fossa.
IX.	Years.	Glioma, infiltrating and involving the median portions of both temporal lobes.	Both sides of superior longitudinal sinus; both temporal (middle fossa) and frontal lobes.

The constancy of cyst formation, after decompression operations over the parietal and temporal lobes, is worthy of

consideration by surgeons. Case VIII. was the only case in which cysts of small size were found occurring after a recent operation.

Sections through these cysts and the underlying brain show that the cysts have formed beneath the outer endothelial layer of the arachnoid, which is adherent to the overlying tissues covering the field of operation. The presence of nests of endothelial cells surrounding the cysts suggests the possibility of the cysts being formed in or beneath the arachnoid villi. Much more work would be necessary to determine satisfactorily this point. It seems plausible, however, that the disturbances of the normal relations of the arachnoid villi, and the formation of adhesions to the overlying soft tissues, after the removal of the dura, may account for the accumulation of liquid in the arachnoid.

If this theory is correct, the formation of these cysts probably would be prevented by the removal or destruction, by cauterization, of the arachnoid and pia. The possibility of injuring the brain substance does not need to be considered in cases where the total destruction of the same area is expected to follow as a result of a post-operative hernia.

The conclusions to be drawn from these autopsies, in regard to the transmission by the brain, of pressure caused by tumors, are confirmatory of the results of the experiments of Leonard Hill (The Physiology and Pathology of the Cerebral Circulation, 1896) and Harvey Cushing (Physiologische und anatomische Beobactungen über den Einfluss von Hirnkompression auf den intracraniellen Kreislauf und über einige hiermit verwandte Erscheinungen. Mitteilungen aus den Grenzgebieten der Medizin und Chirurgie, ix, Heft 4 and 5, 1902). Both of these experimenters recorded the transmission of pressure in dogs by means of manometers and thus determined that the falx cerebri, the tentorium cerebelli, and the falx cerebelli act as barriers and serve to localize the effects of pressure exerted upon any given area of the cortex. This is especially true of the tentorium as the falx cerebri may be readily dislocated laterally (Cushing). That downward

dislocation of the pons and medulla in cases of cerebellar tumors occurs to a much more marked degree than with tumors of the cerebrum is well known. The effect of the tentorium is well shown in Case VII., where most of the hernias were found in the lateral sinus and floor of the posterior fossa on the side where the tumor was situated. The hernias of the cerebrum were very small and may have been caused by the cerebral metastases. Tumors at the base of the brain also are liable to produce cerebellar hernias (Cases V., VI., and VIII.). The best example of widespread transmission of pressure is that of Case IX., where the tumor involved both frontal lobes. In Case I. it is probable that hernias into the sinuses were overlooked. The hernias into the left middle fossa were unquestionably the effect of the cysts which formed after the decompression operation. Case VIII. illustrates the limitation of hernias to one-half of the cerebrum in a case of a tumor of the right temporal lobe. Internal hydrocephalus, which is very common with tumors of the cerebellum, is probably the cause of hernias of the cerebrum, when the pressure is below the tentorium.

From the above facts and because of the reasons advanced by Beneke, it is certain that the one cause of multiple hernias of the cerebrum and cerebellum is increased intracranial pressure. In two cases of internal hydrocephalus and one case of a huge extradural tumor in infants, autopsied since I began this study, no hernias were found. The rapid growth of the bones of the cranial cavity increase its capacity and so prevent the creation of a marked increase in pressure and hernia formation.

That multiple hernias of the brain may be caused suddenly is proved by Case II. (cerebral hemorrhage), where fragments of cerebellar tissue were forced into the lateral sinus, behind arachnoid villi. Microscopically, one can distinguish between the rapidly and slowly formed hernias by the nature of their contents.

Aside from the localization of the hernias in or near the large sinuses of the dura, the most striking anatomical

relationship is that to the vessels of the dura. When hernias of large size were found, they were always clustered about the vessels. This was always particularly marked about the middle meningeal vessels and their branches in the middle fossæ (Fig. 1.)

Von Recklinghausen did not attempt to determine the relation of the hernias to anatomical structures in his case. Beneke determined the occurrence of hernias into the arachnoid villi. In the description of his second case he mentioned the existence of endothelial lined fissures of the dura which he states run from the inner to the periosteal surfaces. He believed the fissures contained small arachnoid villi.

In the present study, many hernias were studied by means of serial sections and in every instance remains of arachnoid villi could be found. In most hernias in the neighborhood of the superior longitudinal sinus, the brain tissue literally injects the larger villi and there is no difficulty in determining the exact location of the extruded brain tissue. Similarly the hernias of the cerebellum often partially fill easily recognizable villi. The hernias at the base of the brain, however, often show no gross evidence of connection with arachnoid villi, and are never branched in the manner of the hernias in the large villi at the vertex. This difference in the shapes assumed by the hernias is explained by the differences in size and shapes of the arachnoid villi found in the neighborhood of the great sinuses and of those found at the basis of the brain, in relation to the meningeal veins.

Key and Retzius have determined, by means of injection methods, that arachnoid villi occur in the following positions: the superior longitudinal sinus and especially the lacunæ laterales or accessory sinuses, the transverse sinus, the superior petrosal sinus, the cavernous sinus, the middle meningeal veins in the middle fossa, the meningeal veins close to the superior longitudinal sinus, a small sinus occasionally found on the outer side of the first division of the Gasserian ganglion and the straight sinus (from the cerebellum).

No mention is made of arachnoid villi in the lateral sinuses. The frequency of hernias into the lateral sinuses and, upon microscopic examinations, the finding of structures identical with the arachnoid villi led me to search for them in a normal young male adult. Arachnoid villi of small size were found on both sides coming from the arachnoid of the cerebellum, and entering small accessory sinuses which are similar to the lacunæ laterales of the superior longitudinal sinus. These villi are easily visible in sections without magnifying. The largest ones are branched and are identical in structure with those found in the neighborhood of the superior longitudinal sinus. The regions examined were those in the vicinity of the entrance of the inferior cerebellar veins. This was done by removing the cerebellum with the intact dural covering and then sectioning through both structures. Other villi were found external to the entrance of the inferior cerebellar veins, and these villi were found by noting delicate adhesions between the dura and arachnoid (Fig. 6). The existence of arachnoid villi in the floor of the posterior fossa near the median line, along the occipital sinus, has been determined by finding their remains in sections of hernias from this location.

Since the number of hernias may far exceed the number of visible arachnoid villi in any given location, search was made in normal and pathological cases for microscopic villi. Serial sections were made of the middle meningeal veins and surrounding dura from the middle fossa and at the level of the inferior border of the parietal bone, and the presence of minute villi was established. They were also found accidently in a set of serial sections made from the superior frontal gyrus. The smaller of the microscopic villi consist simply of tufts of endothelial cells projecting into endothelial lined fissures of the dura in the neighborhood of small veins (Fig. 9). The larger are branched and run obliquely for long distances into the dura and these are the only ones that remain attached to the dura when the latter is removed from the brain. They consist of connective tissue covered by endothelium continuous with that of the arachnoid. The

connective tissue may be compact or loose in texture, except at the extreme tip, where it is always loose meshed (Figs. 8 and 10). It is probable that the distribution of minute arachnoid villi is far more widespread than has been believed. The few observations I have made were done in order to verify the finding of remains of arachnoid villi, which are always demonstrable at the periphery of hernias of the cerebrum and cerebellum. In view of the above facts it is safe to conclude that multiple hernias of the cerebrum and cerebellum always enter the dura through fissures occupied by arachnoid villi.

The gross appearances of the hernias have been accurately described by Beneke. The shape naturally varies according to the location. Those in the superior longitudinal and the accessory sinuses are often branched, as may be those from the cerebellum in the lateral sinuses. The majority are spherical or pear-shaped, having taken place into simple forms of arachnoid villi. Hernias, which do not penetrate above the level of the dura may be extremely variable in shape or not noticeable except by microscopic examination. These latter hernias, as will be explained later, are rapidly formed and consist of softened brain tissue, forced like an injection mass into preëxisting spaces. The large hernias occupy pits in the bone; a covering of dura is always found, and sometimes when the hernias can be pulled out from the dura a smooth covering derived from the arachnoid is demonstrable. The fissuring of the dura noted by von Recklinghausen is, I believe, simply an exaggeration of normal structure in the neighborhood of arachnoid villi due to the pressure atrophy. This is especially well seen on the inferior surface of the lateral sinuses and along the superior longitudinal sinus. The tufts of brain tissue which represent the pedicles of the hernias are always found between the strands of dura, but the clefts are simply the enlarged fissures occupied by arachnoid villi (Figs. 1, 2, 3, and 4).

In two cases, microscopic examinations were made of the bone containing pits occupied by hernias, and proof was obtained of the active absorption of the bone. The absorption

of the bone is shown by the presence of osteoclasts and of lamellæ cut at all angles where the trabeculæ abut on the walls of the pits. Groups of giant cells about small fragments of bone are occasionally found on the outer edge of the dura. Besides these two cases, in every case of hernias of large size, giant cells were found attached to the dural covering in sections of the hernias where there had been contact with bone.

Beneke's opinion that the pits in the skull were always partly preformed by arachnoidal villi cannot be opposed, though in some locations it is extremely rare to find pits for arachnoid villi in normal cases. Luschka (Arch. f. Path. Anat. u. Physiol. u. f. Klin. Med., xviii, 1860, quoted by Key and Retzius) gives the following locations where pits due to arachnoid villi may be found, aside from the neighborhood of the superior longitudinal sinus: the anterior half of the parietal bones and especially close to the spheno-temporal sutures; the great wing of the sphenoid; the tegmentum tympani and occasionally in the vicinity of the petro-squamous suture. These locations agree closely with those of the pits in cases of hernias of the brain, however, since intracranial pressure may cause thinning of all the bones of the cranial cavity it is possible that hernias into microscopic villi may alone be responsible for pit formation.

Before beginning the microscopic description of the hernias, and the relations of the contents to the arachnoid villi and dura, a short description of the structure of normal arachnoid villi is necessary.

According to Key and Retzius the smaller villi are pear or balloon shaped and consist of a loose mesh-work of connective tissue. The base of a villus is continuous with the arachnoid of the brain; the surface is covered with endothelium continuous with that of the arachnoid. The smallest villi may not reach the veins or sinuses, but all project into the dura. Some may lie in contact with veins without entering. When projecting into a vessel, they always receive from the dura or vessel wall a thin coat of connective tissue

and endothelium. The connective tissue may be lacking so that only two layers of endothelium cover the surface of the villus. The space between the villus and the investment from the vessel is lined by endothelium continuous with that of the inner surface of the dura and is traversed by delicate strands of connective tissue, covered by endothelium. The larger villi are branched and may anastomose with neighboring villi. Liquids injected into the subarachnoid space fill first the villi, then the space enclosed by the dural covering, and finally pass into the sinuses. Suspensions of cinnabar in water pass through the villi as well as solutions of dyes. Liquids injected into the subdural space over the villi will not pass into the villi, though it does pass easily into the sinuses. These results were verified upon living dogs.

The application of modern histological methods can add nothing of great importance to the above description of the structure of the arachnoid villi. It is certain, however, that the arachnoid villi vary in structure, but chiefly in the compactness of their connective tissue. Those in the neighborhood of the superior longitudinal sinus may be composed of very dense connective tissue and this is usually the case when there is thickening of the pia, which is usually most marked in their region. Such dense or sclerosed villi, even in cases of long continued increased intracranial pressure, do not contain hernias. The normal arachnoid villus contains spaces between the bundles of fibrous connective tissue which at the base of the villus seem to be continuous with those of the subarachnoid mesh-work. At the periphery of the villus there are definite spaces lined with endothelium which in " wet brains " are usually injected with finely granular material. These endothelial lined spaces, as near as I can determine, are most easily demonstrable beneath the nests of endothelial cells, which are always found on the surfaces of arachnoid villi. In sections of villi projecting into the sinuses the double investment of endothelium from the inner surface of the dura and from the vessel wall can be made out. Often these two layers enclose a small amount

of connective tissue. Between the endothelial covering of the villus and the investment derived from the dura and vessel wall is the subdural space filled with finely granular material, probably precipitated from liquid present before fixation. There are no blood vessels in arachnoid villi. Between the brain and the base of an arachnoid villus there is only a delicate mesh-work of connective tissue, containing blood vessels, though the number and arrangement of vessels is not peculiar to this location. The more compact layers of the pia and arachnoid extend upwards into the villus, around the periphery of its base. This arrangement practically makes a break in the pia arachnoid covering of the brain and probably is of mechanical importance in the formation of hernias.

In the discussion of the mechanics of multiple hernia formation, the following facts must be taken into consideration: (1) That the brain is enclosed in an unyielding case of bone. (2) That the veins and sinuses of the dura are compressible (the lateral sinuses probably yielding only where there are arachnoid villi). (3) That local compression is possible (because of the existence of compartments in the cranial cavity and the compressibility of veins). (4) That the weakest points in the dura are those where the arachnoid villi enter.

General readjustment of brain tissue takes place in every case of increased intracranial pressure as is shown by the flattening of the convolutions, the obliteration of the sulci, and in the downward dislocation of the brain as a whole.

The movements of the brain tissue, when under pressure, must be towards yielding points: the veins and sinuses. The greatest movement of any given point must be at the place of yielding, which necessarily determines the situation of the resultant of pressure lines. The movement of the brain tissue is probably responsible for the softening at points below the arachnoid villi.

Microscopically, in the flattened sulci, indentations of the vessels of the pia are plainly visible and injury to the elevated brain tissue is proved by very marked neuroglia increase.

The veins in cross section show no distortions or flattening, and it is probable that the diminution in volume is compensated by contraction of the vessel walls. Rapidly-formed hernias are those which lie wholly within the dura and which may run for considerable distances along the sides of veins (Figs. 2 and 3). It is difficult to decide upon the exact location of the brain tissue, though in some instances, at least, it is certain that it gets into lymphatics. In these rapidly-formed hernias there is no increase of neuroglia and of course no pitting of the bone. The brain tissue shows all degrees of necrosis and the only evidence of reaction is the presence of leucocytes, compound granular cells, and other phagocytic cells containing cell detritus. Small blood vessels are carried along with the brain tissue and may be found in the hernias far removed from their original locations. The brain tissue at the base of the hernias shows varying degrees of distortion due to the rearrangement of the ganglion cells and also the granular remains of nerve fiber sheaths and degenerated ganglion cells. The spaces of the arachnoid villi may be distended with granular material and even fragments of nerve fibers and cell remains. The subdural space surrounding the villus may be markedly distended with granular material.

In hernias which have occupied pits in bone there is always a large amount of neuroglia, and in many instances the hernia contents consist almost wholly of dense neuroglia tissue. The dural covering may be very thin and on the outer surface giant cells and occasionally spicules of bone surrounded by osteoblasts may be found. The only reaction in the dura is a slight infiltration with lymphoid and plasma cells. There may be a few polynuclear leucocytes grouped about necrotic nerve elements. In general, the microscopic findings are simply those dependent upon destruction of brain tissue and the removal of the same through the agency of polynuclear leucocytes and mononuclear phagocytic cells. The neuroglia reaction is secondary and could be dismissed at once were it not for certain peculiar relations found

between the neuroglia cells and the connective tissue of the arachnoid villi and the dura.

The proliferation of subpial neuroglia cells with the formation of circumscribed elevations between the vessels of the pia has been mentioned above. Similar circumscribed neuroglia masses are also found beneath arachnoid villi and many small hernias are capped by such neuroglia masses. After very careful study of many sets of serial sections of small hernias I am forced to the conclusion that the neuroglia in contact with connective tissue, and under pressure to a degree that is destructive to the connective tissue, is capable of active proliferation and, to a slight extent, of invasion of the connective tissue of the arachnoid villi and dura. It is possible that many slowly-formed hernias may enter villi behind advancing zones of neuroglia cells. This behavior of the neuroglia is strikingly illustrated in some instances, in the form of outgrowths into the connective tissue surrounding small vessels which enter the cortex from the pia (Fig. 12). Such outgrowths of neuroglia are found only in cases of long-continued pressure and the most plausible interpretation is that connective tissue, in contact with the brain, when injured by pressure yields and disappears before the growth of neuroglia tissue. Beneath arachnoid villi of microscopic size I have found slight elevations of the cortex with a mass of neuroglia cells apparently invading the pia and here also the process is probably secondary to degeneration of the connective tissue (Fig. 11). The peripheries of hernias show the best illustrations of neuroglia activity. Here large masses of neuroglia cells seem to push into the connective tissue, and extend in a direction parallel to the connective tissue fibers. In large hernias, similar nests and advancing cells of neuroglia are found in the dura, and in these instances the connective tissue and endothelium of the villus has disappeared (Figs. 11, 12, and 13).

SUMMARY.

The series of cases furnishing the material for this report practically prove the constancy of multiple hernias of the

cerebrum and cerebellum in cases of increased intracranial pressure.

The distribution of the hernias in relation to the position of the source of pressure adds to the proof for the local compressibility of the brain, and the directions of transmission of pressure, as influenced by the falx cerebri, the tentorium cerebelli, and the falx cerebelli.

In the general rearrangement of brain tissue following increased pressure, the greatest movement is at yielding points. The arachnoid villi, because of their structure and relationship to compressible veins and sinus, furnish yielding points in the encasement of the brain. The softening of the brain tissue, which permits the free extrusion into the arachnoid villi, is most probably due to the mechanical injury following the movement of the tissue towards the yielding points. The widespread distribution of the hernias and the identification in all of them of the remains of arachnoid villi illustrates the large number and general distribution of arachnoid villi, both of which are greater than even the observations of Key and Retzius would indicate. Microscopic arachnoid villi are often the seat of hernias.

Two types of hernias may be distinguished; those rapidly produced by sudden increase of pressure, such as voluminous cerebral hemorrhage and those produced slowly by gradual increase in pressure, such as accompanies intracranial tumors. The hernias produced slowly are attended by marked and peculiar reactions of the neuroglia, which indicate the survival and proliferation of neuroglia cells under conditions destructive to connective tissue.

DESCRIPTION OF PLATES.

PLATE VI.

FIG. 1. — Sketch of outer surface of dura, showing hernias of cerebrum and relation to vessels (middle meningeal). Natural size. Case IX.

FIG. 2. — Photomicrograph of a section through base of a rapidly-formed small hernia of the cerebrum into the dura. x 45. Case I. From the middle fossa.

FIG. 3. — Photomicrograph of a section through a rapidly-formed hernia at one edge of the base, showing a vein surrounded by brain tissue. x 45. From the middle fossa. Case I.

FIG. 4. — Photomicrograph of a section through the base of a large hernia of long duration which occupied a pit in the floor of the middle fossa. The dura is very much thinned, and upon the outer surface many giant cells were found. x 14. Case I.

PLATE VII.

FIG. 5. — Drawing of a small hernia into an arachnoid villus from the superior frontal gyrus, Case VII. The small mass of neuroglia above the vein on the left is connected with the larger hernia mass at another level. The neuroglia proliferation is characteristic of slowly-formed hernias.

FIG. 6. — Low power drawing of arachnoid villi from the cerebellum. The lateral sinus is collapsed. The villi project, in some instances, into sinuses similar to the accessory sinuses of the superior longitudinal sinus.

FIG. 7. — Photomicrograph of a section through a large hernia of the cerebellum into the lateral sinus. x 14. The coverings from the sinus and the pia-arachnoid are well shown on the left edge, Case V.

PLATE VIII.

FIG. 8. — Drawing of a microscopic arachnoid villus, from the superior parietal region.

FIG. 9. — Photomicrograph of the smallest type of arachnoid villus which consists of endothelial cells chiefly. x 64.

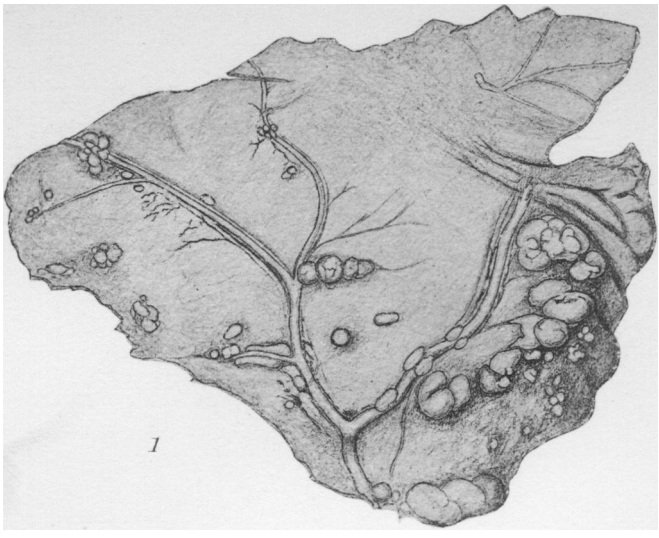
FIG. 10. — Low power drawing of a microscopic arachnoid villus from the neighborhood of the anterior branch of the middle meningeal vein.

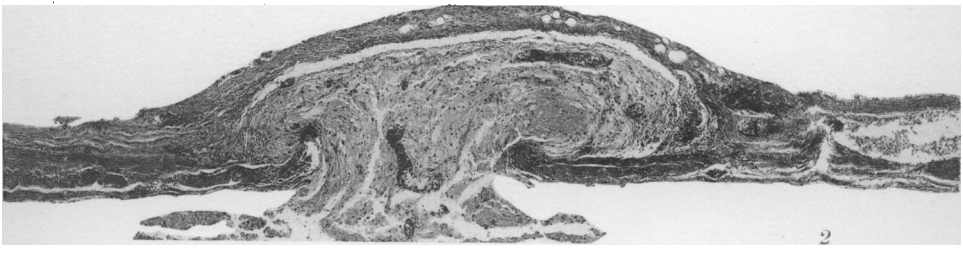
PLATE IX.

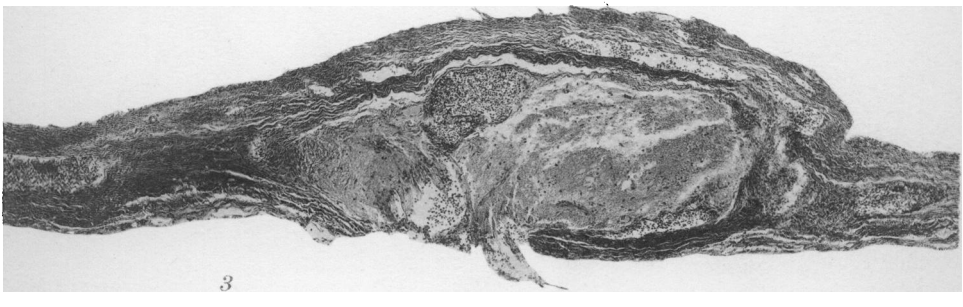
FIG. 11. — High power drawing of a slowly-forming hernia into an arachnoid villus from the superior frontal gyrus, Case VII. Note the proliferation of the neuroglia and the invasion of connective tissue by neuroglia.

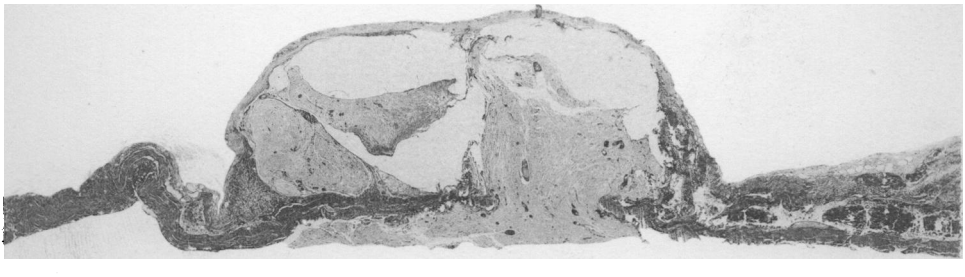
FIG. 12. — High power drawing, Case VII., showing the extension of neuroglia along a small vessel.

FIG. 13. — High power drawing of the edge of a large hernia into an arachnoid villus projecting into an accessory sinus of the superior longitudinal sinus, Case VIII. To show the invasion of connective tissue by neuroglia.









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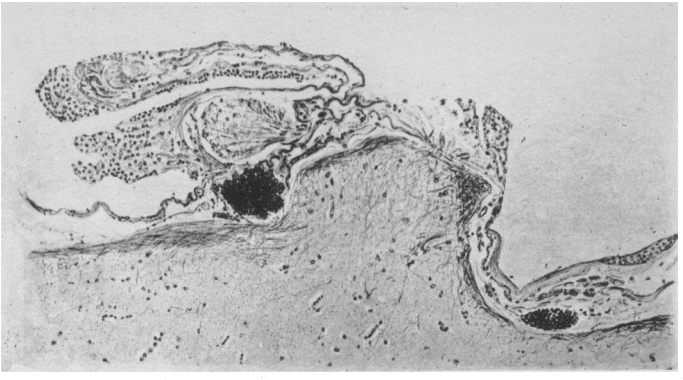

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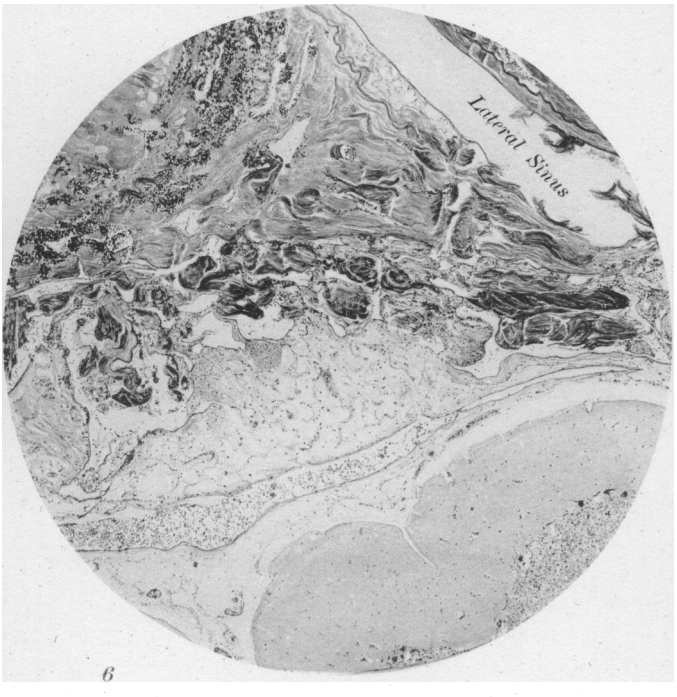

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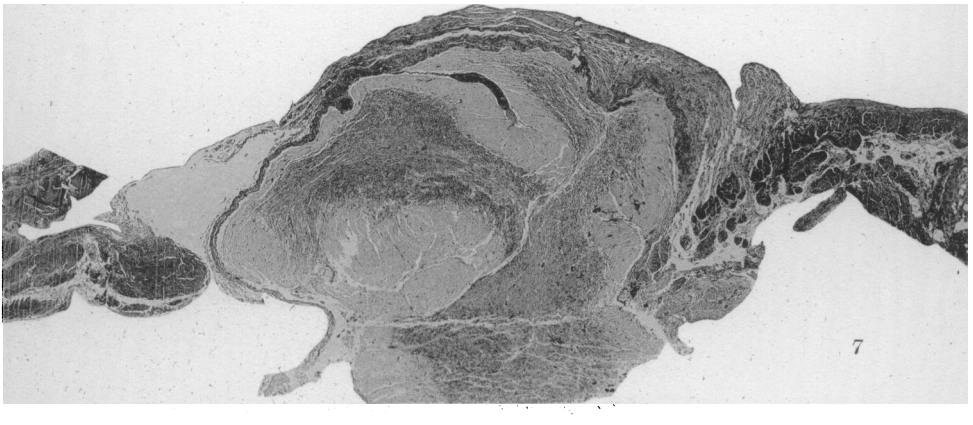

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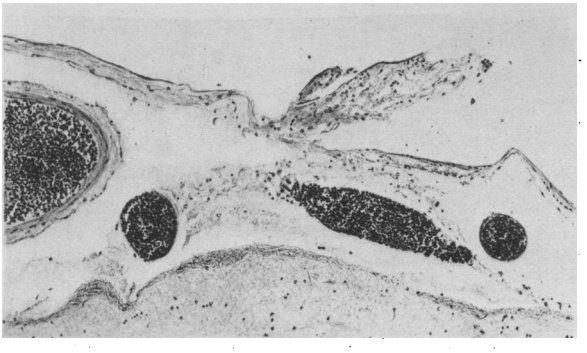

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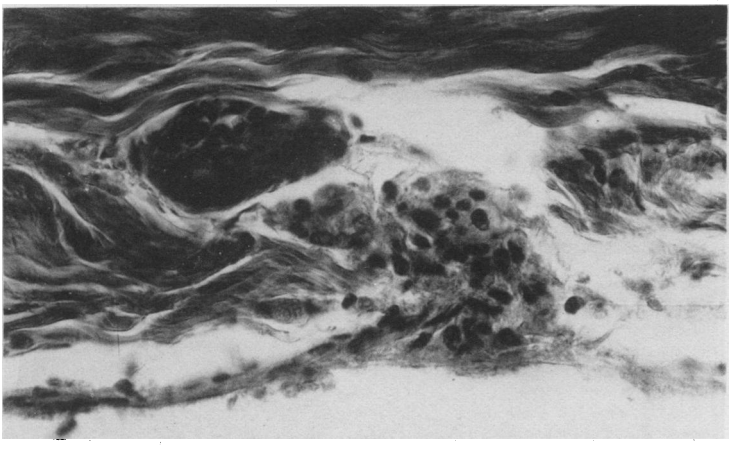

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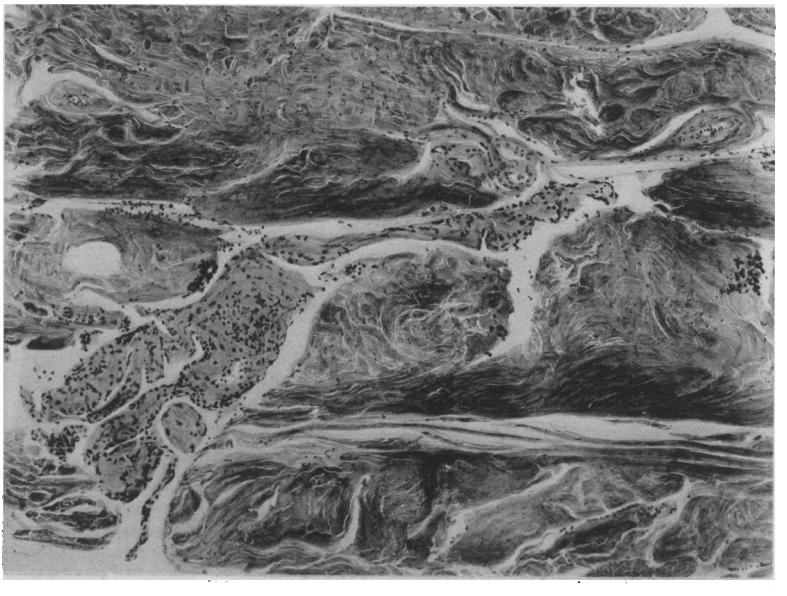

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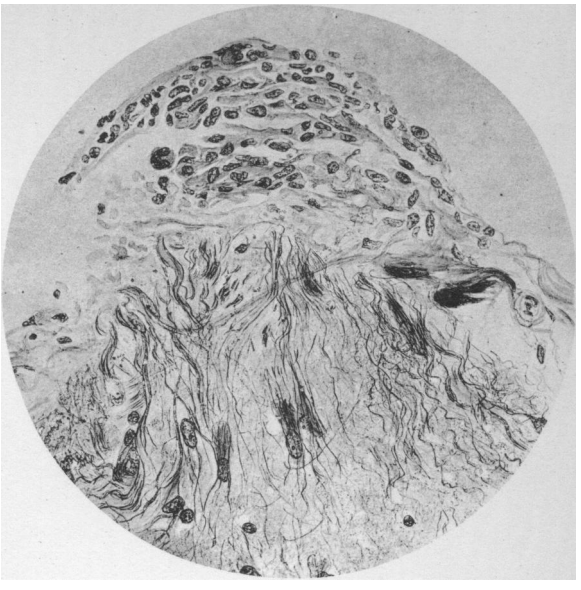

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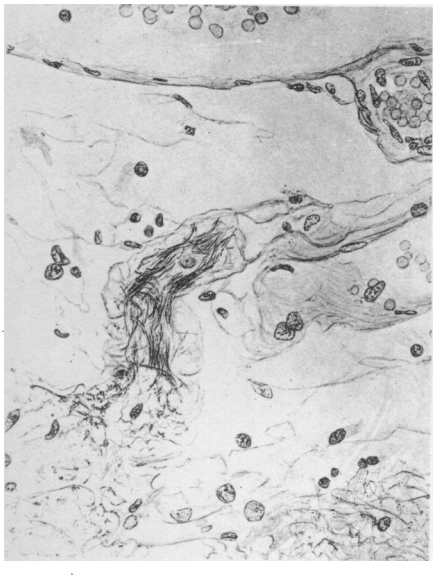

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