STUDIES ON CEREBRO-SPINAL FLUID. NO. VI.*

THE ESTABLISHMENT OF DRAINAGE OF INTRA-OCULAR AND INTRACRANIAL FLUIDS INTO THE VENOUS SYSTEM.

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Introductory. — The observations contained in this paper are the outcome of the studies in this laboratory on the drainage of the fluids of the brain and eye. The problems connected with cranial drainage have been of such a nature that definite conclusions have been reached regarding the mechanism of escape of cerebro-spinal fluid — a passage through the cellular membrane of the arachnoidal villi. Similarly in the eye, the main pathway of absorption of the aqueous humor is along the pectinate villi with fluid passage here also through a cellular tuft. Considerations both of a theoretical and histological nature surely incline one to a belief that no direct communication, in the sense of a series of stomata permitting a free and undisturbed passage of formed elements, exists in either the eye or brain.

But in the eye, in a manner never thought of in the cerebral mechanism, the process of fluid escape by means of open communications with the venous radicles has been affirmed by the workers of the school of Schwalbe.[8] Opposed by Leber,[5] this conception of a direct and open method of fluid escape has been the subject of innumerable reports, with the usual interpretation of unquestioned observations in support of both contentions. Leber's simultaneous injections of a granular suspension and a true solution, with resultant passage of the solution into the venous systems and absolute retention of the granular material within the ocular cavity, offer convincing proof that open communications, sufficient to permit the passage outward of minute granular elements, do not exist in the filtration angle of the eye.

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In the study of ocular drainage reported in the foregoing communication, it was attempted throughout to correlate physiological findings with histological structures, in the hope that any conclusions of the process of fluid escape might rest upon more than anatomical evidence. And here, as in many other problems, the attempt to make such a critical correlation has been surrounded with difficulties of decision. As in Leber's and Schwalbe's observations, our findings after a ferrocyanide injection at times might be interpreted as affording evidence of a direct opening between anterior chamber and venous system and yet again, subsequent observations argue conclusively against such a process. With the development of our idea of an escape of fluid through villous invaginations into the great scleral sinuses, the possibilities of direct communications between the two systems became more and more remote. Without doubt, the results of our observations are to be interpreted solely as demonstrating the passage of aqueous humor through pectinate villi into the venous canals of the sclera. With also the obvious presence of an endothelial covering over the villus in its occupation of the inner wall of these analogues of Schlemm's canal, the passage of the fluid through a cellular membrane becomes established.

Even with histological evidence at variance with any conception of open communications between the ocular fluid and venous systems, the physiological interest necessarily attached to such a possibility led to an attempt to place the idea upon an experimental basis. It was thought that in this way it might be possible to secure evidence of value in the physiological problems centering about the mechanism of fluid escape. For certainly until now we have had offered no basic principles as to the underlying factors in this process: is absorption determined by osmosis, or is it a simple filtration from a point of higher pressure?

In the preliminary considerations of the problem it was felt that the experimental approach must be rather simple and that success in large measure would be dependent upon the simplicity of the method. The interposition of any tubular system between the fluid spaces promised to yield unreliable results in that the capillary resistance to flow in such tubes would lead astray. Hence attention finally focussed upon the possibility of creating by mechanical means a direct opening between a scleral vein and the aqueous reservoir.

Sinus puncture in the eye. — In the eye of the dog there is a very accessible vein leaving the sclera in the midline above, about .5 centimeter posterior to the corneal edge, and running backward and inward for some distance before joining the large anastomosing veins between the facial and cranial systems (Fig. 12). As this venous trunk drains the anterior ciliary plexus in the upper quadrant, it lent itself as a guide to the largest of these scleral vessels. For in order to secure promising results, it was felt necessary to select a vessel in the sclera whose walls were rendered incompressible by the investing arrangement of scleral strands.

To secure this open communication between scleral vein and fluid reservoir, the following technic was used. The operative procedures were all done on dogs, under ether anesthesia. After division of the conjunctiva over the cornea, the vessel was located and freed from the orbital tissue as far posteriorly as possible. Here it was divided between ligatures, the peripheral end attached to the sclera being left as long as possible. Then into this exposed vein at a point about one centimeter from the sclera, a needle of as large caliber as the vessel warranted was inserted into the lumen toward the sclera. The needle was then carried through the tunics of the eye into the posterior chamber until its point appeared in the pupillary opening (Fig. 11). The needle was immediately withdrawn and the vessel was picked up and ligated close to the sclera. After approximating the conjunctival edges, the animal was undisturbed for forty-eight hours. At the end of this period the observations were terminated.

During the period of observations from the time of operation until the animal was sacrificed, repeated ophthalmological examinations were made in every case, eight in all. In none of these animals was any evidence of intra-ocular hemorrhage discernible at any time. In all the examinations the fundic structures could be clearly seen, even though in some of the eyes there were obvious lenticular opacities, apparently from the operative trauma. This absence of blood in the ocular cavities was verified by microscopic examination in a number of the cases.

The failure to demonstrate blood elements within the ocular chambers in these cases, both by ophthalmologic and microscopic study, surely argues strongly for the conception that, should the artificial opening remain patent, the intra-ocular pressure must be maintained at a level above that of the venous system. But it became necessary to demonstrate the patency of this new communication and this was done in two ways.

The first of these methods of demonstration concerned an alteration in the relative fluid and venous pressures. To secure this, with the animal under ether, at the end of the forty-eight-hour interval after the establishment of the artificial communication, the fluid pressure of the eye was reduced to practically zero by a corneal decompression. The anterior chamber was immediately filled by a sudden gush of blood. Subsequently, on microscopic examination the source of this blood was found to be the scleral sinus with bleeding into the ocular chamber through the artificial opening.

The second method of verifying the permanency of this open communication between scleral sinus and fluid reservoir dealt with the injection of ferrocyanide solutions with subsequent precipitation. If, in such an eye, after the establishment of an artificial opening between fluid and venous systems, an injection be made into the aqueous chamber without alteration in the normal intra-ocular tension, the precipitated Prussian blue granules could be traced, without intermission from the aqueous reservoir directly through the artificial pathway into the scleral venous sinuses.

The observations recorded above have, it is believed, established on a firm experimental basis the possibility of a direct communication existing between the fluid and venous systems of the eye. The absence of blood elements in the reservoirs after the initial puncture, the bleeding from the punctured scleral vessels after aqueous decompression and the possible injection of the scleral sinus along the artificial pathway from the posterior chamber — these are essential for the verification of the patency of the communication.

That such a direct communication remains open in the normal eye is all the more interesting and important. It does not lend support to either of the views advanced by Leber and Schwalbe but possesses a physiologic and possibly therapeutic significance. In these eyes the processes of fluid escape must have continued in the angle, for the pectinate villi were intact; apparently the villous structures offer some resistance to fluid outflow rendering the artificial pathway the point of least resistance for fluid escape. If this conception were not correct, the artificial opening must necessarily have collapsed or become otherwise occluded.

One physiological conclusion may be drawn from these experimental direct communications. It follows that the intra-ocular fluid pressure must constantly be reduced to the venous pressure. The eye has often been likened to a closed box and the physics of a closed fluid system must be considered here as in the cranial chamber. A momentary increase in venous pressure might possibly cause some blood to enter the aqueous reservoirs in these eyes, but a great hemorrhage into the eye would be an impossibility due to the indistensibility of the scleral wall. Conversely, if the pectinate villi do not play some part in maintaining this pressure balance between the fluid and venous systems it follows that the sinus blood would reach the aqueous chamber eventually, because of the increased rate of escape furnished by the new direct communication.

These observations support Henderson's[4] conception that after iridectomy the iridial veins remain patent. To this permanency of the direct opening he ascribes the beneficial effects of the operation in glaucomatous eyes. In this case the problem is somewhat different because of the increased intra-ocular tension.

We may conclude, then, that if a direct communication between the aqueous reservoir and the scleral sinuses be established in the canine eye, it will remain patent for at least forty-eight hours, without permitting intra-ocular hemorrhage to take place.

Sinus puncture in the normal cranium. — In view of the close analogies which were constantly being suggested by the coincident work in this laboratory upon the fluid processes of the eye and brain it was soon suggested that an equivalent sinus puncture be attempted in the cranium. The literature dealing with the escape of cerebro-spinal fluid does not concern a controversy over the possibility of direct communications between the cerebro-spinal spaces and the venous sinuses, as is the case in the ocular problems.

For this work on the head the superior longitudinal sinus of the dura, owing to its size and accessibility, lends itself admirably. In these experiments it was found quite important that the opening between the sinus and the fluid reservoirs be made in such a manner that subsequently the skull would be intact. To accomplish this, the following technic was employed: Through a small scalp incision the skull is exposed in the middle over the angle formed by the semilunar lines. About one centimeter posterior to this angle a small perforation (1.75 millimeters in diameter) is made through bone to the dura. In this perforation is placed a needle which fits snugly. The point of the needle is then pushed through the sinus, an opening being made in this way through its roof and lateral wall. The needle may then be inserted into the subarachnoid space or may be continued through the corpus callosum into the third ventricle. In either instance the appearance of cerebro-spinal fluid has been taken as the indication for its removal. As soon as this fluid appears at the opening of the needle it is immediately withdrawn as quickly and carefully as possible, avoiding the loss of any more fluid than is unavoidable (usually 2–3 drops). A bit of bone wax held in readiness as the point leaves the skull seals the opening in the bone.

Four healthy dogs operated upon in this way, after recovery from anesthesia, behaved in all respects as other normal animals. The punctures in these cases were made anteriorly in the region of the motor area in the hopes that any intracranial abnormalities would be demonstrated by motor disturbances. The dogs were allowed to live from one to three days, at the end of which time they were sacrificed.

The first one alone showed the presence of blood in the cerebro-spinal spaces outside of the sinus. In this one animal there was a slight staining of the arachnoid; this was explained by the fact that at operation the cerebro-spinal fluid was allowed to drain off rather freely. Compensation for this loss of fluid necessarily had to be made within the closed cranium, and apparently cerebro-spinal fluid was not secreted rapidly enough, as blood flowed from sinus into the subarachnoid spaces through the artificial opening. In the other animals of the series there was absolutely no evidence of retrograde hemorrhage into the cerebro-spinal spaces, for in these cases such a loss of fluid was carefully guarded against. The longest observation covered a period of three days, the protocol of which is here given.

JULY 25, 1913, OBSERVATION XX. (Dog, mongrel.)

9.30 A.M.: Under ether anesthesia the skull was exposed through small scalp incision over angle of semilunar lines. A perforation 1.75 millimeters in diameter was made through skull in midline 1 centimeter posterior to the angle. A needle was inserted into sinus with subsequent slight leakage of blood around needle, but with no sign of bleeding through tube. The needle was carried through opposite lateral wall of the sinus and a few drops of cerebro-spinal fluid were obtained at the needle opening. The needle was quickly withdrawn and the small cranial defect filled with wax. As the puncture was in midline and as the needle was only carried through the sinus wall the fluid was probably obtained from the subarachnoid space. The scalp incision was closed and animal was returned to cage.

11 A.M.: Animal has recovered from the ether and is standing in the cage. When placed on floor it walks perfectly.

July 28: Animal since operation has shown no difference in behavior from normal dogs.

3 P.M.: Animal sacrificed (ether and exsanguination from femoral artery). A mass ligature was placed around neck. The superior longitudinal sinus and dura were exposed anterior to occipital protuberances. The dura and the arachnoid were opened. A cannula was quickly inserted into the superior longitudinal sinus as far posteriorly as possible and a warm gelatine mass was injected into the sinus. Following this, cerebro-spinal fluid at first alone then mixed with gelatine appeared at openings in arachnoid. The whole head was placed in cold water for one-half hour and then fixed in 10 per cent formalin.

On section the gelatine mass could be followed from the sinus through the artificial opening into the subarachnoid and the subdural spaces between the hemispheres. From here it spread into the basilar cisterns and could also be traced caudally to the cervical region of the cord. Between the hemispheres there was a small amount of blood mixed with the gelatine, presumably derived from the sinus during injection.

In the protocol just recorded the persistence of the open communication was substantiated by the passage of the gelatine injection mass from the sinus into the subarachnoid space (which had previously been opened). The second method of verification of the opening employed in the eye has also been used in these problems of the cerebro-spinal spaces. This consisted of the establishment in the routine manner of a direct communication between the cranial venous and fluid systems and of a subsequent relief by artificial means of the intracranial pressure. This disturbance in the normal balance between the two systems resulted in an immediate perfusion of the meningeal spaces with blood, coming, as subsequently determined, directly from the sinus through the artificial opening (Fig. 9).

That the relative pressure relations of the cerebro-spinal spaces and of the dural sinus might be further visualized, an observation was made in an anesthetized dog with the two systems in communication. This connection of the two was obtained by inserting cannulæ into the cisterna magna and into the superior longitudinal sinus and joining the two by glass tubing and rubber connections. Stopcocks and connections with a saline reservoir were introduced into the system so that either cannula could be washed at will.

When the sinus and cistern were thrown into direct communication by release of the stopcocks the blood from the sinus did not run into the cannula but remained with slight pulsation at the level of the sinus opening. The experiment is necessarily crude, taking no account of the capillarity of the tubes and so on, but it is serviceable in the demonstration of the possibilities of the direct openings.

When viewed physiologically these observations upon animals in whom direct and open communications had been made between cerebro-spinal and venous systems are of interest in that they show that within the meninges the same relations between fluid space and dural sinus exist as in the eye. For here also we have a constant reduction of the cerebro-spinal pressure to that of the sinuses with the vis a tergo sufficient and the flow constant enough to prevent fusion of the two body fluids. It is likewise important to understand that within the cranium as within the eye the physics of a close system filled with fluid must endure.

These observations indicate that during the limited time of the experiment a direct communication, and one which will remain patent, can be established between the cerebro-spinal spaces and the dural sinuses.

Sinus puncture in experimentally hydrocephalic animals. — In another series of animals before performing the puncture of the sagittal sinus an internal hydrocephalus was produced by the occlusion of the aqueduct of Sylvius according to the method devised by Dandy. Since, in our experiments, an intact cranium was desired, the occluding cotton plug was inserted through a slit in the occipito-atlantoid ligament without disturbing the occipital bone. The ligament was closed tightly after the insertion of the obstruction. After the initial establishment of the acute internal hydrocephalus a direct communication between the meningeal spaces and the sagittal sinuses was made in five animals. The sinus punctures were performed according to the same method as in the normal, with the exception that in these cases the needle was always carried through to the third ventricle. It is understood that in these cases a direct opening into a vessel is not needed for the relief of symptoms, for a simple communication between the ventricles and the subarachnoid space, with the presence of normal arachnoidal villi, should be sufficient to permit drainage. The experiments were used only to determine if a sinus puncture, after the production of an internal hydrocephalus, would lead to further complications. Then, too, it was hoped that in the presence of a high degree of fluid retention under increased pressure the initial flow through the artificial opening would be sufficient to start a continuous pathway of drainage at this point. The longest of the four observations in these experiments was one week, at the end of which time the experimental hole in the sinus remained open (Fig. 10). The protocol follows.

June 30, 1913, Observation XII. (Mongrel puppy.)

Operation: Under ether anesthesia the occipito-atlantoid ligament was exposed and a short median incision made in it. The dura and arachnoid were opened permitting an escape of cerebro-spinal fluid. The aqueduct of Sylvius was occluded; the subsequent drainage of a small amount of cerebro-spinal fluid soon ceased and the ligament was closed tightly.

July 1: Animal in good physical condition, but exhibits the characteristic symptoms of an acute internal hydrocephalus.

July 2: Hydrocephalic symptoms persist and the animal makes but few spontaneous movements.

10 A.M. Sinus puncture. Cranial perforation made in midline of skull 3 centimeters posterior to angle of semilunar lines. A needle was inserted into sinus and carried through it until cerebro-spinal fluid appeared. Perforation closed with wax.

July 9, 10 A.M. Sacrificed. Ether. The skull cap was removed immediately, and the wound in roof of sinus was easily made out. The superior sagittal sinus was opened and the clot evacuated. In the trough directly under the skull and upper sinus puncture a break in continuity of the lateral sinus wall was visible; apparently this was the puncture opening. The left lateral ventricle was injected with ferrocyanide solution and was fixed immediately in acid formalin. As the acid precipitated the Berlin blue in the formalin solution the granules could be seen streaming from the opening in the lateral wall of the sinus into clear formol.

Subsequent macroscopic examination showed the opening in the corpus callosum to be patent. The lateral ventricles were still widely distended, however, and stained throughout with the blue precipitate. The aqueduct was obstructed by the cotton block (Fig. 10).

With the demonstration of the persistence for seven days of this direct communication between the sagittal sinus and the subarachnoid spaces, the therapeutic application of the sinus puncture was undertaken in a case of a hydrocephalic kitten which was brought to the laboratory for investigation and treatment. The complete record of the animal is here given.

July 16, 1913: A kitten, three weeks old, one of a litter of three females born of a normal maltese mother, was admitted for relief of an enlargement of the head.

During parturition (primiparous) the two other kittens were born first and without difficulty, but owing to the large size of the head of the third kitten delivery was difficult.

Since birth this third kitten's head has continued to grow large; it has experienced great difficulty in nursing and finding its way around; it does not play like other kittens and has refused nourishment.

Physical examination: The kitten (Figs. 5 and 6) is fairly well nourished. The skin is freely movable over body, but is rather tight over head. The fur is rough and uneven, although there is apparently no loss of hair. Weight, 340 grams. Length, nose to tip of tail, 29 centimeters. Head: The cranium is extremely large and almost spherical in shape.

Head measurements: Coronal circumference in front of ears, 17.5 centimeters; occipital protuberance to nasal angle, 9.5 centimeters; greatest breadth, 5.5 centimeters. Between the right parietal and frontal bones, 2 centimeters from midline, there is a small open fontanelle into which the tip of the little finger may be introduced. The flat bones of the head are slightly movable. The eyes are large and protrude markedly. The nictitating membrane projects above the lower lid at the angles. The edge of the lower lid is relatively high and hides the lower half of the iris and pupil. The margin of the upper lid is high. Ophthalmoscopic examination not made. The eyes of the kitten follow the finger in all directions. The ears are placed relatively low on the head (Fig. 5). Hearing is evidently good, as the kitten responds to calls. The gait is very ataxic.

July 19: Mother and remaining two kittens of litter obtained. These are in perfect physical condition.

COMPARATIVE MEASUREMENTS OF HEADS OF LITTER.

	Circumference Coronal in Front of Ears.	Occiput to Angle of Nose.	Greatest Breadth of Head.	Weight.
Hydrocephalic.......	17.0 cm.	9.25 cm.	6.0 cm.	350 gms.
Female I.	14.0 "	7.50 "	5.5 "	425 "
Female II.	13.5 "	7.00 "	5.5 "	340 "

July 20: The hydrocephalic kitten shows a marked peculiarity in gait, characterized by a tendency to overstep and to fall forward. This seems to be due to spasticity of the hind legs which stiffen when the animal starts to walk, throwing the hind-quarters high in the air and projecting the body forward. The kitten can nurse mother at times. July 22: Animal is in very poor condition this morning; it tumbles aimlessly about the floor. It seems very much fatigued. On closer observation it is found that the elevation of the back is not due entirely to the push of the spastic hind legs, but, at times, the hind legs are actually elevated from the ground by the tensely contracted muscles of the back. At other times the kitten is forced to balance itself on its forepaws, from which position the animal either again manages to get its hind-quarters on the ground or, what more frequently happens, it is thrown head over heels forward, performing a complete somersault. 2 P.M.: The kitten is in very bad condition (weight, 320 grams). It cannot stand at all, for as soon as it makes any attempt to rise it is thrown forward. It cannot nurse mother on account of unsteadiness, nor will it swallow milk when put into mouth. As condition was growing worse it was decided to make an attempt at relieving intracranial pressure.

3 P.M.: Operation. The skin over vertex was shaved and cleaned. The puncture was made through skin and fontanelle near middle (R and B 19 G. needle). Cerebro-spinal fluid was obtained. As a permanent drain was desired, however, and since it was not certain that this puncture had passed into the sinus (no blood) a second attempt was made. The skin was incised as far as the bone in the midline, and the needle inserted. In this procedure, blood was obtained and there was reasonable assurance that the sinus was entered. Following the appearance of the blood the needle was advanced until cerebro-spinal fluid was obtained. The skin was closed with two sutures. Amount of fluid lost — about 2 cubic centimeters. The kitten immediately showed signs of relief and within an hour and a half was able to walk fairly well, though it was still unsteady. It drank milk from pan several times during afternoon. It became playful and would strike at finger if moved before its eyes, but it seems to tire easily. July 23: Condition very much improved. It walks very well and falls only occasionally, as when assuming a position requiring a balance.

Thus when licking a forepaw it falls. July 24: Kitten remarkably improved. It now drinks alone from a deep bowl without losing equilibrium. It can run and frolic without losing balance. Weight, 380 grams. July 26: Return of former symptoms with marked instability. The animal remains quiet when undisturbed. It will not drink milk and requires feeding from bottle.

9.30 A.M.: Operation. Second sino-ventricular puncture through midline. Several cubic centimeters of bloody fluid obtained. 3 P.M.: Great improvement. Kitten drinks milk from pan and runs about. July 27: Condition very good. Animal still shows a certain amount of instability when walking, but does not fall. It will follow a person all over the room. July 28: Condition excellent. It can run and play with other kittens. Its hind legs are still spastic. Weight, 380 grams. July 29: The fontanelle seems smaller. The skin is more wrinkled and movable over head. Weight, 400 grams. Head measurements: Coronal circumference, 17.5 centimeters; nose to occiput, 9.5 centimeters; breadth, 6 centimeters. Weight of other kittens, 600 and 500 grams, respectively. August 4: Condition remains good. The fontanelle has entirely disappeared. The eyes are still exophthalmic. The lower lids cover about one-half of iris and pupil. Its gait is becoming ataxic again. August 5: The gait is still more ataxic. The kitten assumes grotesque position noted earlier in history. Refuses milk but eats salmon greedily. Rather lethargic. Weight, 380 grams.

3 P.M.: Third sino-ventricular puncture. The needle entered to one side of midline and the fluid obtained (3-4 cubic centimeters) was clear. Following puncture the condition again immediately improved, but gait was still very ataxic toward evening. August 6: A marked change for the better. The kitten walks about without falling. August 12: Until to-day kitten has remained quite well. It again refuses food. Its gait has become very unsteady and it falls frequently. Its eyes protrude slightly more than usual. The fontanelle is not felt.

2 P M.: Fourth sino-ventricular puncture through midline. Several cubic centimeters of fluid are removed with some blood present. August 13: Animal has never been seen in such excellent condition. It runs rapidly over the floor and jumps off and on to a wooden platform about 4 inches high with perfect ease and balance. It plays with objects large enough to attract attention, and romps with other kittens. There is only the slightest suggestion of ataxia. August 16: Since puncture, four days ago, animal has been unusually well, showing little signs of physical abnormality aside from size of head. The other kittens are developing more rapidly and are more agile. All their movements can be duplicated by the hydrocephalic animal, although less quickly. The two normal kittens have a fine, slick suit of fur. The sick one has not the clean, shiny appearance of the others, and the hair of the body stands more or less on end. August 18: The pressure symptoms have again become marked. Fifth sino-ventricular puncture; several cubic centimeters fluid. Usual improvement. August 24: Condition good until to-day, requiring another,

the sixth puncture. Distinct subsequent improvement. August 26: Condition excellent. Runs, plays, and eats hungrily. August 28: Animal continues to be well. Only slight tremor of head still persists. The smaller of the two females (controls) is sick and refuses to eat.

	Circumference Coronal in Front of Ears.	Occiput to Angle of Nose.	Greatest Breadth.	Distance Between Ears.	Weight.
Hydrocephalic.....	19 cms.	10.0 cms.	7.0 cms.	5 cms.	620 gms.
Female I..........	16 "	9.5 "	6.5 "	4 "	780 "
Female II.........	15 "	8.0 "	6.0 "	4 "	500 " (sick).

August 29: Kitten in excellent condition all day. It played, jumped, and ate heartily. August 30: Kitten was found lying on floor in morning next to dish containing some spoiled salmon, left from night before. Kitten vomited some salmon. Belly was enormously distended, manipulation painful. Abdominal wall was soft. Breathing was difficult. Animal was retching as if attempting to expel stomach contents. A tube was passed and stomach lavaged. Few shreds of salmon were obtained. Animal was placed in incubator. Died one hour after it was first seen.

As soon as life was extinct an injection was made into the subarachnoid space through the occipito-atlantoid ligament and also into the left ventricle. The head was immediately fixed in 10 per cent acidulated formalin. This was changed to 10 per cent formol after washing in tap water for 24 hours.

Autopsy: Heart and lungs normal. Stomach contained several shreds of salmon, and the small intestines were very greatly distended with gas. Large bowel contained feces. Nothing else abnormal found in viscera. Spinal cord showed no pathological changes. Head: after removal of the skin the calvarium was found to give no indication of the position of the fontanelle palpated on admission.

At the point where the punctures had been made two healed scars could be seen in the midline and one other just to the left of the midline. On removing the calvarium the dura was found to be free. The superior longitudinal sinus was well developed and at two places showed the scars of former punctures which had passed through its center (Fig. 4). To the left of the sinus corresponding to the point noted in the skull another scar was visible. The convolutions were everywhere flattened. The entire top of the cortex was removed in one piece to protect the sinuses and a large cavity occupying almost the entire cranium was disclosed (Fig. 2). No signs of hemorrhage. The cortex was in no place more than .5 centimeter thick. The falx cerebri and corpus callosum were mere rudiments of the normal structures. The superior surface of the cerebellum was exposed by a cortical defect on the right side (cf. Figs. 1 and 2). A smaller cortical defect exposed the meninges from within to the right of this area. At the base of the cavity two protrusions on either side represented the optic thalamus and lenticular nucleus, over the former of which were found the choroid plexuses. Foramina of Munro patent. Large third and fifth ventricles. Exposure of cerebellum and cervical cord show marked herniation of these structures, former through foramen magnum. The aqueduct of Sylvius is open and the ventricles communicate with the cisterns.

For a control, Female I. of the litter was sacrificed on the same day that the hydrocephalic one died. The injections were made in the same way.

To sum up, we have in this case a kitten afflicted with an idiopathic internal hydrocephalus showing all of the usual signs seen in children having the same disease. During the six weeks and a half in which it was under observation, it was six times relieved by sino-ventricular puncture. In some of these punctures, in two at least, the path of the needle was directly through the superior longitudinal sinus. After each puncture the condition of the kitten was immediately improved. The general improvement lasted practically a week in each instance. Whether this improvement was due alone to the relief of pressure attending the loss of fluid at each tapping or whether the openings in the sinuses facilitated drainage, is difficult to decide. It was apparent, however, that the punctures through the sinus were followed by no intracranial extravasation. On gross examination the opening made by the puncture through the lateral wall of the sinus persisted; there was no thrombus formation or other block in its lumen.

General summary. — The observations recorded in the foregoing paragraphs offer evidence that an artificial communication between the fluid spaces and the venous sinuses will remain patent in both the eye and the brain. The periods of observation have not been extensive but have been considered to be long enough to demonstrate the permanency of the opening. Not only will such abnormal connections of the fluid persist in the normal animal, but they will play a similar part in cases of idiopathic internal hydrocephalus, as evidenced by the protocol of the hydrocephalic kitten. (In 1895 Gärtner[2] suggested the ideal method of drainage for cases of internal hydrocephalus to be from the cerebro-spinal fluid reservoirs directly into the venous trunks of the head. However, not until 1908 did his idea obtain a practical application, when Payr[7] in Germany devised a method for the transplantation of vessels between the dural sinuses and the ventricle. Somewhat later, McClure[6] in America, independent of Payr, transplanted a portion of the basilic vein into the scalp and with it connected the subdural space and external jugular vein of a child suffering with internal hydrocephalus. Since this time the operation has been repeated several times, and in 1913 Haynes[3] modified the technic by substituting for the transplanted portion of vessel a piece of rubber tubing with which he made a communication between the superior longitudinal sinus and the median basilar cisterns.)

The physiological bases for the pressure relations of fluid and venous systems are fairly well established by these observations. These relations in both the eye and brain must be considered solely from the view-point of the physical phenomena in any closed fluid system. It seems probable that in both situations the fluid pressures are constantly being reduced to the level of the venous pressure in the great sinuses and that, because of the resistance of complex fluid pathways, the fluid is at a slightly higher pressure than that in sinus.

No retrograde hemorrhage from the great sinuses, no apparent ill-effects and no obvious change in the physiological relations have been observed in either the brain or eye after the establishment of a direct communication between the fluid and venous systems.

CONCLUSIONS.

(1.) A direct communication between the sinuses of the sclera and the fluid reservoirs in the canine eye has existed for at least forty-eight hours without hemorrhage into the ocular cavity.

(2.) A direct communication between the superior longitudinal sinus and the subarachnoid space of normal dogs has remained patent during observations up to seven days in length, without hemorrhage into the fluid spaces.

(3.) Sino-ventricular punctures in the case of a hydrocephalic kitten were followed by improvement in the animal's general condition. No intracranial bleeding was occasioned by these punctures.

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DESCRIPTION OF PLATE.

PLATE X., FIG. 1. — Control kitten. Section of head for comparison with Figure 2.

FIG. 2. — Hydrocephalic kitten. Section of head showing dilatation of lateral ventricles, thinning of cortex, flattening of convolutions. The optic thalamus, lenticular nucleus, and choroid plexuses can be seen on the floor of each ventricle.

FIG. 3. — Control kitten. The removal of the cortex and dura has been made in relatively the same position as in Figure 1.

FIG. 4. — Hydrocephalic kitten. Picture showing dura with location of puncture wound, two of which can be seen in midline directly over the superior longitudinal sinus. A third can be seen on the left of the midline.

FIG. 5. — Hydrocephalic kitten. Picture taken two days before death subsequent to last puncture.

FIG. 6. — Hydrocephalic kitten. Picture taken on same day as Figure 5. Kitten is balanced for a spring from the wooden platform on which it is standing.

FIG. 7. — Lateral view of head of hydrocephalic kitten after removal of skin. It shows the greatly increased size of the calvarium and the bulging forehead.

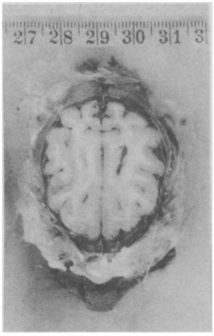
FIG. 8. — Lateral view of head of control kitten, presented for comparison to Figure 7.

FIG. 9. — Brain of dog three days after sinus puncture (experimental hydrocephalus). Sinus puncture patent. Straw is inserted through opening into sinus and runs lateral to the falx. Dark staining due to hemorrhage just before death as a result of opening arachnoid.

FIG. 10. — Brain of dog seven days after sinus puncture (experimental hydrocephalus). Sinus puncture patent. Injection of sinus from ventricle. Hair inserted into opening, passes into longitudinal fissure between falx and hemisphere.

FIG. 11. — Diagram showing course of needle in producing a communication between the scleral sinus and aqueous reservoir. After the removal of the needle the vein is ligated at *t*.

FIG. 12. — Sketch showing position of vein used for producing the sinus puncture of the eye (see text).



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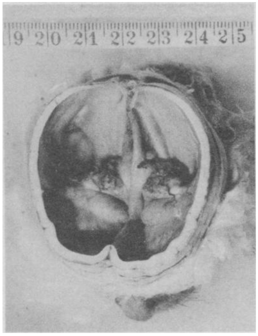

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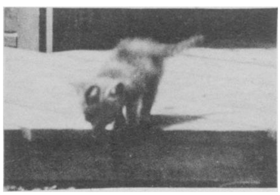

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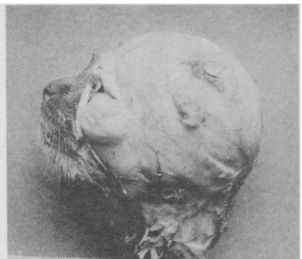

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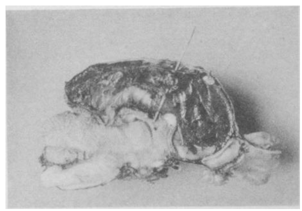

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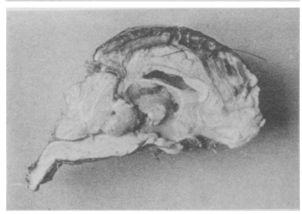

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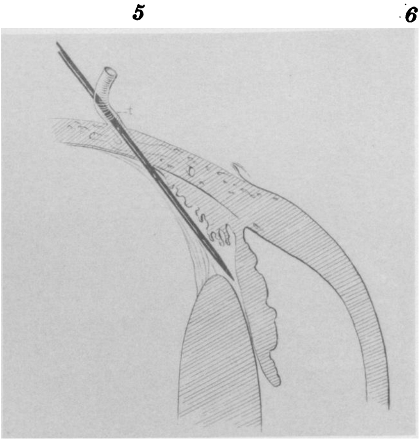

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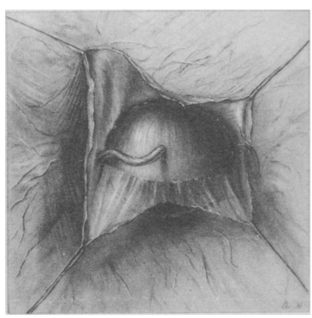

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