

RÖNTGENOGRAPHY OF THE BRAIN AFTER THE INJECTION OF AIR INTO THE SPINAL CANAL

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As was shown in a recent publication,¹ one or more of the cerebral ventricles can be sharply outlined in a röntgenogram if the ventricular fluid be withdrawn and replaced by an equal quantity of air. In the course of this work it was soon noted that in many cases some of the air had passed out of the ventricular system and could be seen in filaments on the surface of the brain, that is, in the sulci. In order to reach the sulci from the point of injection in a lateral ventricle, the air must have followed the normal pathways by which cerebrospinal fluid circulates. It must have passed through the foramen of Monro into the third ventricles, thence into the fourth ventricles, through the aqueduct of Sylvius, and then, having left the ventricular system, it must have entered the cisterna magna by way of the foramen of Magendie and the paired foramina of Luschka. Finally, from the cisterna magna it must have passed along the various cisternæ under the base of the brain and then by numerous branches have reached the termination of the subarachnoid space—the sulci. Not infrequently, the entire subarachnoid space was graphically defined by the air shadows.

These observations at once gave promise of new possibilities in intracranial diagnostic study. Many lesions of the brain affect part of the subarachnoid space directly or indirectly. In hydrocephalus of the communicating type, adhesions at the base of the brain obliterate the cisternæ and the cerebrospinal fluid cannot reach the sulci over the cerebral hemispheres; a local area of subarachnoid space may be obliterated by a tumor situated on or near the surface of the brain; a defect in the brain due to atrophy must necessarily be filled with cerebrospinal fluid, which may maintain communication with the subarachnoid space. These, and no doubt many other conditions, should be demonstrable by the absence or by the presence of air over the cerebral hemispheres.

After the injection of air into a cerebral ventricle a certain amount will soon appear on the external surface of the brain if the head is carefully manipulated so that the air is guided to the small aqueduct of Sylvius and the fourth ventricle. But the time of escape of air from the ventricles and of its appearance in the cerebral sulci are variable. The more completely the ventricles are filled with air the greater the probability that it will appear externally; and the more dilated the iter and the foramina of Luschka and

¹ Dandy, W. E.: *Ventriculography Following the Injection of Air Into the Cerebral Ventricles*. ANN. SURG., July, 1918. *Fluoroscopy of the Cerebral Ventricles*. The Johns Hopkins Hosp. Bull., February, 1919.

Magendie (as in hydrocephalus) the more readily will air appear externally. Nevertheless, it was evident that at best the amount of air that will reach the cerebral sulci must vary greatly, according to the conditions existing in each individual case.

The problem therefore before us was: How can we in every case be sure of obtaining a complete injection of the subarachnoid space? The solution lies in the direct injection of air into the spinal canal. By this method the influence of the ventricular system is entirely eliminated; the air passes directly into the cisterna magna and thence into the ultimate ramifications of the subarachnoid space.

The technic is essentially similar to that described elsewhere for intraventricular injections. A small quantity of spinal fluid is withdrawn and an equal amount of air injected into the spinal canal. This process of substitution is repeated until the fluid ceases to appear on aspiration. There is no need to sterilize the air, because it is always free from pathogenic organisms.

Undoubtedly this procedure is not devoid of danger. Medullary distress, even fatal results, might well follow from increased intracranial pressure if the amount of air injected were even slightly in excess of the fluid withdrawn. The danger would certainly appear to be much greater in intraspinal than in intraventricular injections, because in the latter direct pressure on the medulla in large measure is inhibited by the tentorium cerebri. In my own cases no bad effects have followed and the results have led me to believe that with proper care and judgment the procedure is entirely harmless. I have always left the open needle in the spinal canal for two or three minutes after the injection has been finished, thus rendering the intraspinal pressure directly under control. If the needle is left open, the intraspinal pressure becomes equal to the atmospheric pressure, which is less than the normal intraspinal pressure. This reduced pressure is an additional safeguard against any possible development of a "reactive" intracranial pressure.

The position of the body is all-important in intraspinal injections—in fact, in all air injections, because the air rises as the fluid gravitates. The head must be at least twenty degrees higher than the needle. With each injection the air will then rush to the brain and a new supply of fluid will fall to the point of the needle. No doubt the sitting posture would be more satisfactory, because it would allow a more complete and uniform injection of the subarachnoid spaces over both cerebral hemispheres. In the recumbent position, which I have used exclusively, mainly for the comfort of the patient, it is possible that the injection may be more complete over the surface of the higher hemisphere than over the lower hemisphere, and that on turning the patient from one side to the other (in order to take both right and left lateral views of the head) important changes in the distribution of the air may be induced by the effects of gravity. In the sitting posture, rotation of the head would not alter the position of the air in the spaces, because gravity would not be brought into play, and a more accurate photograph

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of the "air mantel" on each hemisphere would be obtained. If, however, the intracranial subarachnoid space is thoroughly injected, there should be but little change due to gravity and the recumbent posture should prove practically as effective as the sitting posture. Additional experience will probably indicate the position of choice.

I have injected air intraspinaly into eight patients—four children and four adults—from Professor Halsted's service, without any bad effect. The amount of air has varied from 20 to 120 c.c. In one patient a mild headache followed but disappeared in three hours; vomiting but no headache occurred in another case; in the others no complaints were made. In reality, the effects should be much the same as those following the usual lumbar puncture.

One difficulty in the injection procedure should be mentioned. The aspiration must be gentle because the needle may plug at times, presumably with fibres of the cauda equina. If the suction is very gentle this may be obviated. In no case was there pain from injury to the nerves.

It must always be remembered that spinal punctures are very dangerous in all patients with intracranial tumors. A spinal puncture should never be made (if a tumor is present) unless the intracranial pressure has been previously relieved by a ventricular puncture or by some other procedure.

What becomes of the air? Air disappears from the subarachnoid space quite rapidly. It is absorbed as from other tissue spaces and undoubtedly passes directly into the blood. Usually no air is demonstrable in the röntgenogram twenty-four hours after the injection. Absorption from the subarachnoid space is many times faster than from the ventricles.

Practically all cerebrospinal fluid is absorbed from the subarachnoid space; very little from the ventricles, and the absorption of ventricular fluid occurs only after it has passed into the subarachnoid space.² When air is injected into a lateral ventricle, its rate of absorption seems to depend upon the freedom of access to the subarachnoid space. If the ventricles are normal the air will disappear in the course of a few days. If an internal hydrocephalus is present, the absorption time is greatly increased because an obstruction prevents the air from reaching the subarachnoid space. In cases of ventricular dilatation it may require two to three weeks for the air to disappear. The rate of absorption of air from the ventricles and the subarachnoid space appears to be relatively the same as that for the absorption of fluids from these cavities, although the absolute time required is greater for the absorption of air.

Röntgenography of the Normal Subarachnoid Space.—If the spinal and intracranial subarachnoid spaces are normal, the air which has been injected intraspinaly will fill all the intracranial spaces (Figs. 1-3). The cisterna magna shows as an air-filled space of varying size, anterior to the squamous part of the occipital bone. The cisterna chiasmatica, which is the anterior

² Dandy, W. E., and Blackfan, K. D.: Internal Hydrocephalus. *Am. J. Dis. Child.*, 1914, viii, 406. Second paper: *Am. J. Dis. Child.*, 1917, xiv, 424. Also: *J. Am. M. Ass.*, 1913, lxi, 2216.

terminus of the cisternæ, usually shows quite distinctly, and from it several branches may be seen passing upward into the cerebral sulci. The intensity of the shadow of the cisternæ under the medulla, pons, and midbrain is greatly modified by the dense bone at the base of the skull, notably the petrous part of both temporal bones. The continuity of the shadow of all the cisternæ can, however, nearly always be traced if the X-ray is good and the injection has been complete. The sulci appear as a network of lines over all the surfaces of the cerebral hemispheres. In general appearance the injected sulci suggest very closely the shadows of the vessels in the diploe, although the arrangement is different. In the earlier ventriculograms, in which only a few sulci contained air, the shadows were erroneously looked upon as markings of the diploëtic veins. Sulci have not been observed around the cerebellum, but frequently an envelope of air can be seen completely surrounding it. This envelope of cerebellar air is continuous with the cisterna magna. In one plate in which the upper part of the spinal canal was included, the spinal subarachnoid space was full of air, and in this column of air the shadow of the spinal cord was very distinct (Fig. 5).

The cerebellum frequently appears as an island (Fig. 3). Since the tentorium cerebelli is in apposition with part of the pericerebellar subarachnoid space, the shadow of this space marks the under surface of the tentorium. In cases in which the lateral ventricles are enormously dilated, a ventriculogram will delimit the upper margin of the tentorium. By combining the upper and lower shadows in such a case, the outlines of the tentorium are quite sharply seen. Mention of this is made merely to show how sharply the X-rays will differentiate tissues in a medium of air.

*Localization of Intracranial Lesions by Intraspinous Injections of Air.*²—

The cisternæ may be regarded as the vital part of the subarachnoid space. Inasmuch as they form the trunk of the subarachnoid tree, all cerebrospinal fluid must traverse them in order to reach the cerebral sulci. The sulci are important because in them practically all cerebrospinal fluid is absorbed. Any obstruction in the cisternæ, therefore, leads to hydrocephalus because of a diminished absorption of cerebrospinal fluid. Hence it becomes of the utmost importance to determine whether the cisternæ are patent or whether they have been obliterated. Intraspinous air will always reach the sulci if the cisternæ are patent; and conversely, if the air does not reach the sulci, the cisternæ must be obstructed at some point. Furthermore, with a good X-ray one can see just where the obstruction is situated.

In this series of eight cases, the location of the lesion has been accurately determined in three. In the remaining five, the subarachnoid space was normal. In the three patients in whom the lesion was located by means of intraspinal air, other methods had entirely failed. The findings in these cases will be briefly stated.

²The röntgenographic detail in these plates we owe to the skill of Miss Mary Stuart Smith, in the X-ray service of Doctor Baetjer.

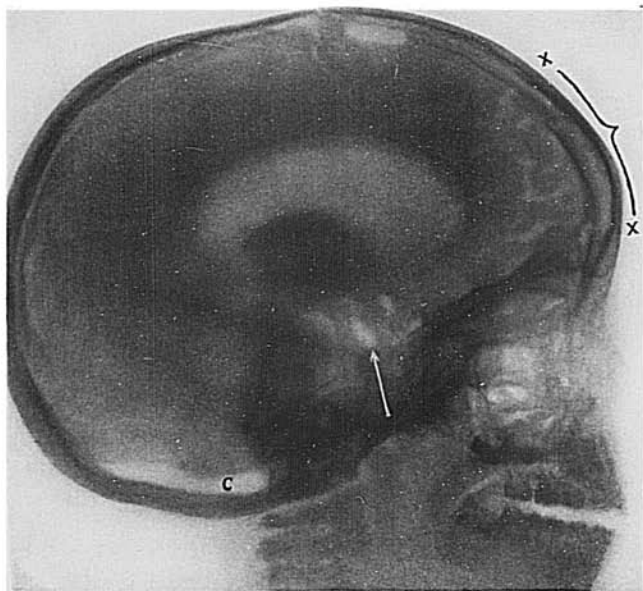


FIG. 6.—Photograph of roentgenogram of head after injection of air into ventricle (not retouched). This patient had an early hydrocephalus following acute cerebrospinal meningitis. Only a small area of the cerebral sulci contain air (cf. brackets between X and X on surface). The obstruction which caused the hydrocephalus was not in the cisternæ but in the main branches which radiate to the sulci. The arrow points to the cisternæ which appear as a series of "blotches"; part of this appearance is probably due to the dilated trunks (obstructed above) which pass from the cisternæ to the cerebral sulci. The partial filling of the cerebral sulci (X to X) explains the slow development of the hydrocephalus. C, cisterna magna.

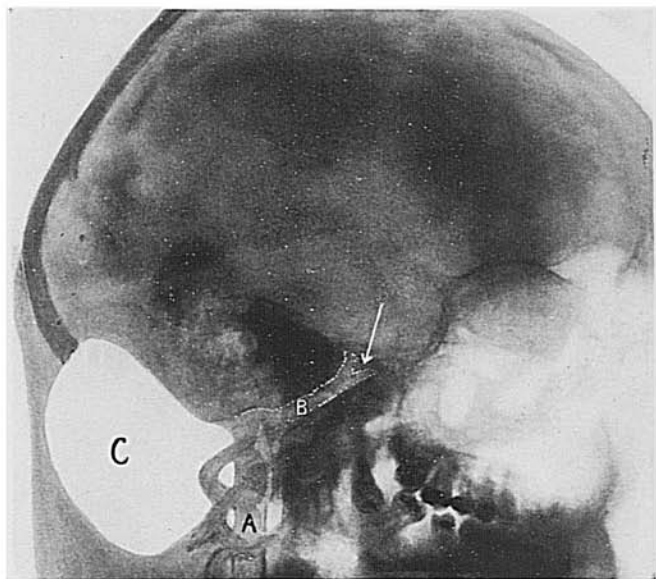


FIG. 5.—Retouched photograph of a roentgenogram of the head, after an intraspinal injection of air. The patient was suffering from the effects of an intracranial tumor which was localized only by the aid of the air injection and after a cerebellar exploration had revealed no growth. The operative defect in the occipital bone can be seen. In this region an enormous collection (C) of cerebrospinal fluid has accumulated. This corresponds to a greatly enlarged cisterna magna. Even the upper part of the spinal cord is visible because the spinal canal is filled with air. B, cisterna medullaris and pontis. The arrow points to the block in the cisterna. Here, a midbrain tumor was found and partially removed through a transcerebellar incision. It had closed both the aqueduct of Sylvius and the cisterna. The large collection of fluid (C) is due to the occlusion of the cisterna. It will be seen that none of the cerebral sulci contain air.

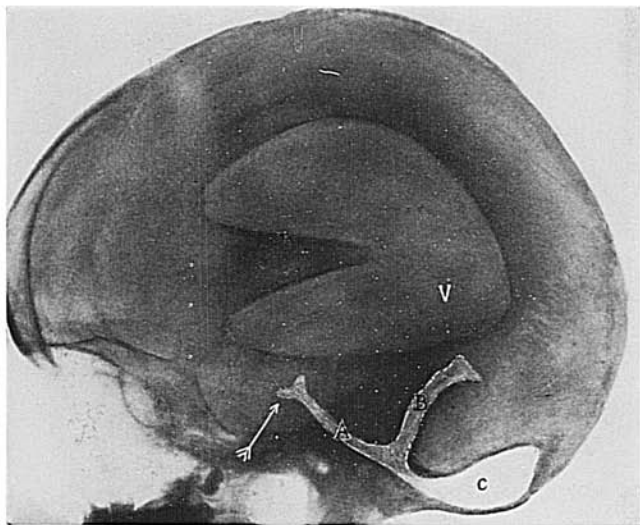


FIG. 4.—Retouched photograph of a roentgenogram of the head after an intraspinal injection of air. The patient had internal hydrocephalus. It will be noticed that none of the sulci are injected as in Figs. 1, 2, and 3. At the arrow, an obstruction due to adhesion has blocked the cisterna. *A*, cisterna pontis and medullaris. *B*, cerebellar subarachnoid space, also only partly open. *C*, cisterna magna, considerably enlarged. *D*, lateral ventricle, which partially filled with air after the intraspinal injection.

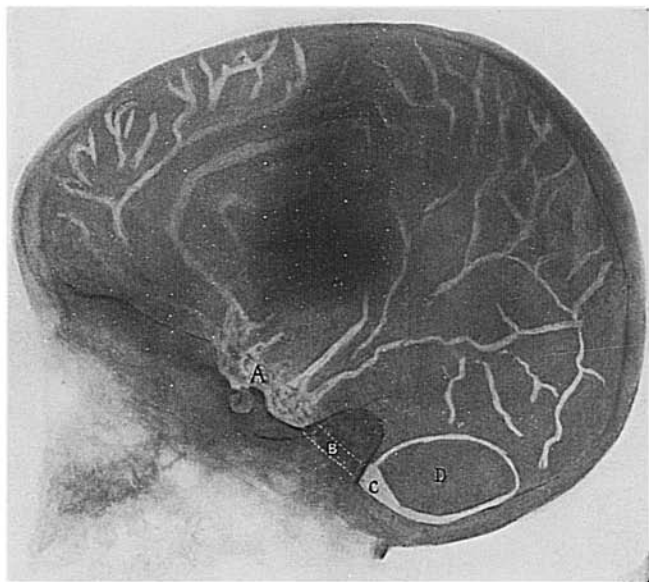


FIG. 3.—A retouched photograph of a roentgenogram of the head after an intraspinal injection of air. The subarachnoid space is probably normal. The lines of the component parts of the subarachnoid space have been intensified because of the loss of detail through photographic reproduction. A, cisterna interpeduncularis; from it many large branches can be seen establishing direct communication with the cerebral sulci. B, cisterna shadow subdued by the dense temporal bones. This part of the cisterna can be seen in many X-rays. C, cisterna magna; from it the cerebellar subarachnoid space completely encircles the cerebellum (D). The large horizontal sulcus shown directly connecting with the cisterna, in all probability, is on the mesial aspect of the brain and passes around the corpus callosum. It is impossible to tell which of the other sulci are median and which are external.

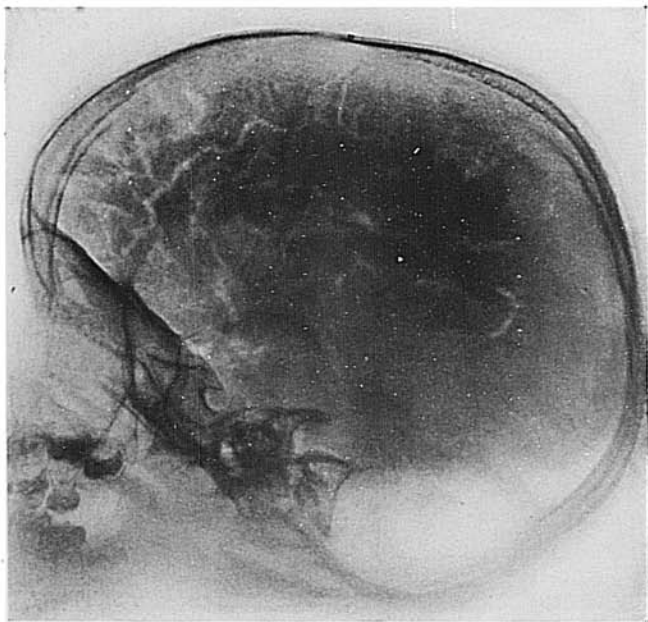


FIG. 2.—Photograph of a roentgenogram of the head after an intraspinal injection of air. The sulci and cisterna are more distinct than after the intraventricular injection as shown in Fig. 1.

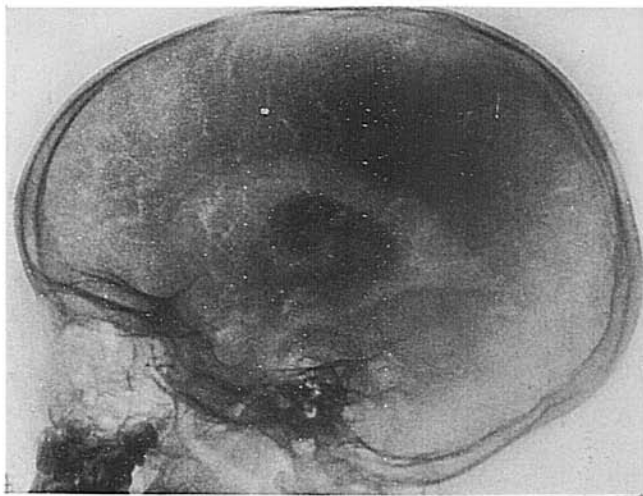


FIG. 1.—Photograph of a roentgenogram of the head after injection of air into a lateral ventricle. The air has passed out of the ventricular system and filled the cerebral sulci, which appears as a network of lines. The cisterna interpeduncularis and the major branches passing to the cerebral sulci are fairly distinct just above the sella turcica. The lateral ventricle is normal.

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In a case of hydrocephalus, 110 cc. of air were injected intraspinaly. It filled the cisterna magna, extended along the cisterna medullaris, and was stopped at the point of obstruction in the cisterna pontis (Fig. 4). This obstruction, due to adhesions from meningitis, had prevented the air reaching the sulci and thereby caused hydrocephalus. Necropsies have shown that communicating hydrocephalus is usually caused by adhesions in the cisternæ.⁴ I have since produced this disease in animals by occluding the cisterna with a perimesencephalic band of gauze.⁵

The injection of air gave still further information. Although it could not reach the cerebral subarachnoid space, which is normally the path of least resistance, it passed through the basal foramina of Luschka and Magendie, the fourth ventricle, the aqueduct of Sylvius, the third ventricle, the foramen of Monro, and partially filled a lateral ventricle (Fig. 4). The fact that the air passed into the ventricle showed that the hydrocephalus was of the communicating type. It should be noted that air has not been observed to enter the ventricle except in hydrocephalus. Normally, the cerebellum is in such close apposition to the floor of the fourth ventricle that, despite the absence of valves, the retrograde flow of air into the fourth ventricle is prevented. It is conceivable that the precise localization of the obstruction by the air method may render operative relief for the obstruction possible.⁶

Our second case presents an even more interesting pathology. The patient was a child three years of age. She had passed through an attack of acute cerebrospinal meningitis, but instead of complete recovery, lethargy and vomiting had ensued. Internal hydrocephalus was suspected by Doctor Blackfan, and confirmed by ventriculogram. A month later a second ventriculogram showed a measurable increase in the size of the lateral ventricle, but the rate of growth was markedly less than in the typical form of this disease. The air passed freely along the cisternæ and into the sulci over a very restricted area of the cerebral cortex (Fig. 6), not more than one-fourth of all the sulci showing the injection. Nor could it be determined whether the injected area was bilateral or unilateral. Exactly the same röntgenographic findings were present in the two X-rays taken a month apart; in fact, the same convolutions could be traced in both. The sulci could be followed into the cisterna chiasmatica.

These data supply a new conception of the pathology of hydrocephalus. The inflammatory process has sealed off all the main branches which radiate from the cisternæ, with the exception of one or possibly more which supply the anterior fourth of the cerebral cortex on one or possibly both sides. Absorption of cerebrospinal fluid from this restricted area has been sufficient to retard to a great extent, though not to prevent, the development of hydrocephalus. Should more branches from the cisternæ subsequently open, it is quite probable that, owing to the increased absorption which would follow, the accumulation of fluid will be entirely arrested. Such a development could easily explain many spontaneous cures in hydrocephalus. It is very doubtful if these pathological changes in the brain would be detected at necropsy.

A third case was in a boy of nineteen, who was suffering from intracranial pressure. An internal hydrocephalus was discovered. But what had caused the hydrocephalus? From his symptoms a tentative diagnosis of a cerebellar tumor was made, and since the signs and symptoms pointed to both sides equally, a vermis tumor seemed most likely. After a thorough cerebellar exploration I was unable to find any trace of the

⁴Dandy, W. E., and Blackfan, K. D.: Internal Hydrocephalus (second paper). *Am. J. Dis. Child.*, 1917, xiv, 424.

⁵Dandy, W. E.: Experimental Hydrocephalus. To appear in *ANNALS OF SURGERY*.

⁶In the December number of the *ANNALS OF SURGERY*, 1918, I presented a form of treatment for communicating hydrocephalus. If it should be possible, in a certain number of cases, to restore the channel of the cisternæ, this treatment would be superior to a bilateral choroid plexectomy.

tumor. The foramen of Magendie was normal. Three weeks after this operation, the phenolsulphonophthalein test showed that a complete obstruction was present at some point between the third ventricle and the foramen of Magendie. Air (120 c.c.), injected intraspinaly, was stopped in the anterior end of the cisterna pontis; none reached the cerebral sulci (Fig. 5). These findings could admit of only one interpretation—the pressure of a tumor in the region of the aqueduct of Sylvius, which had occluded it and the cisterna pontis. At operation a tumor as large as a hickory nut was found in the midbrain, and partially removed after bisection of the vermis of the cerebellum. The iter had been completely obliterated by the tumor.

Another interesting radiographic finding in the case was the enormous amount of fluid which had collected at the base of the brain after the first operation. We have frequently noticed after cerebellar operations in which a tumor was not found that such an accumulation of fluid followed, but the explanation had never been clear. The X-ray picture seems to indicate that the closure of the cisternæ causes the fluid to accumulate, or, in other words, bring about a localized hydrocephalus; the fluid forms in the fourth ventricle (the iter being closed). Another point of interest in this röntgenogram is the sharp outline of the spinal cord (Fig. 5).

A fourth case was that of a boy of eighteen. Hydrocephalus of a year's standing had followed an acute illness which had been diagnosed as measles. At operation the hydrocephalus was found to be due to closure of the foramina of Luschka and Magendie by dense adhesions. I made a new foramen of Magendie and wanted to be sure that it was functioning before allowing the patient to go home. Six weeks after the operation, air injected into the ventricles passed through the new foramen of Magendie and filled the cisterna magna and many of the cerebral sulci. We now could feel certain not only that the foramen of Magendie was patent, but also that all the subarachnoid space was receiving cerebrospinal fluid for absorption. The boy has since resumed his studies in college.

It also seems probable that we shall be able to localize spinal cord tumors by means of intraspinal injections of air. In one of our cases (Fig. 5) the spinal cord and the surrounding air-filled space are sharply outlined. Should the spinal canal be obliterated, either by a tumor or possibly by an inflammatory process, it is conceivable that the air shadow will extend up to the level of the lesion. Its intensity will naturally be greatly reduced by the great density of the spine, and particularly of the bodies of the vertebrae. A lateral view of the spine, by eliminating the maximum amount of bone, will probably give the best results. If the spinal canal is not obliterated by the tumor, the injected air will pass freely into the intracranial subarachnoid space, none being left in the spinal canal. This happened in one of our cases in which a spinal cord tumor was suspected. The passage of air into the brain was difficult to explain at the time of the injection, as the symptoms had been present for four years and a tumor of such duration would certainly have blocked the spinal canal. At operation a chronic transverse myelitis was found. Instead of an enlargement of the spinal cord, there was a constriction, which readily explained the failure of air to stop at the suspected zone.

As yet we have not had an opportunity of studying the radiographic findings in tumors of the cerebral hemispheres. It is conceivable that local effects may be noted in the sulci, or possibly even the direct or indirect effects of pressure on the cisternæ may be discovered.

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The practical value of intraspinous injections has been thoroughly established by the results in the few cases here reported. As a matter of fact, we shall often be able to localize a tumor from either a ventriculogram or from an X-ray of the subarachnoid space alone, an analysis of the signs and symptoms of the individual case enabling us to determine which should be tried first. From the data obtainable from the combination of intraventricular and intraspinous injections it is difficult to see how intracranial tumors can escape localization.

CONCLUSIONS

1. By substituting air for cerebrospinal fluid through a lumbar puncture, all parts of the subarachnoid space can be clearly seen in a röntgenogram.
2. Not infrequently, an air shadow will completely surround the cerebellum, showing clearly its size and shape.
3. The spinal cord can be seen surrounded by a column of air.
4. The cisternæ appear as large collections of air at the base of the brain; the cerebral sulci as a network of tortuous filaments of air.
5. After an intraspinous injection, provided that the subarachnoid space is intact, the air will always fill the cerebral sulci.
6. But if the cisternæ are blocked at any point by a tumor or adhesions, the air will not be able to reach the cerebral sulci.
7. The exact position of the obstruction in the cisternæ can often be seen in the radiogram. In one of our cases of communicating hydrocephalus, the obstruction was in the cisterna pontis. In a second case of communicating hydrocephalus the cisternæ were patent but all except one or two of the main branches were occluded. In a third case a tumor was located in the midbrain solely by means of the radiogram.
8. In a case of hydrocephalus, air passed from the spinal canal into the lateral ventricle, demonstrating the patency (and dilatation) of the foramina of Magendie and Luschka, the aqueduct of Sylvius, and the foramen of Monro. The hydrocephalus was, therefore, of the communicating type.
9. A case of hydrocephalus was cured by constructing a new foramen of Magendie. Six weeks later, air injected into the ventricles passed through the new foramen, showing that it was still functioning. The air also filled the cerebral sulci, an indication that the entire arachnoid space was patent.

EXPLANATION OF FIGURES

Much detail is lost in photographing and reproducing the figures. Figs. 1, 2 and 6 have not been retouched. Figs. 3, 4 and 5 have been retouched (even to the extent of being almost diagrammatic) in order to show clearly the essential details which otherwise would have been lost to the reader.