FIGS. 1 AND 2.—Diagrammatic representation of main intracerebral arteries as seen in antero-posterior and lateral views.

KEY.

- A—Internal Carotid.
- B—Anterior Cerebral.
- C—Middle Cerebral.
- D—Anterior Communicating.
- a—Vertebral.
- b—Basilar.
- c—Posterior Communicating.
- d—Posterior Cerebral.

CEREBRAL ANGIOGRAPHY

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Introduction

Cerebral angiography has now become an essential diagnostic procedure in certain neurological diseases and a valuable pre-operative procedure in assisting the neurosurgeon to plan his operation. Largely as a result of angiography, vascular neurosurgery has been made possible.

Moniz (1927) introduced the method nearly a quarter of a century ago. In the early days the procedure could not be lightly undertaken for it involved an open operation on the neck to expose the carotid artery and the contrast substances used were not without danger. In recent years the direct or percutaneous puncture of the vessel has been satisfactorily performed and an almost benign contrast substance (diodone) has been used. Further than this the vertebral artery can now be successfully punctured through the skin, thus allowing all the main intracranial vessels to be examined radiologically. Previously vertebral arteriography was very seldom undertaken as the approach was almost a major operation in itself.

Anatomy

A detailed knowledge of the vascular tree is essential before undertaking angiography. Not only must one know the disposition of the main vessels, but also the common anomalies. One of the fascinations of angiography is the great variations of normal. The variations are much greater than the cerebral ventricular system and the subarachnoid basal cisterns. Further it is important to appreciate the limitations of angiography. In some respects it is far more crude than histological or clinical methods. It must be constantly borne in mind that only the *main* vessels can be outlined radiologically. Thus certain tumours may fail to reveal their abnormal vascular pattern, which is easily seen under the microscope, but not detectable by ordinary radiological methods. Microradiography, developed by the late A. E. Barclay, may in the course of time correct this defect. Then again the neurologist may be able to diagnose a limited or even fairly gross cerebral thrombosis which will not be demonstrable at all at angiography.

Four main arteries supply the brain; two internal carotids and two vertebrals. These vessels form an anastomosis round the base, called the

Circle of Willis. The two external carotids must also be mentioned as they are important, particularly in meningiomas and certain angiomas.

Figs. 1 and 2 show the internal carotid and vertebral arteries and their main branches. Though the representation is somewhat crude anatomically it gives a picture as seen radiologically in the two basic projections—lateral and anteroposterior.

The direction of blood flow in the Circle of Willis is somewhat variable. For example the posterior cerebral arteries are filled only from the basilar in about two-thirds of cases, while in the remaining third the posterior communicating artery is large enough to accept enough blood to fill the posterior cerebral artery. Thus, in about one-third of carotid angiograms the posterior cerebral artery is filled. Again the two posterior communicating arteries may be of different sizes so that sometimes the posterior cerebral artery is filled from one internal carotid artery, but not from the other on the opposite side.

For further details of the arterial pattern and its relation to important structures, the reader is referred to anatomical textbooks.

Technique

There is no space to describe technique in detail. Those interested are referred to Lindgren (1947), *British Journal of Radiology*. The most important single factor is a good team used to working together. Introducing the needle into the vessel requires considerable practice before one becomes skilled, but after performing about 50 punctures it should be possible to succeed in nearly every case.

The carotids of young children may be difficult to puncture as the lumen is small, the vessel is very mobile and the necks of small children are very short. Local anaesthesia preceded by basal narcosis should be adequate in the majority of cases. Only when the patient is uncooperative for some reason such as semi-coma, mental deficiency or undue apprehension, is a general anaesthetic necessary. Patients under about 16 years nearly always require a general anaesthetic.

Films should always be taken in at least two planes. The most important are the lateral and anteroposterior. Oblique and basal views are sometimes helpful as ancillary projections. Phlebo-

FIG. 3.—Large aneurysm of internal carotid artery, seen on AP view at inner angle of orbit.

grams are essential in tumour diagnosis. In most cases two phlebograms, taken 2 and 4 secs. after the arteriogram, are sufficient. If another series of pictures is taken in the same projection the timing of the arteriogram and phlebograms can be altered suitably, so that in effect six phases, not three, of the vascular flow are obtained. Some workers consider that many more films should be taken—up to 20 in about 10 secs.—but it is doubtful if additional information is obtained for ordinary clinical purposes. There is no doubt that this more elaborate method is of physiological value, but for routine work it is very expensive and exposes the patient to a considerable amount of radiation.

The Contrast Substance

Diodone is used exclusively nowadays. The closely related substance, iodoxyl, often used for intravenous pyelography, should not be used. Diodone is quite harmless in the tissues, while iodoxyl is not. Thus if a periarterial injection of diodone is given to a patient, no harm results. 35 per cent. solution should always be used for lateral views and the greatest concentration permissible in my opinion is 42.5 per cent. This is obtained by mixing equal quantities of 35 and 50 per cent. solutions. About 40 per cent. solution is usually necessary for anteroposterior projections, where a greater thickness of bone and brain has to be penetrated.

The Dangers of Angiography

The only danger of any importance is the contrast substance. It is hypertonic and the stronger the solution the more hypertonic it becomes. It is probable that an oedema of the brain is produced by stronger concentrations, and indeed some oedema may be caused transiently by the lower concentrations. Fits, hemiplegia and coma have all been seen; and in patients with very large tumours, which are made for all practical purposes still larger by the oedema, death has occurred in three cases in my experience of over 1,000 examinations. Incidentally this figure probably favours very well with ventriculography though not with intravenous pyelography, where the same drug is used, but in different circumstances.

On the whole it is fair to say that diodone, when used in concentrations not greater than 42.5 per cent. is a most satisfactory and almost entirely safe drug.

Dosage

Usually it is not necessary to give more than four injections, sometimes less. Occasionally eight or nine injections have to be given to achieve the diagnosis. 10 cc. is used each time but there is about 3 cc. of 'dead space' in the injection apparatus. Thus about 7 cc. actually enters the artery each time.

(A)

FIGS. 4 (A) AND (B).

Parietal angioma supplied by middle cerebral vessels and showing a large vein, which is filled in the arterial phase, draining up to the superior sagittal sinus.

The Applications of Cerebral Angiography

There are two main pathological groups that can be investigated:—(1) Vascular and (2) Neoplastic. The first group may be subdivided into (a) spontaneous vascular disturbances, and (b) traumatic. Both carotid and vertebral angiography may be used but the scope of the former is by far the greater.

Spontaneous Vascular Disturbances

I. INTRACRANIAL ANEURYSMS

It has been known for several years that spontaneously occurring aneurysms of the larger intracranial arteries are not uncommon, and that similar aneurysms of arteries elsewhere in the body are exceedingly rare. The large majority are thought nowadays to be congenital in origin. That is not to say that they are present at birth, but there is a congenital weakness of the arterial wall which is a potential site for aneurysmal formation. Perhaps the stresses of life and increase of blood pressure with age cause the weak wall to bulge and form an aneurysm. It has been found that most such aneurysms occur at or very near bifurcations of arteries. This rule does not apply always, particularly in the proximal part of the intracranial portion of the internal carotid artery. When a bifurcation is not adjacent to the aneurysm the

(B)

FIG. 5.—Internal carotid artery—thrombosed 2 cm. from origin.

strength of the theory is preserved by postulating that branches were present in the particular situation in early embryonic life.

A very small proportion of intracranial aneurysms are arteriosclerotic. These are usually fusiform, while the congenital type tend to be pedunculated. An even smaller group are mycotic—those secondary to septic emboli. It is doubtful whether any are syphilitic.

The size varies tremendously, some are so small that they may not show angiographically. Every gradation of size is seen—from that of a pea seed to a hen's egg.

The symptoms and signs depend on two main factors; (1) whether or not the aneurysm has burst and therefore caused a haemorrhage, and (2) its size. Further subsidiary factors must be postulated to explain the features shown by many aneurysms. First it must be remembered that these larger vessels under discussion lie in the subarachnoid space and not in brain substance. Thus a rupture of the smallest aneurysm may cause a severe or fatal subarachnoid haemorrhage, but give no other signs. But since the majority lie on or near the Circle of Willis they will be very adjacent to the upper six cranial nerves (with the exception of the olfactory pair). Pressure on one or more of these nerves will produce valuable

localizing signs and sometimes symptoms of pain, when the fifth nerve is pressed upon. Many aneurysms of no more than 0.5 cm. diameter can produce quite severe signs.

When one considers the larger aneurysms, other features may present themselves. Just as aneurysms of the descending thoracic aorta may erode bodies of vertebrae, intracranial aneurysms can erode the skull bones and also naturally the much softer tissues of the brain itself. Occasionally one sees much or part of the sella or superior orbital fissure destroyed by carotid aneurysms in the vicinity of the cavernous sinus. Aneurysms arising from more peripheral vessels such as the anterior and posterior communicating artery, anterior, middle and posterior cerebral arteries may press upon or erode brain tissue. Such aneurysms may be quite silent, even when very large, particularly if they invade the frontal lobe. Again they may simulate tumours and can only be differentiated by arteriography. Such a case was described by the writer (P.R.S.M. 1949). If such aneurysms burst they may either bleed into brain tissue, or if sufficiently adjacent, rupture into the ventricles. Aneurysms of the vertebral or basilar arteries, pressing upon, but not necessarily invading the pons, may be quite indistinguishable from pontine tumours except by angiography.

FIG. 6.—Left Subdural haematoma. Note also displacement of anterior cerebral vessels.

Part or all of the wall of some aneurysms calcifies and this feature combined with the erosive qualities already described, makes plain X-rays of the skull an essential precursor to angiography.

Presenting Signs and Confirmation of Diagnosis

The above description makes it apparent that aneurysms present in a variety of ways :—

(a) *Pure subarachnoid haemorrhage.* Here the diagnosis is usually simple by clinical methods, supported by lumbar puncture. However from the point of view of treatment it is the localization which is very important. Sometimes one is assisted in lateralizing the lesion by a partial aphasia, lateralized headache, perhaps a transient weakness of one side of the face or a limb. But in the majority of cases one has to guess and so it is often necessary to perform carotid arteriograms on both sides. If they are both negative, one vertebral artery must be filled to outline the posterior part of the arterial tree. By this means nearly, but not quite all, aneurysms are localizable. The remainder are presumably either too small or have thrombosed.

A current burning question is when to perform an angiography on a patient with a known subarachnoid haemorrhage? Some authors say it is

necessary to wait six weeks, others ten days and yet others that no delay is necessary. The writer agrees with the last group and regards the condition as a surgical emergency. There seems to be no valid reason for delay.

(b) *Aneurysms pressing on cranial nerves.* This is a smaller group than that presenting with subarachnoid haemorrhage. In this group the aneurysms do not always bleed but manifest themselves by pressing either on a motor nerve to the eye, the optic nerve or the fifth nerve. Thus some are associated with intense pain. Aneurysms of this group (Fig. 3) are easier to localize radiologically for they are lateralized clinically and often the vessel from which they arise can be predicted clinically—for example carotid, anterior communicating, posterior communicating and so on. Only one carotid artery needs to be punctured in such cases. Furthermore it is in this group that signs are seen on the straight X-rays, such as localized bone erosion or calcification.

(c) *Aneurysms invading brain substance and presenting as 'tumours.'* This is the most difficult group to diagnose clinically. In the other two groups the clinical diagnosis is relatively easy, but the localization may be difficult or impossible. In this last group the clinical localization may be moderately accurate but the pathological diagnosis

FIG. 7.—Parietal meningioma outlined in venous phase.

is often incorrect, and indeed aneurysm may not even be considered in the differential diagnosis.

Unless an angiogram is performed the diagnosis may not be revealed until surgical exploration.

(d) '*Silent*' aneurysms. There is no doubt that 'silent' aneurysms exist and some possibility that they are not uncommon. They may perhaps be likened to diverticula of the colon which are so often 'silent' or symptomless.

The writer has seen one case of aneurysm which had bled and was well localized clinically and confirmed arteriographically. There were two silent aneurysms on the tree of the opposite internal carotid artery. Another case was of a malignant glioma of the parieto-occipital region shown angiographically. There was a 'silent' aneurysm of the internal carotid artery at the site of entry into the subarachnoid space.

2. ARTERIOVENOUS FISTULA

Such lesions can occur between the intracavernous portion of the internal carotid artery and the cavernous sinus. Such cases are very rare and the writer has seen only one example.

3. VASCULAR MALFORMATIONS (angioma)

Until recently they were thought to be rare within the skull. However with greater use of

cerebral angiography many more are being revealed. The writer has seen over 50 in the last three years. Quite a large proportion have a bruit which often can only be heard by very careful auscultation. Rather less than one-third show changes on the plain X-rays which may be obvious or very difficult to detect. The obvious ones show gross enlargement of the diploic vessels, while the less obvious may only show an enlargement of the foramen spinosum on the affected side and minimal vascular changes in the skull vault. Some cases suffer from epilepsy and others have localizing cortical signs. Advanced cases may show mental deterioration.

Pneumography often reveals no abnormality, or perhaps a little dilatation of the lateral ventricle on the affected side, without displacement of the septum lucidum. Until recently such cases were usually diagnosed as cortical atrophy.

There is a very small group which first manifest themselves by subarachnoid haemorrhage. There have previously been no physical signs or symptoms, and the angioma is not suspected until it is seen on the angiogram. Such a case was recently seen in which the angioma lay along the medial surface of the hemisphere, being derived from the pericallosal branch of the anterior cerebral artery.

FIG. 8.—Large posterior temporal lobe tumour displacing Sylvian vessels upwards.

Radiological features of angiomas (arteriovenous aneurysms)

The majority of these tumours are situated on the distribution of the middle cerebral artery (Figs. 4a and 4b), but some lie on the medial surface of the brain and are supplied by the anterior cerebral artery. Both these groups may receive a secondary blood supply from the posterior cerebral artery. These tumours vary very much in their size, shape and depth, but nearly always part of the tumour lies on the surface.

The external carotid artery also takes part in supplying some angiomas, and this feature is usually apparent clinically. Tortuous vessels somewhere over the skull with or without a naevus may point to the lesion, but without any angiogram it is impossible to state how much of the lesion is intracranial.

The following features are usually seen on the angiograms:—

1. The hypertrophied carotid vessels on the affected side.
2. The hypertrophied vessel or vessels directly supplying the angioma.
3. The tortuosity of the supplying vessels.
4. The poor filling of the vessels not supplying

the angioma. For example, if the lesion is supplied by a branch of the middle cerebral artery, the anterior cerebral artery may not fill at all.

5. The huge efferent veins leading to the venous sinuses. These vessels are filled in the arterial phase, a feature not seen in other lesions.

6. The capillaries of the brain are by-passed.

7. The veins are usually seen already to have emptied in the phlebograms.

Treatment

Recently surgeons have been extirpating the more accessible and not too large angiomas. Some of the results are excellent. It is important to perform a post-operative arteriogram in order to see if all the tumour vessels have been removed.

4. THROMBOSIS OF THE INTERNAL CAROTID ARTERY

This condition is less uncommon than is generally supposed, and the writer has seen eight cases demonstrated by arteriography in the last three years. Moniz states that the possibility of a carotid thrombosis should be considered in any obscure case of hemiplegia.

The classical and almost constant site for the thrombosis is about 2 cm. distal to the origin of the

internal carotid artery (Fig. 5). Unlike femoral arterial thrombosis, the condition is often seen in younger patients in the third or fourth decades.

When performing an arteriogram it is very important to show the bifurcation of the carotid artery on the radiographs. This may be difficult with short-necked people. If the bifurcation is not shown it is sometimes wrongly assumed that the injection has been made into the external carotid artery, for that vessel alone is seen on the radiograph.

5. EMBOLUS

Only emboli of the larger arteries can be shown by angiography.

6. INTRACRANIAL HAEMORRHAGE

If intracranial haemorrhage is suspected in a case, an immediate arteriogram may reveal the diagnosis by displacement of vessels and so provide the surgeon with sufficient evidence of localization to enable him to enucleate the clot. This procedure has only been practised recently and insufficient experience has been gained to assess its value.

7. CHRONIC SUBDURAL HAEMATOMA

This is a not uncommon condition and the diagnosis is not always obvious as quite frequently there is no history of trauma. Arteriography provides a pathognomonic picture in the anteroposterior position and shows the middle cerebral vessels displaced medially away from the inner table of the skull (Fig. 6). This is an example of the absolute necessity of taking anteroposterior pictures, for the lesion cannot be shown at all in the lateral view

The Diagnosis of Intracranial Tumours by Angiography

Recently this method has been used more and more as a diagnostic method and for the localization of intracranial tumours. Valuable though the method is, it must not be forgotten that ventriculography is an extremely accurate method and cannot be dispensed with. The two investigations are complementary and it is very important to decide which method should be used first in any given case. In order to save the patient unnecessary investigations, arteriography should precede ventriculography whenever:—(1) a vascular lesion is suspected, (2) a supratentorial lesion is suspected which has been localized either clinically or on the plain X-rays, as for example a pineal shift, a patch of pathological calcification or abnormal vascular channels in the skull.

On the other hand ventriculography should precede angiography when a posterior fossa or mid-brain expanding lesion is suspected.

Although vertebral angiography has been used in the diagnosis of posterior fossa lesions, it cannot compare in accuracy with ventriculography. Lesions in or around the sella may require both carotid angiography and ventriculography. Ventriculography usually provides a more accurate picture of the size of the lesion, while angiography may be helpful in determining the pathology, particularly if the lesion is an aneurysm, and the majority of aneurysms are situated in the region of the sella.

For the most part then, angiography is of particular value in the diagnosis of tumours on or near the surface of the cerebral hemispheres. These tumours may be revealed in two ways. (1) By retaining the contrast substance in their vessels and thus outlining themselves on the angiograms, or (2) by displacement of the anterior or middle cerebral arteries and thus allowing the localization to be deduced by the same methods as one applies for ventriculography. When the vessels in the tumour are shown on the angiogram one can state the size, shape, position and morbid anatomy of the tumour. Thus a more complete picture is obtained than by ventriculography. Unfortunately many tumours do not have sufficiently large vessels to reveal themselves in this way.

Tumours Revealed by Angiography

(a) *Meningioma.* Though not the commonest brain tumour, it is one of the most important to the neurosurgeon in that it is nearly always benign. Furthermore the majority of these tumours are surgically accessible. Whenever a supratentorial meningioma is suspected, angiography is indicated. About 50 per cent. of such tumours cast a shadow on the angiograms. The quality of shadow varies from case to case, but the classical appearance is the so-called 'blush' or 'stain.' The picture is not unlike that of the kidney sometimes seen at pyelography. The organ stands out homogeneously stained, the so-called nephrogram. It is caused by the contrast substance being loaded in the renal capillaries. Similarly the contrast substance becomes loaded in the capillaries of a meningioma. For this reason the 'blush' is sometimes not seen on the radiograph taken in the arterial phase. This is an example where phlebograms are so necessary. In some meningiomas larger vessels are filled and the tumour is revealed in the arteriogram. After experience of angiography in about 60 supratentorial meningiomas, one has the impression that the greater part of the blood supply is via the internal carotid artery, rather than the external, even in cases where the plain X-rays show quite large branches of the middle meningeal artery. Very occasionally the bulk of the blood supply is from the external carotid

tid artery. In such cases it is desirable to puncture the external carotid artery in the neck. This is difficult as the vessel cannot be palpated separately from the internal carotid artery in the neck. One cannot yet say why certain meningiomas give a 'blush' and others do not. It probably depends partly on the blood supply and partly on the situation of the tumour (Fig. 7).

(b) *Glioma*. The pathological classification of the gliomas is difficult and ideas are constantly changing. These tumours show almost every gradation, from the very rapidly growing, highly malignant types, to the very slow growing, almost benign types. There seems to be some relationship between the degree of malignancy and the vascularity. If the two extremes are considered, one finds that most of the very malignant tumours are highly vascular and that a large number of the vessels are very primitive, of large capacity, and often have an arteriovenous angiomatous formation in miniature. At the other end of the scale—the very benign tumours—there is a paucity of blood vessels.

It is reasonable to expect that angiography can be helpful in the more malignant types, and this is in fact true. Various writers have given different figures of the percentage of malignant gliomas whose vessels can be seen on angiography, but most of the figures are about 50 per cent.

The typical picture, sometimes seen only in the arterial phase, sometimes in the venous and sometimes in both, shows a large number of rather short, often slightly tortuous vessels, frequently of relatively large calibre.

In a small proportion of cases an almost pure capillary 'blush' is seen, and the author has misdiagnosed three malignant gliomas as meningiomas. This error is not usually serious as all surgeons operate on meningiomas, but it is possible to see the reverse state of affairs where a meningioma gives an angiographic pattern indistinguishable from a malignant glioma. For this reason the diagnosis of tumour pathology made by angiography should always be accepted with some reserve and histological confirmation, either by a needle biopsy or section of part of the tumour should be attempted in every case.

(c) *Metastasis*. Some intracerebral metastases are sufficiently vascular to be demonstrated angiographically. If more than one tumour is seen on the angiogram the diagnosis is virtually certain. It is sometimes difficult to differentiate the single metastasis from a malignant glioma as the pattern of the blood vessels may be very similar. However metastases tend to be discrete and sometimes show a surrounding marginal vein, while gliomas tend to be more diffuse and it is difficult to delineate their margin on the radiograph.

Most intracerebral metastases come from the bronchus and a chest radiograph, combined with bronchoscopy, is usually sufficient to confirm the diagnosis, though occasionally the primary tumour may be so small as to elude both the radiologist and bronchoscopist.

The Angiographic Diagnosis of Tumours without Pathological Vessels

Angiography is valuable in the localization of many such lesions. Most pneumoencephalographic diagnosis is dependent upon the correct interpretation of the deformity of the ventricular system. Lysholm developed this to such a high degree that he could accurately localize nearly all intracerebral expanding lesions, provided they were of sufficient size to cause some displacement or distortion of the ventricular system.

The same methods can be applied to the main cerebral vessels and their branches. The accuracy of the method is not so great for two reasons: (a) the vessels are less susceptible to displacement than the ventricular system, and (b) the variations of the normal arterial tree are very much greater than the ventricular system, which is very constant. Thus considerable experience with angiography is required before it is possible, in difficult cases, to assert that the pattern is or is not within normal limits.

Having localized a tumour by angiography one cannot accurately predict its pathology if its vessels do not fill on the angiograms. But here one is no worse off than with pneumoencephalography where again the morbid anatomy cannot usually be predicted. The advantage of angiography is that there is quite a considerable chance of predicting the pathology and outlining the exact extent of the tumour, as described above.

Although it has been stated that angiography is a less accurate method of localization than pneumoencephalography, tumours in certain situations nearly always displace main vessels sufficiently to allow a confident diagnosis of localization to be made. For example, subfrontal tumours regularly displace the proximal portion of the anterior cerebral artery upwards. Nearly all temporal tumours displace the middle cerebral artery or its main branches upwards (Fig. 8). Low lateral parietal tumours displace the middle cerebral vessels downwards and occipital tumours displace them forwards. Tumours in other situations are less reliable in causing a characteristic vascular displacement.

In this last section the word 'tumour' is used in its widest sense to include all types of expanding lesion.

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