Magnetic probe for the stereotactic thrombosis of intracranial aneurysms^{1,2}

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The development of a method for the stereotactic thrombosis of intracranial aneurysms should significantly reduce the morbidity and mortality associated with this disease. By removing the necessity for visual exposure of the aneurysm, stereotactic surgery overcomes the problems of brain retraction and manipulation of blood vessels which constitute the major limiting factors in current surgical therapy (McKissock, Richardson, and Walsh, 1962). Moreover, because a stereotactic probe is inserted through a small burr hole, the operation can be performed under local anaesthesia. Consequently, it may be possible to institute stereotactic surgery immediately after the patient is admitted to the hospital and thereby remove the risk of recurrent haemorrhage which accompanies the prevailing practice of delayed treatment. The techniques of stereotaxis have been adequately developed to allow accurate placing of a probe against an intracranial aneurysm, but an effective means of thrombosing aneurysms has not been available.

We have previously reported a technique for creating a focal intra-arterial thrombus by the attraction of intravascular iron powder to an extravascular magnet (Alksne and Fingerhut, 1965; Alksne, Fingerhut, and Rand, 1966a and b; Fingerhut and Alksne, 1966). On the basis of our laboratory experiments, we have developed a magnetic stereotactic probe for clinical use which is inexpensive, easy to use, and effective. The construction and use of this probe is the subject of this report.

SPECIFICATIONS

Structurally, the most important consideration in designing the magnetic probe was to reduce the probe's size to the minimum while maintaining its strength at

the maximum. Functionally, the probe needed to provide for the injection of an iron suspension directly into the aneurysm. In addition, the necessity for three to five days of chronic implantation required the magnetic component to be detachable.

SIZE We have arbitrarily selected $\frac{1}{4}$ inch as the maximum allowable diameter for the probe although it is possible that a larger probe could be tolerated in certain areas of the brain. Because the strength of a magnet varies directly with its total mass, we have used magnetic material for the entire intracranial portion of the probe. The length of the magnet, therefore, depends on the distance from aneurysm to scalp.

DIRECT INJECTION We demonstrated in animal experiments that direct injection of iron suspension was essential if aneurysms of 1 cm. or more in diameter were to be totally thrombosed. Furthermore, in two patients on whom we operated before the development of the direct injection technique, transient neurological deficits developed when an iron suspension was introduced into the carotid artery. We have therefore concluded that all of the iron in all cases should be injected directly into the aneurysm using a needle which passes through the centre of the probe.

DETACHABILITY Laboratory experiments indicate that the magnet should be in contact with the metallic thrombus for three to five days to ensure that the clot will not be dislodged. During this time early organization occurs. The magnet, therefore, must be detachable so that it can be disconnected from the extracranial stereotactic device and fixed rigidly to the skull. The varying distance from aneurysm to skull dictates that the detachable magnets be available in lengths from $1\frac{1}{2}$ to 3 in.

MATERIALS

After pilot experiments, we selected Alnico 5 permanent magnets as the material of choice. The magnets are best described by stating their dimensions rather than their strength because the common unit of physical measure, the gauss, does not adequately indicate the factor which we consider most important. The gauss reading of a magnetic material, which represents the number of lines

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²Constructed by Trenton H. Wells, Mechanical Developments Company, Southgate, California.

FIG. 1. The magnetic stereotactic probe is shown disassembled. Above is the magnet. Note that it is blunted on one end for ease of insertion and threaded on the other for attachment to the non-magnetic extension which is also shown.

The special needle can be seen to be a composite of a short 27 gauge needle soldered into an 8 in. 22 gauge needle. When the probe is assembled, the needle can be inserted so that the 27 gauge portion protrudes beyond the end of the magnet.

of force per square centimetre, is greatest at the pole of the magnet. For creating metallic thrombi, however, the field strength 1 cm. beyond the magnet is more important. The distant field can be enhanced by increasing the length of a bar magnet although the gauss reading at the pole remains the same. This apparent inconsistency is explained by the fact that the lines of force are projected farther in space by the longer magnet even though they are not increased in number (Parker and Studders, 1962).

Cylindrical Alnico 5 permanent bar magnets $\frac{1}{4}$ in. in diameter and $1\frac{1}{2}$ to 3 in. in length form the basic unit of the probe. A conduit inserted in a slot down the core of the magnet allows a 22 gauge needle to be passed the full length of the probe. One end of the magnet is blunted for ease of insertion. The other end is threaded for attachment to a non-magnetic extension which adapts to the stereotactic device (Fig. 1). The magnets should be remagnetized before each use to ensure maximum strength.

The injection needles are constructed by inserting a $\frac{5}{8}$ in. segment of 27 gauge needle stock into a blunt, 8 in. 22 gauge needle (Fig. 1). Needles fabricated from ferromagnetic material facilitate the injection of iron suspension through the magnetic field by shielding the lumen. Otherwise, the system tends to become a magnetic filter and retain the iron within the needle.

PROCEDURE

The location of the aneurysm is determined by angiography. The patient is placed in the stereotactic device¹ with the dome of the aneurysm as the target point. The

¹We have used the Rand-Wells stereotactic instrument.

FIG. 2. Lateral carotid angiogram showing the magnetic probe abutting an anterior communicating artery aneurysm. The probe has been inserted stereotactically through a frontal burr hole.

site for the burr hole is selected to allow the probe to pass through the least important brain area.

The magnetic probe is inserted under x-ray control until the aneurysm is contacted (Fig. 2). The needle is then inserted through the magnetic probe until it projects 2 to 4 mm. into the aneurysm. Immediate injection of iron suspension is begun.

To facilitate slow, continuous injection, we have used an automatic injector² set at a flow rate of 0.5 ml. per minute. Our iron for injection consists of 1 g. of type SF Carbonyl iron powder³ in 10 ml. of 25% human serum albumin.⁴ The suspension is mixed in the syringe and tubing every two minutes to prevent settling. This is accomplished by placing a three-way stopcock at the junction between tubing and needle which allows the entire contents to be agitated by barbotage.

Because the iron microspheres are radio-opaque, the development of the metallic thrombus can be followed on plain radiographs (Fig. 3). The total clot is about 25% larger than the iron bolus due to natural surrounding thrombus. Between 5 and 10 ml. of iron suspension must be injected for complete obliteration of an aneurysm 1 cm. in diameter. Repeat arteriograms must be performed to determine the actual size of the thrombus but it is important that the total amount of contrast agent used is kept to a minimum.

After the aneurysm is obliterated, the magnet is detached from the stereotactic device and fixed to the skull so that it remains abutting the aneurysm (Fig. 3). Two screws are placed at the margin of the burr hole. The screw heads and the threaded end of the magnet are then encased in cranioplasty acrylic. As a result, the magnet is fixed rigidly to the skull but can be easily withdrawn at any time by removal of the screws.

²Supplied by Trenton H. Wells, Mechanical Developments Co., Southgate, Calif.

³Supplied by General Aniline and Fom Co., 435 Hudson St., New York, N.Y.

⁴Supplied by Cutter Laboratories, Berkeley, Calif.

FIG. 3. Lateral radiograph of the skull taken one day post-operatively on the same patient whose angiogram is shown in Figure 2. Two probes were necessary to obtain complete thrombosis of the aneurysm. Note that the magnets now end flush with the skull. The screws can be seen which, together with the threaded ends of the magnets, are encased in acrylic to create a rigid support. The entire probe is a permanent magnet.

The radio-opaque metallic thrombus can be seen in the aneurysm. Note that the iron does not completely fill the aneurysm. Nevertheless, repeat angiography failed to fill the aneurysm indicating that the remainder was filled with radiolucent natural thrombus.

FIG. 5. Lateral radiograph of the head, same patient as in Figs. 2 and 3, taken six weeks after aneurysm thrombosis. The magnets were removed on the sixth postoperative day. Note that the metallic thrombus is essentially unchanged.

FIG. 4. Drawing to show the results of our experiments with laboratory models to determine the optimal magnet orientation. Comparing A and B one can see that an aneurysm is more readily filled with iron when both north poles are approximated if the magnets approach each other at an angle about 90° . Comparing C and D it is apparent that the aneurysm is much more easily bridged with iron when a north and south pole are approximated if the magnets approach at 180° .

FIG. 4.

DISCUSSION

Our clinical experience with the magnetic stereotactic probe is not yet sufficient to make any statistically reliable statements about efficacy, morbidity, or mortality. Nevertheless, the probe has been successful for creating a thrombus in every instance attempted, including both laboratory and clinical experience. In our initial clinical cases we experienced difficulty in completely thrombosing large aneurysms. Subsequently, we have found that the simultaneous insertion of two probes through separate burr holes appears to overcome this limitation. We have concluded that any aneurysms greater than 1 cm. in any dimension will require more than one magnetic probe.

When two probes are required, our experiments with laboratory models indicate that the polar orientation of the magnets should be dependent on their angle of intersection (Fig. 4). The magnetic field within the aneurysm will be strongest when like poles are approximated if the magnets approach each other at an angle of less than 180° . If the magnets approach each other at 180° , however, the magnetic field will be strongest if unlike poles are approximated.

Our laboratory experience indicates that a metallic thrombus, once produced, yields permanent occlusion. The two clinical cases available for follow-up support this finding (Fig. 5). It will, of course, be important to have long-term studies on numerous cases before a final conclusion can be drawn.

In our seven cases we have experienced no difficulty in approaching the aneurysm stereotactically with the magnetic probe or penetrating the aneurysmal fundus with the special needle. We have always begun the injection of iron suspension simultaneously with penetration of the aneurysm so that any tendency for leakage will be immediately arrested by the metallic thrombus.

In an attempt to increase the magnetic field across the aneurysm we are continuing experiments with

electromagnets and with permanent magnets using a larger mass external to the head. The major disadvantage of both of these systems is that they are cumbersome for prolonged magnet contact. In an attempt to obtain better distribution of the magnetic field, we are also experimenting with an auxiliary transnasal magnet placed in the sphenoid sinus.

At the present time, the detachable permanent magnet, adapted for needle insertion into the aneurysm, is the most effective means of creating stereotactic metallic thrombosis. Utilizing a standard technique, we shall attempt to obtain a series of cases to determine whether aneurysm thrombosis with this probe provides a superior method of therapy.

SUMMARY

The technique of magnetically controlled metallic thrombosis is briefly reviewed. Using Alnico 5 permanent magnets, magnetic probes have been constructed for use in the stereotactic thrombosis of intracranial aneurysms. The probes are described and their application to the clinical situation is discussed.

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