Magnetically Controlled Focal Intravascular Thrombosis in Dogs*

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The mortality and morbidity resulting from ruptured intracranial aneurysms serves as an impetus to the surgeon to develop improved methods of therapy. Although it might seem logical to employ early craniotomy in the treatment of the patient with a ruptured aneurysm and thereby remove the risk of recurrent hemorrhage, numerous authors have demonstrated the high operative mortality of such a procedure.5–11 One cause of this mortality is the vasospasm and subsequent infarction which follows surgical manipulation of the already irritated blood vessels. It is possible, however, that a stereotaxic method of treatment which would produce immediate thrombosis of the aneurysm but not require manipulation and retraction of the traumatized brain might significantly improve the aneurysm patient's prognosis.

After experimenting with various means of producing focal intravascular thrombosis, Mullan et al. concluded that the passage of a direct current through a needle electrode was the most effective.14 He has utilized this technique stereotaxically for the treatment of intracranial aneurysms. Unfortunately, however, the thrombi so produced were not permanent.15 In our laboratory we have developed a new method for inducing focal intravascular thrombosis which results in a well-organized permanent occlusion.

Meyers et al. showed that it was possible to use an extra corporeal magnetic field to control the position of microspheres of iron injected into the vascular system.12 Because of the large surface area offered by an accumulation of the iron microspheres, it seemed likely to us that blood coagulation would occur if the material were held in place more than a brief period of time. Therefore, we have modified Meyers' technique by placing a small magnet directly against the adventitia of the artery and holding it in place until the focal accumulation of iron within the vessel stimulates thrombosis.1,2

Materials and Methods

Carbonyl iron microspheres ranging in size from 1 to 5 μ in diameter have been used.1 Carbonyl iron is an extremely pure form of iron which is prepared by the vaporization and condensation of liquid iron pentacarbonyl. The microspheres are supplied in powdered form and are stored in gaseous nitrogen to prevent oxidation.

Initially, the iron to be injected was suspended in 25% polyvinyl pyrrolidone. Recently, however, 20% dextran† in normal saline solution has been substituted because this solution was found to be less irritating to the vascular bed. Concentrated human albumin has been used in the human cases. One gram of carbonyl iron is suspended in 20 cc. of solution to form a mixture; this must be stirred frequently to prevent the iron settling.

Cylindrical Alnico 5 permanent bar magnets 3/8 in. in diameter and 1 in. in length were adequate for the first experiments on small dogs. In larger dogs where greater magnetic field strength was required, magnets 1/4 in. in diameter and 3 in. in length were necessary. Because we have considered the 1/4 in. diameter the maximum probe size for human stereotaxic insertion, we limited all of our magnets to that diameter. We checked the field strength of the magnet with an Annis Magnetometer before each use and remagnetized if a full scale reading was not obtained at 3 cm.

To inject iron suspension into the aneurysm directly, a special magnet-needle complex was developed.‡ A 5-in. Alnico 5 magnet was slotted longitudinally in order to accommodate a 20-

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† Supplied as Carbonyl Iron Powder, type S.F. by General Analine and Dye Company.
‡ Supplied by Abbott Laboratories.
§ Constructed by Trent Wells, Mechanical Development Company, Southgate, California.
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FrG. 1. Arteriogram on a dog performed through a catheter inserted in the right femoral artery and passed retrograde into the abdominal aorta. The hemostat adjacent to the left femoral artery is at the level of the inguinal ligament and indicates the site where the artery can be ligated to create an aneurysmal pouch. In the experiments where the femoral artery itself was thrombosed, the magnet was also placed at this point. (In subsequent figures only the segment of the left femoral artery indicated by the hemostat is shown.)

gauge needle. The needle passes concentrically the full length of the magnet and tapers to 30 gauge where it projects beyond the tip for penetration of the aneurysm. A refinement of this system has been engineered for the human stereotaxic probe.3

The animal experiments were performed on dogs anesthetized with intravenous barbiturate. The femoral arteries were exposed bilaterally from the inguinal ligament to the mid thigh. A catheter was inserted into one femoral artery retrograde into the abdominal aorta. The other femoral artery was used for the experiments (Fig. 1). Using this experimental preparation, we have performed a series of experiments to study magnetically controlled intravascular thrombosis.

1. Thrombosis of femoral artery by injecting iron suspension into abdominal aorta. For these experiments an Alnico 5 magnet was applied directly against the adventitia of the femoral artery 3 cm. beyond the inguinal ligament. After an arteriogram was performed by injecting 8 cc. of Conray* through the aortic catheter to demonstrate radiographically the patency of the vessel and the position of the magnet, carbonyl iron suspension was injected into the abdominal aorta. Repeat x-rays, both plain films and arteriograms, were taken after injection of every 10 cc. of suspension until x-ray verification of complete occlusion of the vessel was obtained. Because the metallic thrombus is radio-opaque, it can be seen on the plain x-rays as well as on the arteriogram.

2. Thrombosis of artificial aneurysmal pouch by injecting iron suspension into the aorta. Artificial aneurysmal pouches were created by ligation of the femoral artery 5 mm. beyond its first main branch. The magnet was applied to the adventitia of the pouch. After arteriographic visualization of the “aneurysm,” iron suspension was injected through the aortic catheter and the development of the metallic thrombus was visualized radio graphically.

3. Thrombosis of an artificial aneurysmal pouch by direct injection of iron into the fundus. Artificial “aneurysms” 1 cm. in length were formed by the same technique. After the magnet was positioned abutting the adventitia, the dome of the pouch was penetrated with the needle designed for this purpose. Iron suspension was injected directly into the aneurysm in 1 cc. increments until arteriograms demonstrated that the pouch no longer filled.

4. Thrombosis of the femoral artery by direct injection of iron suspension into the artery at the point of magnet contact. The experimental procedure was the same as in the first series except that the magnet with the concentric needle was used. All of the iron, therefore, was injected directly into the femoral vessel at the point of magnet contact. Arteriograms were performed after injection of each cc. of iron suspension until the artery was completely occluded.

5. Determining the duration of magnet contact necessary in order to create a permanent thrombus. Thrombosis was produced by one of the techniques already described. The magnets were then fixed in place for intervals ranging from 5 minutes to 7 days. After the magnet was removed, repeat x-rays were taken to establish the persistence of the thrombus.

6. Histologic study of metallic thrombi. Thrombosis was produced by one of the methods already described. Specimens were removed at specified times from 24 hours to 6 months after thrombosis and fixed in formalin. Paraffin sections were stained with H. & E. for light microscope examination.

Results

Metallic thrombi have been produced in 70 dogs in our laboratory at Harbor General

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