Iron-acrylic compound for stereotaxic aneurysm thrombosis

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A new iron-acrylic compound has been developed for stereotaxic thrombosis of intracranial aneurysms. The compound polymerizes rapidly, does not fragment, and is nontoxic. It has been used in a series of experimental animals and in initial clinical cases with good results. The use of this material simplifies and increases the safety of stereotaxic aneurysm treatment.

KEY WORDS • intracranial aneurysm • stereotaxic thrombosis • iron-acrylic compound

METHOD for stereotaxic thrombosis of intracranial aneurysms based on the attraction of intravascular iron to an extravascular magnet was originally described in 1965 and has been modified only slightly since.1 The iron used in this technique was carbonyl iron powder suspended in human serum albumin. After injection, the iron powder was held in the aneurysm by the magnetic field of the stereotaxic probe and the albumin solution was carried away by the circulating blood. The magnet was fixed to the skull and left in place for 5 days to allow time for the blood clot, which formed about the iron, to organize sufficiently to prevent subsequent embolization.

Analysis of the first 41 clinical cases treated by this technique revealed that in several instances in which thrombosis of large aneurysms was attempted, a portion of the "metallic thrombus" fragmented to become an embolus and produced significant neurological deficits. In addition, the need to leave the magnet in place for 5 days was cumbersome and required that the patient be returned to the operating room for its removal. We therefore worked on the development of an iron compound for intravascular injection that would not fragment and would solidify rapidly. Preliminary experiments in our laboratory indicated that silicone compounds were not adequate because blood interferes with rapid polymerization. Subsequent experiments indicate that an iron-acrylic mixture is nonfragmenting, polymerizes rapidly in blood at body temperature, is safe for intravascular injection, and can be used for stereotaxic technique.

Materials and Methods

Carbonyl iron powder* identical to that used previously is the basic ingredient and provides the ferromagnetic properties of the compound we developed. Before it was mixed with the other components the iron was sterilized by cobalt irradiation. The iron powder was suspended in a liquid methyl

*Type S.F. carbonyl iron powder was obtained from General Aniline and Folm Co., 435 Hudson Street, New York, New York.
methacrylate monomer.† The polymerization of the monomer into a solid is catalyzed by methyl methacrylate-n-butyl methacrylate polymer.†

A series of experiments have been performed to determine the optimum mixture of the three components that can be injected through a 7-inch No. 20 needle, will harden at body temperature within 1 hour, and maintain maximum ferromagnetic properties. Our goal was to use the maximum amount of iron and the minimum amount of methyl methacrylate. These experiments were performed by trial and error with varying amounts of methyl methacrylate added to 30 gm of carbonyl iron.

After the optimum proportions of iron and acrylic were determined, the compound was tested for its attraction to a magnetic field and compared with the original iron-albumin mixture. These tests were performed by injecting the two compounds into artificial glass aneurysms 1 cm in diameter through which water was being circulated by a pulsating pump at 100 cc/min.

When the magnetic properties of the iron-acrylic mixture were demonstrated to be adequate, the compound was injected into arteries of 20 animals to test for possible toxicity. All experiments were performed on dogs under general barbiturate anesthesia.

The experiments were designed to test both the systemic toxicity of the compound and the focal vascular reaction to the material.

To evaluate arterial toxicity, the iron-acrylic compound was injected into the surgically exposed carotid artery in the neck and held in place by a magnetic field until polymerization occurred. The resultant iron-acrylic bolus produced a carotid occlusion, and was left in place for periods varying from 4 weeks to 4 months. The carotid artery was then removed and examined histologically for evidence of vessel-wall necrosis or inflammatory reaction. To evaluate systemic reaction, blood pressure, pulse rates, and temperature were monitored during injection of the iron-acrylic compound.

Results

Optimum Iron-Acrylic Mixture

Using 30 gm of carbonyl iron as a starting point we added increasing amounts of liquid methyl methacrylate monomer until a suspension was produced that could be injected through a 7-inch No. 20 needle‡ (Fig. 1). This occurred at 7 cc, but the resultant suspension stiffened sufficiently within a magnetic field to make injection unreliable. We found that 30 gm carbonyl iron in 12 cc of monomer was the optimum mixture.

For ease of handling under sterile conditions the powdered catalyst was measured by volume in a graduate instead of by weight.

†Methyl methacrylate monomer and methyl methacrylate-n-butyl methacrylate polymer manufactured by L. D. Caulk Co., Milford, Delaware, and distributed as “Cranioplastic Kit” by Codman and Shurtleff, Inc., Randolph, Massachusetts.

‡Needle assembly manufactured by Trent Wells Instrument Co., 8120 Otis Street, South Gate, California.
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The addition of increasing amounts of catalyst to the mixture of 30 gm carbonyl iron suspended in 12 cc liquid methacrylate monomer revealed that polymerization was incomplete with less than 3 cc of powder. The addition of more than 6 cc of catalyst produced polymerization in less than 30 minutes and was therefore not acceptable. The desired polymerization was reliably produced with 5 cc of the powdered catalyst.

The optimum mixture of iron and acrylic, therefore, is 30 gm carbonyl iron, 12 cc liquid methyl methacrylate, and 5 cc powdered methyl methacrylate.

Attraction to a Magnetic Field

Experiments comparing the iron-acrylic compound with the iron albumin used previously reveal that in a moving aqueous medium an Alnico 5 magnet ¼ inch in diameter will hold a 1.0 cm long iron-acrylic bolus as compared to a 0.6 cm long clump of carbonyl iron particles. The new material, therefore, in addition to being nonfragmenting and rapidly polymerizing, has superior magnetic properties.

Toxicity

The intracarotid injection of the iron-acrylic compound produced no change in blood pressure, pulse, temperature, or respiration of any of the 20 animals injected.

Histological examination of sections taken from canine carotid arteries 4 weeks to 4 months after vascular occlusion with an iron-acrylic bolus revealed the expected loss of endothelium and subendothelial proliferation of granulation tissue containing hemosiderin-laden macrophages. There was no inflammatory reaction, no necrosis, and no alteration of the media (Fig. 2).

Clinical Application

Radiographs from a patient with an aneurysm of the anterior communicating artery are shown in Fig. 3. This patient was considered a poor candidate for open craniotomy because of a recent myocardial infarct. The aneurysm was thrombosed stereotaxically with the iron-acrylic compound. He was discharged from the hospital 5 days after stereotaxic thrombosis without neurological deficit and has returned to work.

Discussion

A mixture of 30 gm carbonyl iron, 12 cc liquid methyl methacrylate monomer, and 5 cc powdered catalyst appears to be optimum for stereotaxic magnetic thrombosis of aneurysms. This compound polymerizes at body temperature to a nonfragmenting solid in 30 to 60 minutes, and can be held in greater volume by the magnetic probe than the previously used iron in albumin suspension.

Methyl methacrylate has been used for many years by neurosurgeons for crani-
oplasty without apparent toxicity. Recent reports, however, have indicated occasional transient periods of hypotension when a similar material is used to secure artificial hip prostheses. Our experiments indicate that the small volume of material used for aneurysm occlusion should not be expected to cause any systemic reaction. In addition, polymerization within the vascular system produces neither acute nor chronic inflammation.

In order to use this new compound clinically one minor modification in technique is required. The previous injection system must be replaced by a steel syringe that will create sufficient pressure to push the viscous material down a No. 20 needle (Fig. 2). The initiation of the polymerization process can be delayed indefinitely if desired by keeping the iron-acrylic mixture cold before use, but the mixture should be allowed to return to

FIG. 3. Upper Left: Preoperative angiogram. Upper Right: Postoperative skull x-ray film showing the iron-acrylic bolus. Lower: Postoperative plain angiogram (left) and subtraction angiogram (right) revealing complete occlusion of the aneurysm with normal patency of neighboring vessels.
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room temperature for 10 minutes before intra-aneurysmal injection is begun. During this time, sufficient cross linkage will occur to prevent separation of the iron from the acrylic when it enters the magnetic field.

References


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