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Preliminary Experience with an Electrolytically Detachable Fibered Coil

Van V. Halbach, Christopher F. Dowd, Randall T. Higashida, Peter A. Balousek, and Ross W. Urwin

Summary: We report our preliminary experience with a new embolic device, the electrolytically detachable fibered coil, in the treatment of four patients with high-flow arteriovenous shunting.

The tremendous advances in the ability to safely treat intracranial vascular disease has largely paralleled the development of variable stiffness microcatheters, which can provide access to distal cerebral vessels, and the newer embolic agents, which can be delivered through them. The variable stiffness microcatheters introduced in the mid-1980s permit the precise delivery of a wide variety of embolic agents to the cerebral circulation. We report our preliminary experience with a new embolic device, the electrolytically detachable fibered coil, in four patients with a variety of neurovascular disorders.

Methods

Description of Coils and Delivery System

The coils are made of platinum, have a spiral design with a decreasing radius, and contain Dacron fibers interspersed throughout their length. The new placement of the Dacron fibers on the electrolytically detachable fibered coil, as compared with the pushable fibered coil, was done to prevent fiber migration and reduce friction. The fibered platinum coil is attached to an insulated stainless steel delivery coil with a small gap at the junction between the coil and the delivery wire. The insulation on the delivery wire is Teflon-coated. The coils are manufactured in a variety of sizes, ranging from one with a 3-mm circular memory, which spirals down to a 2-mm helical size, to one with a 6-mm circular memory, which spirals down to 2 mm. The currently available sizes, including circular memory and total length, are summarized in the Table. Figure 1 is a photograph of the coil.

A total of 44 electrolytically detachable fibered coils (Guglielmi detachable coils [GDCs] and Vortex coils; Target Therapeutics, Fremont, Calif) were delivered through variable stiffness microcatheters (Target Therapeutics; Cordis Endovascular Systems, Miami Lakes, Fla) in an attempt to treat a variety of high-flow neurovascular disorders. Although one patient was treated with coils delivered through a single prototype braided microcatheter called the Turbo Tracker (Target Therapeutics), the rest were treated with a similar braided microcatheter manufactured by Cordis.

During embolization, the coil is immediately introduced into a sidearm perfusion device; the outer Teflon introduction sleeve is then removed, and the coil is gently pushed to the desired position. We found that several of the largest coils produced moderate to high friction during negotiation of a tight turn in the distal section of the microcatheter and had to be advanced and delivered by injection of heparinized saline into the sidearm, which propelled the fibered coil to the end of the catheter. We delivered the remaining coils by gently pushing on the delivery wire. Once the coil was precisely delivered to the desired site, it was detached by electrolysis, using the same power supply as the GDC system.

In case 1, 20 electrolytically detachable coils were used alone after three prior attempts to close bilateral direct carotid cavernous fistulas with other embolic agents at another institution had failed. In case 2, a total of 16 electrolytically detachable fibered coils were used in conjunction with a single GDC. This GDC device was chosen only because of the unavailability of smaller fibered electrolytically detachable coils at the time. In the remaining two cases, the new embolic device was used in conjunction with GDCs (one case) and fibered pushable coils (Vortex coils and Tornado coils, Cook Inc, Bloomington, Ill).

All four patients had systemic anticoagulation during the procedure with a 70 U/kg bolus and 35 U/hr for the duration of the procedure. The effects of the heparin were monitored with an activated clotting time (Hemochron, International Technidyne: Edison, NJ). At the termination of the procedure, the heparin was reversed with protamine sulfate except in patient 2, who received systemic heparinization for 24 hours.

Cases

Case 1.—A 22-year-old man was involved in a motor vehicle accident that resulted in a basal skull fracture. Over the ensuing days, chemosis and exophthalmos developed and he was discovered to have bilateral direct carotid cavernous fistulas. The fistulas were treated at an outside institution on three separate occasions with detachable balloon therapy on the right side, failed detachable balloon therapy on the left, and transvenous placement of fibered coils on the left, all of which were unsuccessful in completely closing either fistula. The patient's signs and symptoms progressed, with rapidly increasing exophthalmos and rapidly declining vision.

At the time of transfer to our institution, the patient had lost all light perception in the right eye and had finger counting only in the left. In addition, he had a complete ophthalmoplegia on the left, and intraocular pressure on medical therapy was 55 mm. There was massive lid edema, chemosis, and exophthalmos, with funduscopic evidence of a central retinal artery and vein occlusion on the right.

Emergent endovascular therapy was undertaken. The prior attempts at treatment had occluded the transvenous approach on the left (Fig 2A and B). Through a prototype braided Teflon-lined microcatheter (Turbo Tracker), placed from a

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Electrolytically detachable fibered coils: currently available sizes

Initial (distal) Coil Diameter, mm	Proximal Coil Diameter, mm	Total Length, mm
2	6	115
2	5	80
2	4	50
2	3	30

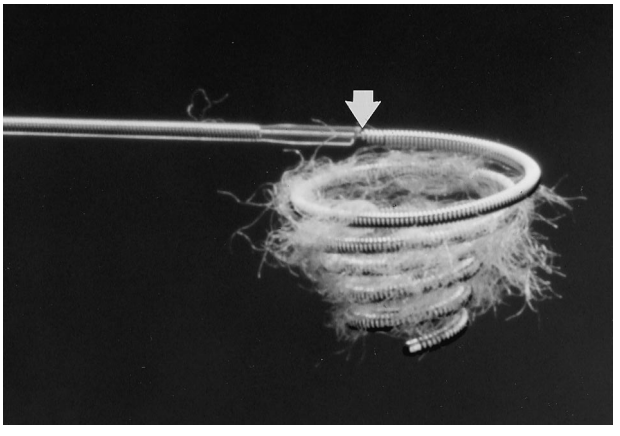

FIG 1. Photograph of a coil shows the electrolytic detachment zone (*arrow*) joining the insulated delivery wire to the fibered spiral coil.

transarterial route, a series of electrolytically detachable fibered coils were delivered into both cavernous sinuses adjacent to the fistula site. In several instances, the fibered coils initially herniated through the fistula site into the parent vessel during delivery; however, all the coils were successfully repositioned back into the cavernous sinus and detached. A total of four coils were placed into the left cavernous sinus, resulting in complete closure of the fistula site (Fig 2C). The larger right cavernous sinus was again treated via a transarterial approach with 16 detachable fibered coils, which also resulted in complete closure of the fistula (Fig 2D). Clinically, the patient had dramatic and rapid improvement of the chemosis and exophthalmos, intraocular pressure returned to normal, and vision in the left eye improved, as did the ocular motility.

Case 2.—A 25-year-old right-handed man experienced increasing seizure activity. An MR examination (Fig 3A) revealed a large vascular structure in the left cerebral hemisphere. A CT scan showed heavy calcifications involving the wall of the varix, and an arteriogram (Fig 3B) showed a single-hole fistula connecting the left angular artery to the giant varix with a tight loop in the proximal ascending cervical internal carotid artery.

A microcatheter was navigated to the fistula site, but when the guidewire was removed, the microcatheter recoiled several centimeters proximally. Similarly, when a coil pusher or guidewire was introduced through the catheter, both straightened out the cervical loop in the proximal carotid artery, producing distal displacement of the microcatheter by several centimeters (Fig 3C). Because of the wide excursions induced by the coil pusher and guidewire and the presence of many normal branches in the proximal angular artery, it was considered too risky to deliver pushable fibered coils. The rapid flow also made delivery of standard GDCs less desirable, because their softness would allow for distal migration into the fistula. The catheter was left in a proximal position and a series of fibered detachable coils were delivered through the microcatheter and then pushed into the fistula site and detached (Fig 3C). Nine coils were delivered in this manner, resulting in complete closure of the fistula (Fig 3D and E). To prevent retrograde thrombosis in the proximal feeding angular artery and downstream clotting in draining veins (which also drained the adjacent parietal lobe), the patient was given anticoagulants for 24 hours. A follow-up arteriogram revealed a trickle of flow through the fistula, which was treated with an additional seven detachable fibered coils and one small GDC. A follow-up CT scan showed thrombosis of the varix, and a follow-up arteriogram at 1 month confirmed complete closure. The patient remains neurologically intact without symptoms.

Discussion

The earliest attempts to embolize high-flow neurovascular disorders involved the nonselective introduction of embolic agents into the proximal internal carotid artery by either surgical exposure or large-bore catheters in the proximal internal or common carotid artery (1). Muscle embolization of direct carotid cavernous fistulas (2) and methacrylate and silicone sphere embolization had variable success rates, which were determined by the vascular anatomy, degree of steal or shunt produced by the fistula or arteriovenous malformation, altered hemodynamics, and, to some degree, luck. The direct surgical approach, with exposure of the cavernous sinus, was previously performed with the introduction of fine copper wire into the cavernous sinus in an attempt to thrombose abnormal connections, such as direct carotid cavernous fistulas (3, 4). Radiologic guidance was not used during such surgeries, and, on occasion, the wire mesh would herniate through the rent in the carotid artery and produce unwanted parent artery occlusion or a distal embolus. These pioneering techniques were supplanted with the introduction of detachable silicone and latex balloons and calibrated leak balloons.

Detachable balloons have proved to be an ideal embolic agent for the treatment of direct carotid cavernous fistulas (5–10) and vertebral fistulas (11), and have proved to be effective in parent artery sacrifice for cavernous and intracranial aneurysms (12–14). Detachable balloons have also been used successfully for the treatment of intracranial direct arteriovenous fistulas (15) and preoperatively for the control of deep feeding vessels to arteriovenous malformations (16). Detachable balloons, however, have inherent drawbacks in treating intracerebral high-flow states. The traction used to detach balloons in distal locations can on occasion displace the balloon and produce undesirable stresses on the often tortuous feeding vessels. Since detachable balloons cannot successfully treat all carotid cavernous and vertebral fistulas, transvenous and transarterial coil embolization can be useful in selected cases (17, 18). In rare instances in which the usual transarterial routes are unavailable (18, 19–21) or the patient has a collagen deficiency, such as in Ehlers-Danlos disease (22), fibered coils have emerged as the treatment of choice.

Development of the variable stiffness microcatheter in the mid-1980s permitted treatment of a variety of neurovascular disorders with an assortment of embolic agents. The earliest platinum coil embolic agents our group used were the cut ends of micro-

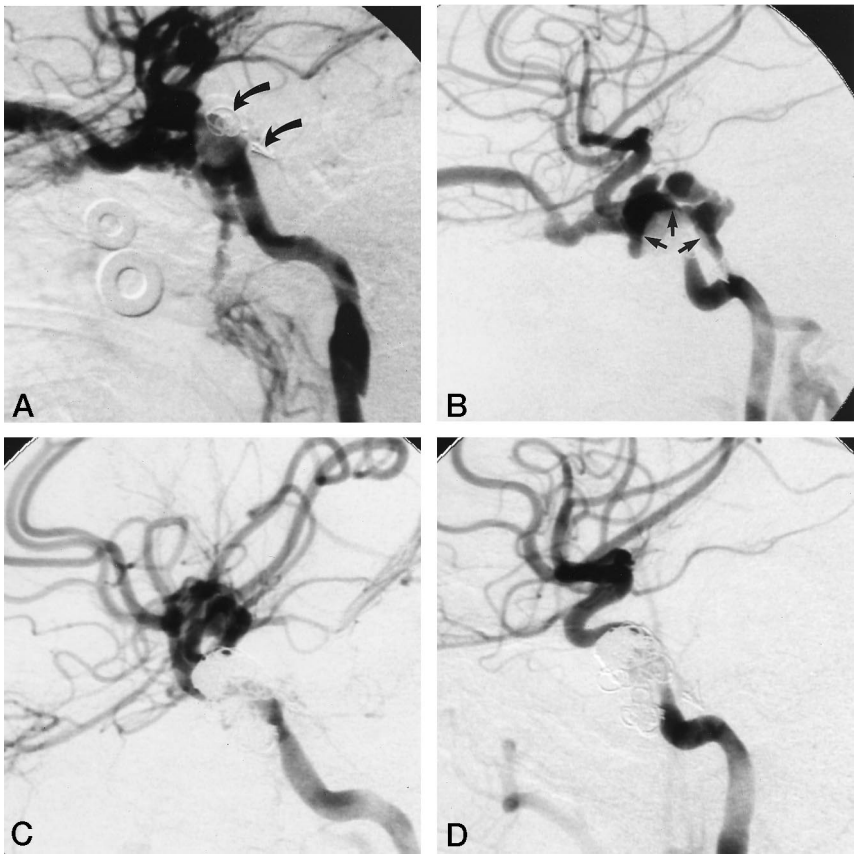

FIG 2. Left (*A*) and right (*B*) internal carotid artery injections, lateral projection, after embolization with transvenous coils (*curved arrows*) and detachable balloons (*straight arrows*), show persistent bilateral direct carotid cavernous fistulas.

Left (*C*) and right (*D*) internal carotid injections, lateral projection, after treatment with electrolytically detachable fibered coils show complete occlusion of the fistulas.

guidewires (23), which, while effective in many cases, proved less than ideal. Shortly thereafter, the platinum coil was enhanced with the addition of Dacron fibers and complex helical, flower, and, more recently, spiral shapes, which have greatly improved their thrombogenicity. Until now, however, these coils were all delivered via a guidewire or coil pusher. These devices have greatly improved the treatment of a wide variety of vascular disorders, including dural fistulas (18, 24, 25), arteriovenous malformations, and even intracranial aneurysms (26, 27). Nevertheless, deployment of these pushable, fibered, long platinum coils through soft, variable stiffness microcatheters has had inherent drawbacks. Coil migration or recoil of the microcatheter during coil delivery would on occasion deposit the device in an unwanted and sometimes catastrophic position. In a specialty in which millimeters can mean the difference between success and failure, such occurrences have been accepted as unavoidable. The development of snare and retrieval devices (28–30) was largely a response to the shortcomings of pushable coils.

In the early 1990s, Guglielmi and his colleagues introduced a novel embolic agent, the electrolytically detachable coil. This device was designed to treat saccular intracranial aneurysms that were unresponsive to surgery or that were of high surgical risk (31, 32). The device is a nonfibered, extremely soft, uncoated platinum coil that is affixed to a stainless steel delivery wire. After being positioned within the aneurysmal sac, it is detached by electrolysis. If sufficient coil is delivered into the saccular aneurysm, thrombosis will occur. This device has been shown to be highly effective in the treatment of intracranial aneurysms, and was approved for such use by the Food and Drug Administration in September 1995. It has also proved to be highly effective in producing thrombosis in the relatively slow-flow states seen in narrow-necked aneurysms; and scattered reports have documented its success in treating fusiform aneurysms or high-flow fistulas (33–36). As clinical experience with this device has grown, however, there have been treatment failures in which the bare, nonfibered coils failed to produce complete thrombosis at the placement site. Preliminary studies with animal models have been undertaken to evaluate various coatings that may increase the thrombogenicity of the bare platinum coil (37). We have routinely adopted a treatment strategy that often involves placement of the GDC within a dissecting aneurysm or fusiform aneurysm coupled with fibered pushable coils proximal to this to ensure thrombosis. This combination is suitable in many situations but has the risk of inaccurate deposition of the pushable coils previously mentioned.

The advent of the electrolytically detachable fibered coil combines the accuracy in delivery achieved with the GDC and the thrombogenicity of the fibered pushable coil. These coils are suitable for positioning in high-flow states, in which the softer GDCs can be displaced by flow, and in selected parent arteries, in which accuracy is so crucial to success. This stiffer coil

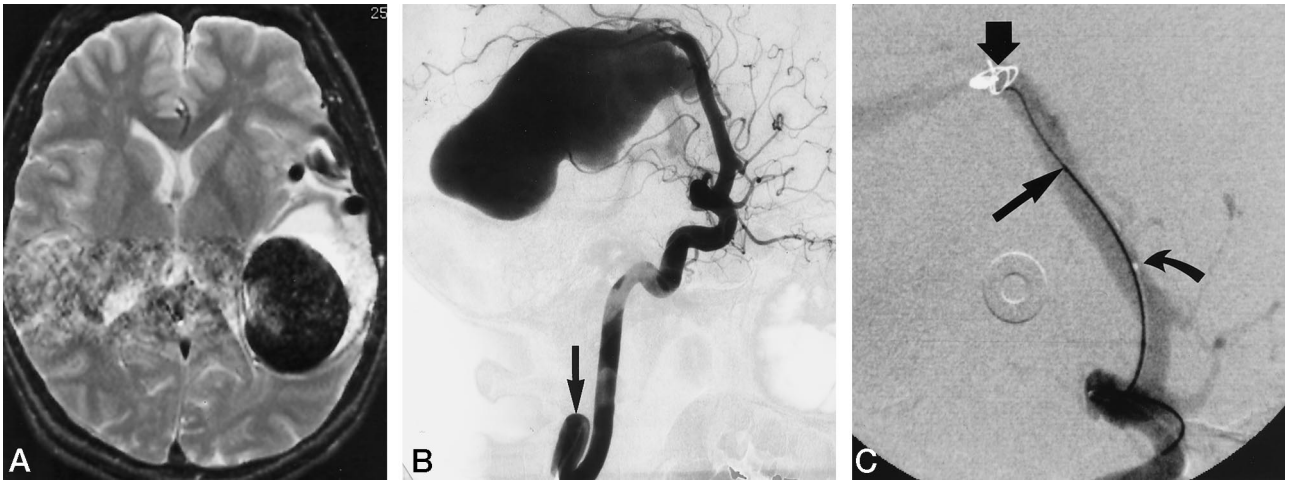

FIG 3. *A*, T2-weighted axial MR image (2000/80/2) shows a large varix in the left hemisphere.

B, Left internal carotid artery injection, lateral projection, shows a solitary arteriovenous fistula supplied by the angular artery. Note the tortuosity in the ascending cervical segment of the proximal internal carotid artery (*arrow*).

C, Roadmap capture during deployment of the first electrolytically detachable fibered coil. During placement of the guidewire or coil pusher the catheter tip was displaced from a distal position (*long straight arrow*) to a more proximal position (*curved arrow*). The coil was pushed from the proximal position to an ideal position at the fistula site (*short straight arrow*) and detached electrolytically.

After embolization, internal carotid artery injection, anteroposterior (*D*) and lateral (*E*) projections, show complete occlusion of the fistula site with preservation of all normal branches.

is probably not ideal for the treatment of saccular aneurysms: while the fibered coils theoretically could produce thrombosis with a shorter coil length, the increased stiffness makes them unsuitable for delivery into a friable structure, such as a ruptured aneurysm. The combination of GDCs placed into a fusiform aneurysm followed by placement of fibered detachable coils into the proximal parent vessel may prove to be an excellent combination, especially when proximal perforators or critical branches must be avoided.

In our study, all 44 electrolytically detachable fibered coils were delivered to the desired site and detached without difficulty. The detachment times varied from 14 seconds to 185 seconds (median, 72 seconds; average, 88 seconds). All the coils subjected to electrolysis detached without difficulty. All four patients had control arteriograms, and in every instance the desired occlusion was achieved. The follow-up postembolization arteriograms did not show any distal embolic occlusions. The embolic agent was delivered successfully through two different microcatheters. Slightly lower friction was achieved with the Turbo Tracker, possibly because of its larger proximal inner diameter. The amount of friction required to deliver each fibered coil is considerably higher than for any GDC and increased with the overall length of the coil, but it is similar to that encountered with commercially available fibered pushable coils.

In case 1, the detachable coil was essential in occluding the high-flow fistulas that had resisted prior treatment with detachable balloons and fibered coils. In case 2, placement of a guidewire or coil pusher through the microcatheter produced dramatic undesired excursions of the tip of the catheter, precluding the use of pushable coils. Liquid adhesive embolization could have been attempted in this single-hole fistula, but the proximity of the fistula to normal proximal branches supplying the angular gyrus (Fig 3D and F) made this a less attractive alternative. The fibered detachable coils could be pushed to the desired site from a more proximal microcatheter position and detached only when in a stable, ideal position.

In all four cases, a fibered electrolytically detachable coil was initially pushed to a position judged to be less than ideal and later repositioned into a more desirable site before being detached. This maneuver was accomplished quickly, with no evidence of thrombus formation and no increase in friction. The use of systemic anticoagulation probably retards the thrombus formation, but may not eliminate this potential drawback. Additional studies are being performed to

determine the effect of time and detachment current on the thrombus produced by this novel device.

Conclusion

Our initial experience suggests that electrolytically detachable fibered coils will become a useful tool in the treatment of selected neurovascular disorders.

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