ELSEVIER

Techniques of Coiling Cerebral Aneurysms

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BACKGROUND
More than 200 aneurysms have been coiled at the UIC Medical Center within the last 5 years. We describe in detail the technical factors that increase the chance of complete occlusion of a cerebral aneurysm with coils.

Aneurysms selected for coiling have good geometry or are in a location that is difficult to reach surgically. Patients with medical conditions that preclude surgical treatment may also undergo coiling.

METHODS
Patients with aneurysms, either ruptured or unruptured, are treated under general anesthesia, fully anticoagulated and deeply paralyzed. Coiling is done under simultaneous biplane roadmapping. After the first coil has created a mesh, the aneurysm is *densely* packed with soft coils of decreasing diameter, until no more coils can be deployed into the aneurysm.

RESULTS
The morbidity and mortality rates associated with the coiling procedure have continuously decreased over the last 5 years. The morphological outcomes have improved, due to extensive use of the remodeling technique and to advancements in materials, such as refinements in the coils themselves or the availability of over-the-wire balloon catheters in different sizes and hydrophilic wires with complex tip configurations.

Twenty-one percent of the aneurysms were considered to be incompletely occluded immediately after coiling. Of this group, one-third of the aneurysms were found to be completely occluded on follow-up angiograms by 6 months; these have remained occluded. One-third were more than 95% occluded after the coiling procedure; in these patients, the dome was completely occluded, but there was a small neck remnant, which has remained stable in all patients on control angiograms obtained at 6 months and 1, 2, and 4 years; none have rebled. These patients are followed medically. The remaining one-third of the aneurysms in this subgroup were less than 95% occluded, although the dome was completely thrombosed. None of them have rebled, but the neck remnant in most has regrown over a period ranging from 6 months to 2 years. These patients have undergone a second treatment—either surgical clipping, permanent occlusion of the parent vessel, or repeat coiling using the remodeling technique. The overall rebleeding rate of incompletely occluded aneurysms is extremely low (less than 1%).

CONCLUSION
The low morbidity and mortality rates and the good morphological outcome obtained in most cases make coiling a reasonable alternative to surgical clipping in properly selected cases.

KEY WORDS
Aneurysm, embolization, Guglielmi detachable coils.

The morphological outcome of cerebral aneurysms treated with coils is a major concern. Do aneurysms that appear to be completely thrombosed on Day 1 remain so on long-term follow-up? What happens to aneurysms that are only partially thrombosed on Day 1? Do they rebleed? Does the neck remnant regrow? How many of these patients require additional treatment?

In recent years, several factors have contributed to increasing the number of aneurysms that are completely thrombosed on Day 1. First is the selection process. Aneurysms are chosen according to geometric criteria; those that are readily amenable to coiling and those with relatively broad necks in which the remodeling technique can be used are selected for endovascular treatment. A second factor is the ability to achieve dense packing of the aneurysm. A good morphological outcome requires good technique; herein we describe in detail our technique for coiling cerebral aneurysms.

Materials and Methods

Patient Selection

The geometric characteristics of the aneurysm are the first criteria to be considered. The ideal dome-

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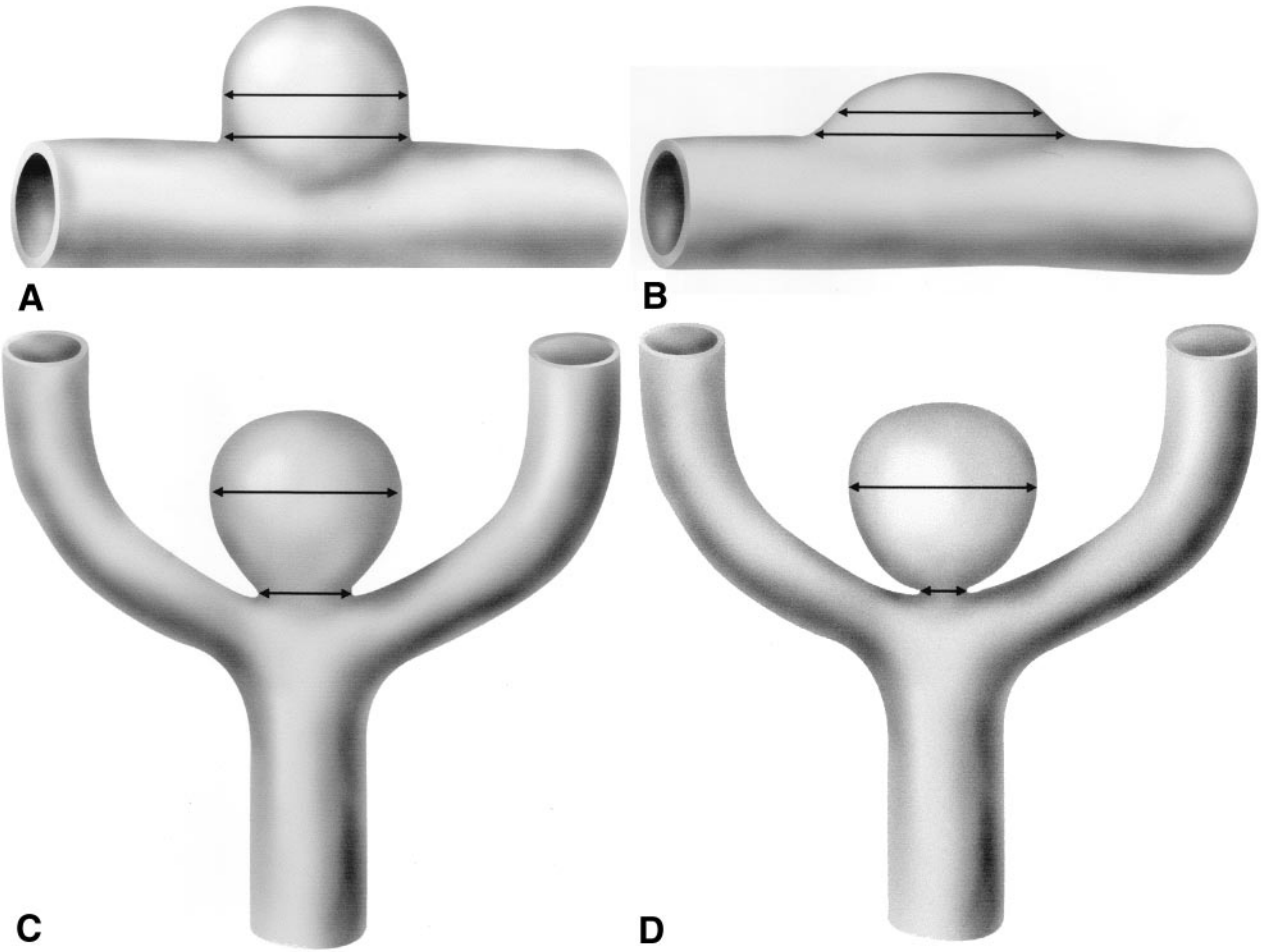


1 Demonstrates the importance of the dome-to-neck (D/N) ratio in selecting aneurysms that are best suited for coiling. **A** D/*N* = 1/1 = 1. This aneurysm may be able to be coiled, with the aid of the remodeling technique; ideally, however, the D/N ratio should be >1. **B** The D/N ratio of this aneurysm is <1. It cannot be coiled even with the remodeling technique. **C** The D/N ratio is 2/1 = 2. This aneurysm can be coiled, probably without the remodeling technique. However, remodeling may improve the morphological outcome. **D** The D/N ratio is 4/1. This is an ideal but rare morphology that allows coiling without the remodeling technique.

to-neck ratio must be ≥2 (Figure 1 **A–D**). A spherical aneurysm is more easily coiled than a pear-shaped one; in the latter it is more difficult to fill the tubular neck with coils. The diameter of the neck is also an important consideration. It should be no wider than the diameter of the parent vessel, and slightly smaller than the diameter of the aneurysm. If the neck is more than 5 mm wide, coiling is unlikely to be successful, even with the remodeling technique.

The location of the aneurysm is also considered; in some cases, coiling may be more risky than clipping. For example, middle cerebral artery (MCA) bifurcation or trifurcation aneurysms, which are easily accessible surgically, are usually not amenable to coiling because of the risk of occluding a major MCA branch. The same applies to anterior communicating artery (ACom) aneurysms, in which coiling may prevent preservation of the A2 branches.

Ruptured aneurysms are always considered for coiling, unless they are associated with a large intraparenchymal hematoma or have unfavorable geometric characteristics.

COILING METHOD

Every aneurysm is treated with the patient under general anesthesia and paralyzed. Because the deployment of the coils is done under roadmapping, the slightest movement of the head would alter the fluoroscopic image, losing the exact position of the tip of the coil and increasing the risk of perforating the aneurysm.

Each patient is fully heparinized, whether the aneurysm is ruptured or not. A bolus of 5,000 units of heparin is injected as soon as the sheath is positioned in the femoral artery; an additional 1,000 units is given every hour until the end of the procedure. The sheath and guiding catheter are also continuously flushed with heparinized saline (2,000 units of heparin per liter of saline) to prevent the formation of clots that might be loosened by the injection of contrast. The heparin is usually reversed at the end of the procedure, unless an embolic complication has occurred or there is concern about coils protruding through the neck of the aneurysm.

A 6F or 7F guiding catheter is used in the internal carotid artery (ICA); 5F or 6F in the vertebral artery (VA). The large lumen of the guiding catheter allows the microcatheter to advance easily, and also provides enough space for repeated injections of iodine contrast. If the remodeling technique is used, we prefer to advance both the balloon catheter and the microcatheter inside the same guiding catheter (8F), rather than puncturing the groin in two places and positioning two guiding catheters in the ICA. In cases of basilar artery aneurysms, however, the dominant vertebral artery is usually not wide enough to accept an 8F-guiding catheter; we therefore use two 5F or 6F guiding catheters, one in each VA.

MICROCATHETER SELECTION

The Excel 10 microcatheter (Target Therapeutics, Fremont, CA) is used for aneurysms with a dome diameter of 6 mm or less; for larger aneurysms, the Turbo Tracker 18 (Target Therapeutics) is used. The new catheters are slightly stiffer in the distal portion than the regular Tracker catheters; therefore, they do not kink. Any kink in the microcatheter increases the friction of the wire and of the coil being advanced through the catheter, reducing the torque control of the wire and sometimes preventing the coil from passing the kink. However, the slightly increased stiffness of the microcatheter may make it more difficult to keep its tip within the aneurysm after the first coil is deployed.

Except for basilar tip aneurysms, in which the microcatheter enters the sac easily, the tip of the microcatheter is usually shaped in the steam according to the orientation of the neck of the aneurysm and the curve of the parent vessel. Curving the tip of the microcatheter can be done with the wire within it, or with a metallic mandrel that can be shaped as necessary after introducing it into the distal segment of the microcatheter.

WIRE SELECTION

We use a standard wire with a preformed J-shaped tip. The tip of the wire precedes the tip of the microcatheter as it is advanced into the cerebral vasculature. Torquing the tip of the wire with a handle held proximally allows us to enter the aneurysm, and then advance the tip of the microcatheter into it. If it is difficult to enter the aneurysm with a standard wire, a hydrophilic Terumo wire may be necessary. Unfortunately, there are only a limited number of distal curves available; one Terumo wire with a 90° angle is available only with the Turbo Tracker #18, not with the Excel #10. Great care must be taken in using the hydrophilic wires, because they may allow the microcatheter to advance suddenly and rapidly, creating a risk of perforating the aneurysm dome.

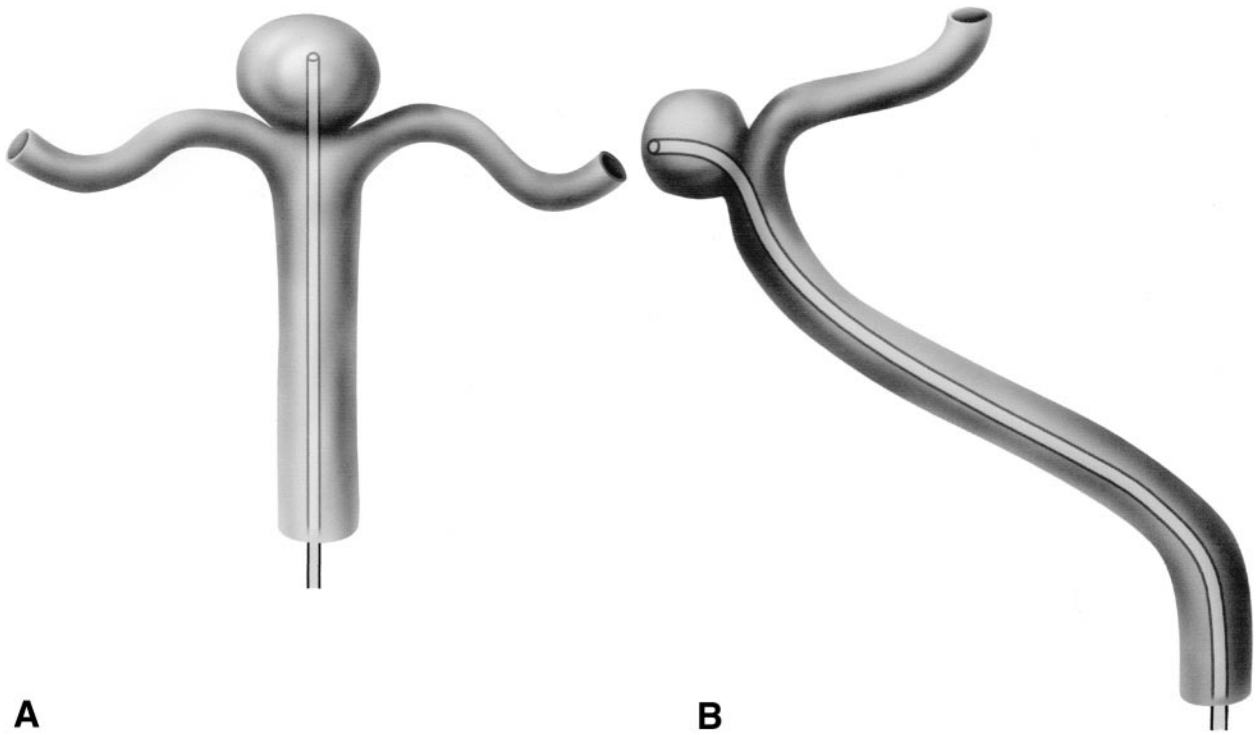
Ideally, the tip of the microcatheter should be at the center of a spherical aneurysm, not against its wall. Combining two orthogonal views of the aneurysm allows us to estimate the position of the microcatheter tip with reasonable accuracy (Figure 1 **A&B**). This is even easier when working with a real-time 3D imaging system.

SELECTING THE FIRST COIL

The selection of the first coil is important because it determines how densely the aneurysm can be packed. The diameter of the first coil should be 1 mm wider than the maximum diameter of the aneurysm, after correcting for the magnification factor. Pear-shaped aneurysms, however, are treated as though they were two aneurysms of different sizes (the dome and the proximal tubular portion). In these cases, the diameter of the first coil should be 1 mm wider than the maximum diameter of the dome of the aneurysm, not its length. The proximal portion of these aneurysms may need to be coiled with the aid of the remodeling technique.

Target Therapeutics has recently developed three-dimensional coils; these form a basket or mesh that fills the periphery of the aneurysm sac, after which the center can be filled with smaller, softer coils. However, the 3D coils are not available in every diameter; for example, there is a 4 mm and a 6 mm diameter coil, but not a 5 mm. In addition, there is a greater risk of perforating the aneurysm with the 3D coils, because the configuration of the first loop is different from the two-dimensional version. The first loop of the 2D coils has a much smaller diameter than those that follow, which reduces the risk of aneurysm perforation.

The deployment of the first coil must be done under simultaneous biplane roadmapping, with the patient totally paralyzed. Working in a single plane increases the risk of perforating the aneurysm; this is illustrated in Figure 2 in which the tip of the catheter appears on the anteroposterior view to be



2 Demonstrates the necessity of simultaneous biplane roadmapping fluoroscopy. **A** (anteroposterior view): The tip of the microcatheter seems to be at the center of the aneurysm. **B** (lateral view): This view shows that the tip of the microcatheter is against the wall of the aneurysm. Clearly, there is risk of perforating the aneurysm with the first coil if it is deployed using only the AP view.

in the center of the aneurysm, whereas the lateral view shows that the catheter tip is against the wall of the aneurysm. The microcatheter is withdrawn slightly as the first coil is deployed; there is no further risk of perforation after the coil has begun to follow the wall of the aneurysm and form a circle.

If the neck of the aneurysm is narrow, the first coil will follow the inner lumen of the aneurysm and straddle the neck without protruding through it and advancing into the parent artery. If the coil will not stay entirely within the aneurysm, however, a balloon may be inflated in the parent artery at the level of the aneurysm neck; this is the remodeling technique described by Moret and Cognard [3]. The first coil is detached with an electrical current only when we are sure that the entire coil is inside the aneurysm, either without the remodeling technique or after the balloon is deflated.

SELECTION OF ADDITIONAL COILS

Usually, the coils that follow the first are softer and of decreasing diameter and length. Each new coil is advanced under a new simultaneous biplane roadmapping image that subtracts the previously deployed coils. This continues until no more coils can be placed within the aneurysm. The tip of the microcatheter spins inside the aneurysm while the first coil is deployed, but is progressively immobilized as the coils become more tightly packed.

Eventually, the tip of the microcatheter will be pushed out of the aneurysm as the coil is deployed; often, maneuvering the catheter using the partially deployed coil as a wire, also under simultaneous biplane roadmapping, allows the microcatheter to re-enter the aneurysm. If this is not successful, the catheter and the last coil are retrieved. This problem may occur before the aneurysm is densely packed; in such cases, good judgment must be used in deciding whether to stop the procedure or to try to re-enter the aneurysm. Maneuvering the microcatheter to try to re-enter the aneurysm obviously increases the risk of aneurysm perforation, as well as the risk of an embolic complication caused by dislodging a piece of clot from the neck of the aneurysm; therefore, we make only a brief attempt to re-enter the aneurysm before retrieving the catheter.

When we have completed the coiling, the aneurysm should be densely packed, with no visible gaps between the coils on either lateral or anteroposterior views. Ideally, the neck of the aneurysm will also be well packed.

At the end of the procedure, the heparin is reversed unless there was an embolic complication during the case that required fibrinolysis. If there is any question of coils protruding through the neck, the patient remains anticoagulated for 48 hours.

Results

Clinical Outcome

Within the last 5 years, 208 aneurysms have been treated with coils at UIC Medical Center, excluding those cases in which coiling failed. The morbidity rate (permanent neurological deficits) was 1.9%; the GDC-related mortality rate was 2.4%. Of the 92 patients with ruptured aneurysms, permanent morbidity occurred in only two patients (2.1%), and the mortality rate was 3.2%. Of the group with nonruptured aneurysms (116 patients; 55.7%), the morbidity and mortality rates were both 1.8%.

Coiling-related morbidity or mortality occurred when the aneurysm was perforated or ruptured during treatment (three patients) or when there was an embolic complication that resulted in a major permanent neurological deficit (two patients). In the ruptured aneurysm group, mortality was considered to be related to the subarachnoid hemorrhage if the patient's neurological status after coiling did not improve. Complications were not considered to be related to the coiling procedure if (1) the patient was comatose and intubated before treatment, and the neurological examination after treatment showed no new findings; (2) there was evidence that the aneurysm was not perforated during coiling; (3) all branches of the MCA and anterior cerebral artery (ACA) were still filling after coiling; and (4) there was no change on the post-procedure CT scan compared to the one obtained immediately before coiling.

The permanent morbidity rate in the last 100 coiled aneurysms has remained the same (less than 2%), and the mortality rate has dropped to zero. Rebleeding has occurred in only two patients (less than 1%); in both cases, coiling was incomplete because of technical problems, and rebleeding occurred very soon after the procedure.

Morphological Outcome

Evaluating morphological outcome is very difficult. There is usually no visible filling of the aneurysm dome immediately after coiling, but there is always some doubt about the complete occlusion of the neck. Therefore, we never report an aneurysm as more than 99% occluded on Day 1. Twenty-one percent of aneurysms are incompletely occluded (95%–99%) on Day 1. Although most neurosurgeons consider this to be an unacceptably high rate of incomplete cure, angiographic follow-up clearly reveals three subgroups. One-third of the incompletely occluded aneurysms appear to be completely occluded on the 6-month follow-up angiogram, and remain so at 1 year and 2 years. One-third show a small neck remnant on follow-up angiograms that remains stable over time. None of the patients in these two subgroups has rebled. The remainder of the patients with incompletely occluded aneurysms have some regrowth of the aneurysm neck only; the fundus remains occluded. Although none of the patients in this subgroup have rebled, all have undergone a second treatment, either surgical clipping or permanent occlusion of the parent vessel, or a second coiling procedure with the remodeling technique if this was not attempted initially.

Discussion

Coiling Technique

Although all interventionalists use essentially the same technique, there are variations in the ability to achieve tight, dense packing of the aneurysm. Resistance and friction within the microcatheter progressively increase as more coils are advanced into the aneurysm; sometimes this can only be overcome by using a handle and pushing the coil very hard, millimeter by millimeter. This is an unpleasant, frightening situation, but it becomes easier to handle with experience.

Day-to-day limitations include the lack of sophisticated distal curves in the hydrophilic wires, and the lack of over-the-wire balloons since Medtronic MIS was forced to remove theirs from the market. We are currently using soft angioplasty balloons (Endeavor; Target Therapeutics, Fremont, CA); however, they are not over-the-wire balloons and do not provide the same stability. Several companies are now working on this problem, and over-the-wire balloons in different sizes should soon be available. Micro Therapeutics, Inc. (Irvine, CA) has recently begun marketing an over-the-wire balloon that seems to work well; we have successfully used it in five patients to date.

Clinical Outcome

All the series in the literature report low morbidity and mortality rates, both of which decrease with experience [6,10,11,15,16,20,22]. As with any new technique, there is a learning curve; better technical skills, better understanding of the aneurysm selection criteria, and improvements in the materials used all lead to higher success rates.

Even in our group of ruptured aneurysms, the morbidity and mortality rates are no higher than have been reported in surgical series. We also do not see symptomatic vasospasm more often after coiling than after clipping (when comparing equivalent Hunt/Hess and Fisher grades); this is true despite the fact that the subarachnoid clots remain after coiling. Rebleeding has rarely occurred after partial coiling. The rebleeding rate in all series is approximately 2%; in our series it is less than 1%. This may be because we take great care, even if there is a neck remnant, to protect the dome of the aneurysm, based on evidence in the literature that most aneurysms rupture at the level of the dome [4].

MORPHOLOGICAL OUTCOME

Many neurosurgeons are uncomfortable with the large number of aneurysms that remain incompletely occluded after coiling. They state that the approximation of the two sides of the neck with an aneurysm clip gives them a high degree of certainty that the aneurysm is completely cured, and that lack of bleeding after puncturing the aneurysm proves that it is completely occluded. Most are so confident that they do not perform control angiograms postoperatively, even though there is minimal risk involved. However, a surgeon cannot be completely certain of what is happening on the other side of the clip—is there a small neck remnant? And what happens if the clip slips, even slightly?

Few surgical series with postoperative control angiograms appear in the literature, particularly considering the number of aneurysms clipped every year. Such series report a 5%–6% rate of incomplete cure after clipping [1–3,5,7–9,12–14,17–19, 21]. Our morphological results show that 79% of coiled aneurysms remain completely occluded on follow-up angiograms. It is extremely rare for neck regrowth to occur in an aneurysm that was densely packed and appeared to be completely occluded immediately after coiling. More important, however, is the morphological outcome of the 21% of aneurysms that are incompletely occluded on Day 1. Only one-third of these patients—7% of the whole series—show neck regrowth over time. This is not much different from the 5%–6% rate of neck regrowth reported after surgical clipping.

Conclusion

The goal of aneurysm coiling, as described herein, is to obtain dense, tight packing of the aneurysm, with or without the remodeling technique. However, the difference in morphological outcome between clipped and coiled aneurysms must also be clearly understood.

Aneurysm coiling is a new technique, and it will take time for it to gain credibility in the neurosurgical community. Many young neurosurgeons are eager to learn this technique, however, and most of them have the ideal background, attitude, and degree of skill. We have no doubt that improvements in the technique and materials will make the procedure more and more attractive to neurosurgeons.

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