Treatment of Experimental Canine Carotid Aneurysms with Platinum Coils

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PURPOSE: To evaluate and compare the deliverability, positioning, stability, and effectiveness of aneurysm occlusion and the incidence of parent-artery thrombosis of two different types of platinum coils, using a canine carotid aneurysm model. **METHODS:** 29 experimental canine carotid aneurysms (19 lateral, 6 bifurcation, and 4 terminal) were constructed and treated with complex-shaped fibered platinum coils and simple curved nonfibered platinum Guglielmi detachable coils (GDCs). **RESULTS:** Fibered complex coils were stable, producing 38% complete aneurysm occlusion and 61% average reduction in aneurysm lumen size but resulting in 19% parent artery occlusions. GDC coils were stable, producing 31% complete aneurysm occlusion and 95% average reduction in aneurysm lumen size with no parent-artery occlusions. **CONCLUSIONS:** GDC coils produced an average reduction in aneurysm lumen size of 95% without any associated parent-artery occlusions. There were no delayed migrations of GDC coils. The ability to remove, reposition, and detach a coil was the most significant feature of the GDC coil.

Index terms: Aneurysm, intracranial; Interventional instrumentation, coils; Interventional neuroradiology, experimental; Animal studies

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Recent developments in catheter and coil technology have improved the effectiveness, safety, and efficacy of the intracranial endovascular use of these devices; however, the behavior of conventional coils for the treatment of intracranial aneurysms has not been optimal. Guglielmi et al (1, 2) recently have described an electrically detachable coil, the Guglielmi detachable coil (GDC) (Target Therapeutics, Inc., San Jose, CA), which may offer several advantages over conventional coils. Using canine aneurysm models, we evaluated the GDC coil and the fibered, complex, nondetachable coil (FC) and compared their effectiveness in producing aneurysm occlusion and the incidence of parent-artery occlusion.

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Materials and Methods

Twenty-nine aneurysms (19 lateral, 6 bifurcation, and 4 terminal) were constructed in 21 mongrel dogs under a protocol approved by the animal care committee. These aneurysms were constructed using a venous pouch technique, the details of which have been reported (3–7). These three aneurysm models have distinctly different hemodynamics and are similar to those described for human saccular aneurysms (8).

FC coils (0.014 inch outside diameter; 3, 4, 6, 8, and 10 cm length) with a complex "flower petal" shape plus silk fibers (5 mm, 25-strand silk fibers every 2 mm) were placed in 16 aneurysms (14 lateral and 2 bifurcation). GDC coils (0.010 and 0.015 inch outside diameter; 8, 15, 20, and 40 cm length) with simple circular shapes (2, 5, and 8 mm diameter) were placed in 13 aneurysms (5 lateral, 4 bifurcation, and 4 terminal) (Fig. 1).

All coils were placed in the aneurysms via a transfemoral approach using a 5-F guiding catheter and a coaxial 2.2-F variable stiffness catheter (Tracker18, Target Therapeutics, Inc.). Coils were placed in the lumen of the aneurysm until: 1) there was no flow in the aneurysm lumen; 2) there was stasis of contrast in the aneurysm lumen; or 3) no additional coils could be placed in the aneurysm lumen without extension into the parent artery. Angiography was carried out before coil placement, immediately after coil placement, and at time intervals of 1 week, 5 weeks, and 3

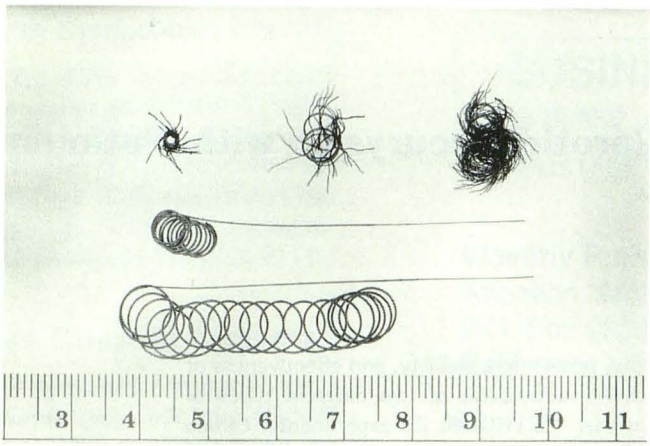

Fig. 1. *Top row,* FC coils (3, 6, and 10 cm). *Bottom row,* GDC coils (15 and 40 cm, 0.015 inch).

months in all aneurysms and at delayed intervals between 6 months and 1 year in some aneurysms. The time interval that an aneurysm was followed after coil placement varied from 3 months to 1 year.

The percent aneurysm lumen occlusion was determined by estimating the area of the aneurysm lumen on the pre- and postcoil placement angiograms and taking the ratio of the postcoil aneurysm lumen to the precoil aneurysm lumen. A single oblique projection of the angiogram was used for these determinations.

Results

Deliverability

FC coils 8 and 10 cm in length were difficult to deliver, requiring forces great enough to deform the delivery catheter and bend the coil pusher. Some 10-cm FC coils could not be delivered regardless of the force used. GDC coils 8, 15, 20, and 40 cm in length were easy to deliver and required subjectively minimal force. All GDC coils could be delivered. FC coils once in the catheter could not be removed and once beyond the catheter tip could not be repositioned. GDC coils could be removed and/or repositioned as long as the coil had not been detached. Detachment of the GDC coil occurs by electrolysis (1, 2). Detachment times varied from 4.77 min to 29.00 min, with a mean detachment time of 11.79 min and a median time of 10.68 min (n = 81). The first coil was usually the shortest detachment time, and the times became progressively longer with each additional coil.

Coil Positioning

GDC coils could be removed and repositioned before detachment. Generally the same force required to deliver a coil was required to remove and reposition a coil. Multiple placements and removals of GDC coils were done in the 13 aneurysms treated with 81 GDC coils. All coils were removable from the aneurysm lumen and could be repositioned before detachment. In one aneurysm (1 of 13) a coil was entangled in previously placed coils and partially dislodged the coil mass during removal. The coil was advanced back into the aneurysm lumen, and the dislodged coils returned to their previous positions in the aneurysm lumen.

Stability

When either FC or GDC coils migrated from their original placement positions they did so along the streamlines of inflow and outflow as previously described (7). This pattern was constant for all three types of aneurysms. Thirty-eight percent (15 of 39) of FC coils migrated from their original placement positions either immediately or on a delayed basis up to 1 week. After 1 week no FC coil migration occurred. One percent (1 of 81) of GDC coils migrated after placement. This occurred immediately after detachment. There were no delayed migrations of GDC coils.

Aneurysm Occlusion

FC coils produced complete aneurysm occlusion in 38% (6 of 16) of aneurysms (Fig. 2). FC coils produced an average reduction in aneurysm lumen size of 61%. Reduction of the aneurysm lumen occurred primarily in the portion of the aneurysm lumen filled with coils; however, some reduction in size occurred in areas not filled with coils (Fig. 3). The average total length of FC coils that could be placed in an aneurysm was 12 cm before an end point was reached, whereas the average was 156 cm for the GDC coil. GDC coils produced complete aneurysm occlusion in 31% (4 of 13) of aneurysms (Fig. 4). GDC coils produced an average reduction in aneurysm lumen size of 95%. Reduction of the aneurysm lumen occurred primarily in the portion of the aneurysm lumen filled with coils; however, some reduction in size occurred in areas not filled with coils (Fig. 5). Incomplete occlusion of an aneurysm occurred with both FC and GDC coils and was the result of either: 1) partial filling of the aneurysm lumen with coils; 2) failure to block the inflow; or 3) coil compaction.

Coil compaction occurred in 63% (10 of 16) of aneurysms treated with FC coils and 85% (11 of

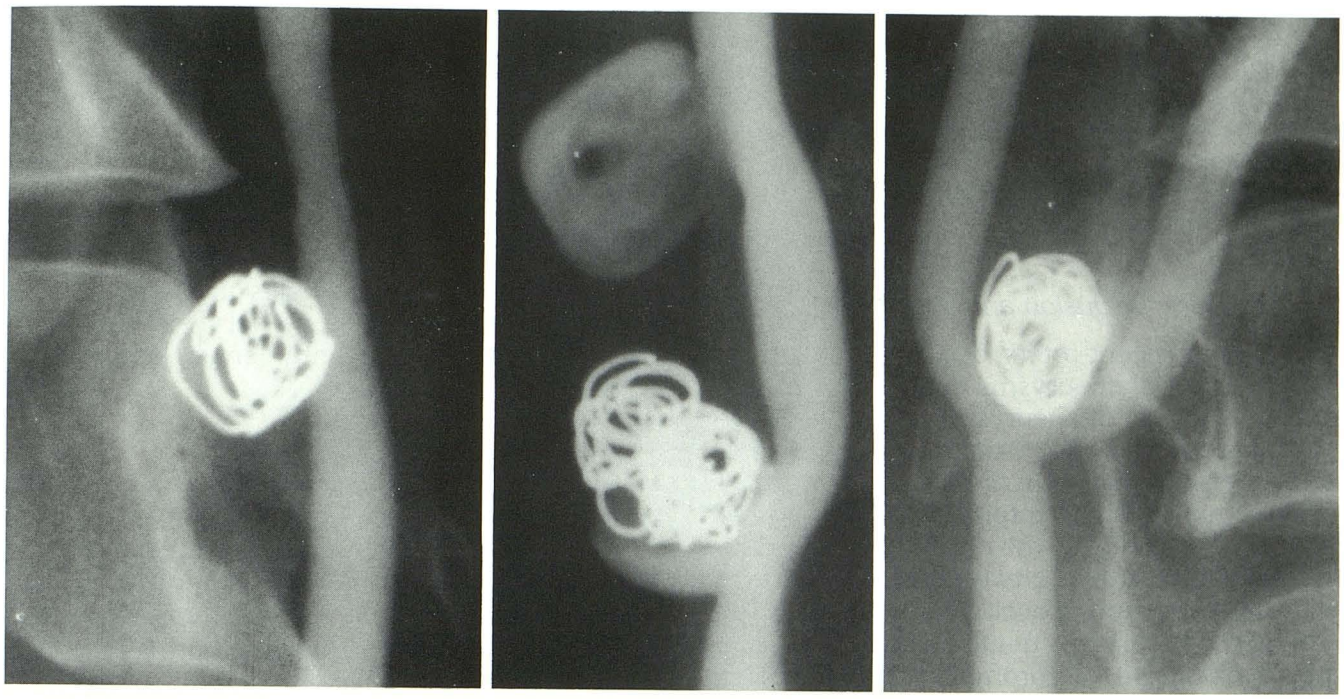

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Fig. 2. Aneurysm occlusion. FC coils placed in a lateral aneurysm show complete occlusion at 3 months. Note large interstitial spaces between loops of coil that are occluded.

Fig. 3. Aneurysm occlusion. FC coil in a lateral aneurysm with partial occlusion of aneurysm, primarily in the region of coils. FC coils produced 61% average reduction in aneurysm lumen size.

Fig. 4. Aneurysm occlusion. GDC coils in a terminal aneurysm show complete occlusion at 3 months.

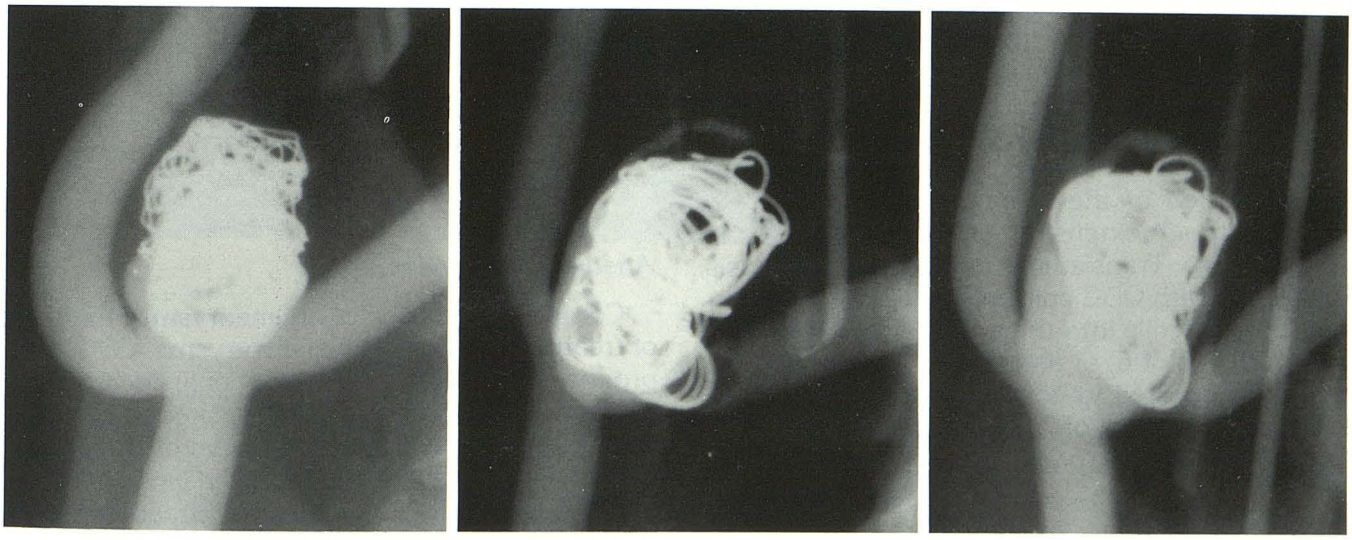

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Fig. 5. Aneurysm occlusion. GDC coils in a terminal aneurysm with partial occlusion of aneurysm, primarily in the region of coils. GDC coils produced 95% average reduction in aneurysm lumen size.

Fig. 6. Compaction and transient parent-artery thrombus.

A, GDC coils in a bifurcation aneurysm immediately after placement show residual aneurysm and parent-artery thrombus associated with extension of a GDC coil into the parent artery.

B, One-week follow-up shows resolution of the parent-artery thrombus (transient parent-artery thrombus) and marked compaction of the GDC coils.

13) of aneurysms treated with GDC coils (Fig. 6A and 6B). Coil compaction always occurred during the first week after placement and did not progress thereafter. The degree of coil compaction was greater in all cases in which coils 0.010 inch in diameter were used as compared with coils 0.015 inch in diameter.

Parent-Artery Occlusion and Thrombus

Complete parent-artery occlusion occurred in 19% (3 of 16) of aneurysms treated with FC coils and 0% (0 of 13) of aneurysms treated with GDC coils (Fig. 7A and 7B). Occlusions of the parent arteries associated with the FC coils were the result of extension of thrombus from the aneurysm lumen in one and the result of coil migration into the parent artery in two cases.

Partial parent-artery occlusion occurred in 13% (2 of 16) of aneurysms treated with FC coils, one due to extension of thrombus into the parent artery and one due to coil migration into the parent artery. Partial parent-artery occlusion occurred in 8% (1 of 13) of aneurysms treated with GDC coils because of coil migration into the parent artery.

Some degree of transient thrombosis occurred in the parent artery and completely resolved during the first week after coil placement. Transient parent-artery thrombosis occurred in 31% (5 of 16) of aneurysms treated with FC coils and in 46% (6 of 13) of aneurysms treated with GDC coils (Fig. 6A and 6B). Transient parent-artery thrombosis associated with FC coils was due to both extension of FC coils into the parent-artery and extension of the thrombus into the parent artery without extension of FC coils into the parent artery. Transient parent-artery thrombosis associated with GDC coils was due only to extension of GDC coils into the parent artery.

In 100% (6 of 6) of aneurysms treated with FC coils that resulted in complete aneurysm occlusion some degree of parent-artery thrombosis occurred.

Discussion

Deliverability

Both coil shape and the addition of fibers to coils are believed to have played a significant role in the length of coil that could be delivered. The length of a single FC coil that could be delivered was limited to 10 cm or less. It was postulated that the combination of the strong memory necessary for the complex shape and the silk fibers increased the mechanical friction between the delivery catheter and the coil. The amount of force necessary to deliver the 10-cm FC coils caused difficulty in maintaining appropriate catheter position and at times exceeded the strength of the coil pusher used to deliver the coil.

Our studies show that the simple circular shapes and the nonfibered design of the GDC coil require subjectively less delivery force and can be delivered in significantly longer lengths than the FC coil.

Coil Positioning

The ability to remove a coil from an aneurysm and reposition it or change to a coil of a different length or shape was very useful in the treatment of an aneurysm with coils. This was the major factor that allowed significantly more total length of GDC coils to be placed in an aneurysm and more complete packing of the aneurysm with GDC coils than with FC coils before reaching a defined endpoint.

Stability

FC coils migrated more frequently from their original placement positions than did GDC coils. This was primarily a function of where the coils were originally placed. Again the ability to remove a GDC coil from an aneurysm and reposition it in a more satisfactory position accounted for most of the differences in stability after placement between the FC and GDC coils.

Aneurysm Occlusion

Complete occlusion of an aneurysm is the goal of treatment of intracranial aneurysms. GDC coils produced consistent occlusion only in areas of the aneurysm lumen densely packed with coils. Occlusion of areas in the aneurysm lumen not densely packed with coils occurred inconsistently and was probably due to altered intraaneurysmal flow as previously reported (7). FC coils were more thrombogenic than GDC coils, as reflected by the similar rate of complete aneurysm occlusion obtained with much less dense packing of the aneurysm lumen with FC coils. This suggested that the addition of more thrombogenic material to the coil (ie, silk fibers) was beneficial. This increase in thrombogenicity of FC coils was, however, also associated with 19% (3 of 16)

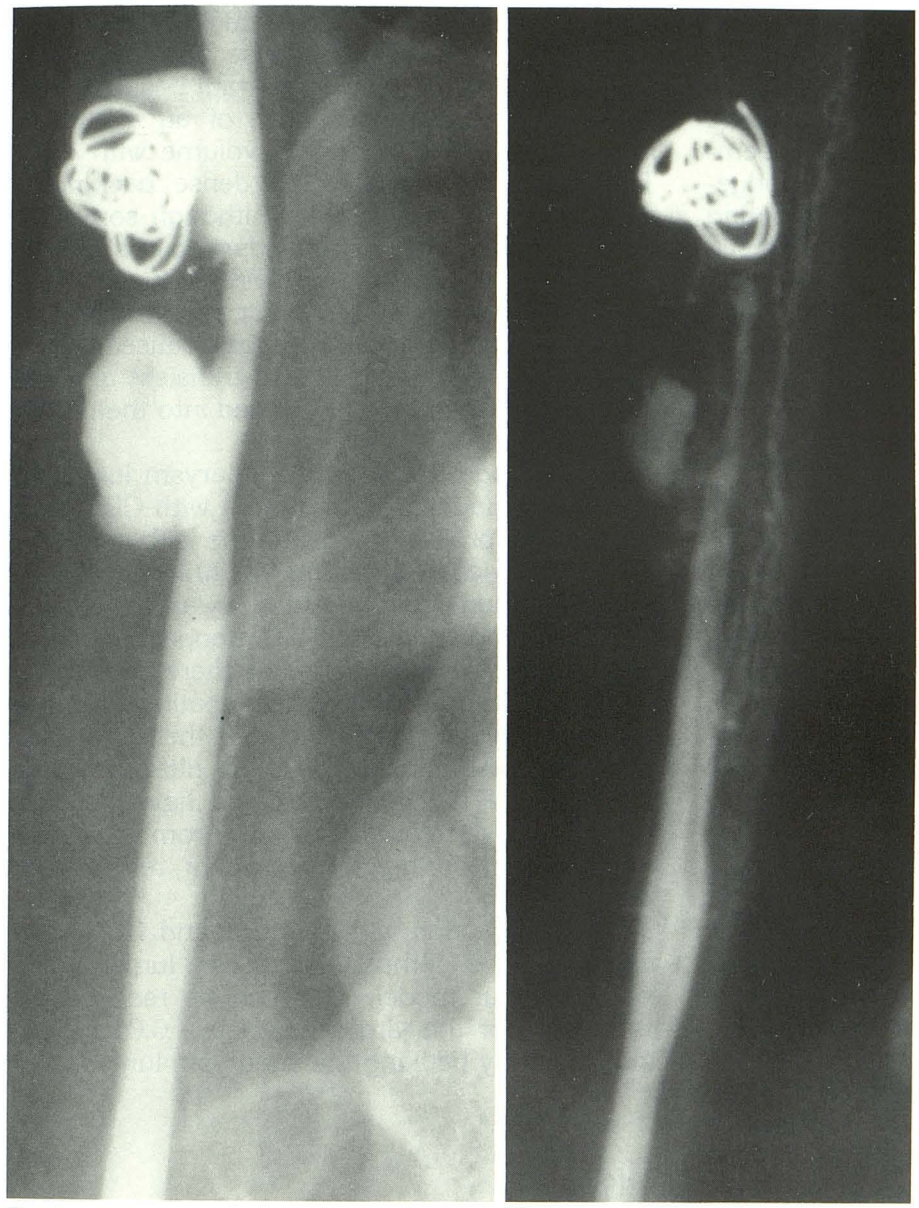

Fig. 7. Parent-artery occlusion.
A, FC coils in a lateral aneurysm immediately after placement show no coil in parent artery and patent parent artery without thrombus.
B, One-week follow-up shows complete parent-artery occlusion.

parent-artery occlusions versus 0% (0 of 13) with GDC coils, and partial parent-artery occlusions with FC coils of 13% (2 of 16) versus 8% (1 of 13) with GDC coils.

The ability to remove and reposition the GDC coil before detachment allowed for a significantly greater total length of GDC coils than FC coils to be placed in the aneurysm lumen before reaching a treatment end point. This factor did not increase the incidence of complete aneurysm lumen occlusion but did reduce the residual aneurysm lumen from 39% for FC coils to 5% for GDC coils.

The total obliteration of these experimental aneurysms has proved to be difficult with currently available endovascular devices. Aneurysms that have anatomic configurations that allow for complete lumen replacement with GDC coils can be completely obliterated; however, it is unlikely that all aneurysms will have such anatomic configurations. Postplacement compaction of coils is another factor that hinders complete obliteration even in some aneurysms that can be initially totally occluded. Increasing the thrombogenicity of the GDC coil might be helpful in increasing the incidence of complete obliteration. The silk fibers

of the FC coils increased their thrombogenicity but also had a significant disadvantage because of parent-artery thrombosis, length limitations, and delivery force requirements. A detachable coil with fibers presents the risk of thromboembolic events during coil repositioning or dislodgement of thrombus formed on the fibers. Coating the surface of a coil with another thrombogenic agent might increase the effectiveness and not alter the coil's other characteristics (9). Delayed activation of the thrombogenic coating also could allow time for the coil to be placed or repositioned without increased thromboembolic risks.

Parent-Artery Occlusion And Thrombus

The incidence of complete parent-artery occlusion correlated directly with the thrombogenicity of the coil used for treatment. Increasing the thrombogenicity of the platinum coil with silk fibers had a positive effect on complete aneurysm occlusion, with less total length of FC coil needed to produce similar incidence of complete occlusion as that produced by significantly greater total lengths of GDC coil. This also had a negative effect by causing more parent-artery occlusion and parent-artery thrombosis even without FC coils extending into the parent artery. The 46% (6 of 13) rate of transient parent-artery thrombosis with the GDC coil was of great concern and results in the potential for adverse thromboembolic events. However, this was predictable, occurring only when the GDC coil extended into the parent artery and was preventable by not allowing any GDC coil to extend into the parent artery. This was not predictable or preventable with the FC coil, as both parent-artery occlusion and transient parent-artery thrombosis occurred with and without FC coils extending into the parent artery.

Conclusions

GDC coils up to 40 cm in length can be delivered easily. FC coils with complex shapes (ie, strong memory) and silk fibers were not as easy to deliver as GDC coils. The maximum length of FC coils that could be delivered was 10 cm.

The ability to remove and reposition the GDC coil was the most significant factor in achieving greater average aneurysm lumen reduction compared with the FC coil. This allowed for more precise placement of the coil and repositioning of the coil to achieve more dense packing of the aneurysm lumen. This is important because platinum coils produce occlusion of an aneurysm lumen primarily by filling its volume with coils. The occlusion produced by dense packing is permanent and predictable. Although some occlusion also may occur secondary to obstruction or disruption of the inflow, this is rarely achieved, not always permanent, and not predictable. The transient parent-artery thrombosis caused by the GDC coil was predictable and transient and occurred only when a coil extended into the parent artery.

The average 5% residual aneurysm lumen in the canine model after treatment with GDC coils is a difficult problem to overcome with currently available devices. Increasing the thrombogenicity of the platinum coils may be a way to address this issue. The addition of thrombogenic fibers is an option; however, in our study there were major disadvantages. Thrombogenic coatings on the surface of the coil might increase their effectiveness (9). These coatings need not alter the characteristics of the coil and could have delayed activation to decrease the risk of thromboembolic complications during coil placement, removal, or repositioning.

Coil compaction with both FC and GDC coils was a factor in complete aneurysm lumen obliteration in our model. This can be reduced by using coils of the largest diameter, 0.015 inch, and by tightly packing the aneurysm lumen.

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Please see the Commentary by Halbach on page 799 in this issue.