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Endovascular Packing of Carotid Bifurcation Aneurysm with Polyester Fiber-Coated Platinum Coils in a Rabbit Model

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PURPOSE: To assess the value of endovascular packing of intracranial bifurcation aneurysms with commercially available coils. **METHODS:** Carotid bifurcation aneurysms were surgically created in 12 New Zealand rabbits with subsequent assessment of the extent of aneurysm ablation following endovascular packing with polyester fiber-coated platinum coils. **RESULTS:** Follow-up angiograms obtained from 29 to 108 days postprocedures showed various degrees of aneurysm ablation. Complete obliteration of aneurysm dome occurred in seven out of eight rabbits, while ablation of aneurysm neck was successful in only one out of eight. No spontaneous thrombosis was observed in seven control animals over a 3-month period. Coils of various configurations used in this experiment all maintained stable intraaneurysmal position. Histologic examination of treated aneurysms consistently demonstrated extensive proliferation of spindle cells on the coil surface and in interstices between coils with channels lined by cells resembling endothelial cells. Organized thrombus was not a prominent feature. **CONCLUSION:** Endovascular packing of human bifurcation aneurysms with current commercially available polyester fiber-coated platinum coils may not result in complete obliteration of the aneurysm with reendothelialization occurring across the aneurysm neck.

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

There are more than 25,000 cases of subarachnoid hemorrhage due to aneurysm rupture each year in North America. The mortality from initial bleeding is approximately 30%, but in patients with rebleeding, it approaches 43% (1). The treatment of choice for most ruptured aneurysms is surgical clipping with preservation of flow in the parent vessel. However, surgical treatment is not always possible for patients in poor medical condition; unfavorable aneurysm anatomy further increases surgical morbidity and mortality. For this subgroup of patients, an alternative therapy is needed. Over the last decade, interventional endovascular procedures have advanced to a level where they are now an acceptable alternative to surgical clipping in selected cases (2–4). However, there are anecdotal instances of rapid aneurysm regrowth (5) or rupture (6) following intraaneurysmal balloon occlusion. An optimal form of endovascular aneurysm occlusion has not been clearly established.

The purpose of this study is to evaluate endovascular aneurysm occlusion by packing with polyester fiber-coated platinum coils using a rabbit carotid bifurcation aneurysm model. The rationale for choosing this model instead of the more traditional canine carotid artery side wall aneurysm model are threefold. First, this model offers a more realistic hemodynamic simulation of most human intradural aneurysms which occur at bifurcations; second, the dimensions of the rabbit common carotid artery are similar to those of the human middle cerebral artery; and third, there is no available data that can predict the long-term outcome of a bifurcation aneurysm treated by endovascular packing with commercially available platinum coils.

Methods

Animal Model

Pasteurella-free New Zealand white rabbits weighing 3.5 to 5 kg were preanesthetized with 0.1 mL/kg intramuscularly of xylazine (100 mg/mL); anesthesia was then achieved with 0.3 mL/kg intramuscularly of a mixture of 10 to 1 by volume of ketamine (100 mg/mL) and acepromazine (10 mg/mL). Twenty-eight bifurcation aneurysms were created according to the technique described by Forrest and O'Reilly (7). Briefly, using a midline incision from the manubrium to the angle of the mandible, a 2-cm segment of the right external jugular vein was resected, cut to appropriate configuration, and placed in heparinized saline. Next, the left common carotid artery was isolated, ligated, and divided at the proximal end of the exposure. The right carotid artery was then exposed and isolated; no arterial punch was used to create ostium of the aneurysm. An elliptical arteriotomy 3–6 mm long was made in the right carotid artery; the free end of the distal left common carotid artery was lifted over the trachea to meet it. Using 10.0 monofilament nylon suture, an arterial bifurcation aneurysm with a vein patch was created with a partial end-to-side anastomosis of the left carotid artery to the arteriotomy. Care was taken to avoid air embolus. The incision was closed after obtaining hemostasis. The rabbit was placed on a heating pad and allowed to recover. The animals were observed daily for intake and output, respiratory status, and motor function of the extremities.

Baseline Arteriography, Controls, and Aneurysm Packing

Following a healing period of 2 weeks, the rabbits underwent diagnostic angiography with a 3.6-F polyethylene catheter via a femoral artery cut-down. In the majority of cases, only a right anterior oblique view that best displayed the bifurcation aneurysm and the parent vessels was obtained. The dimensions of the aneurysms were calculated in reference to a lead marker taped to the rabbit's neck.

The first part of this project was to evaluate the stability of this aneurysm model. If the aneurysm and both carotid arteries were patent at the time of initial angiography, the animal was kept for 3 months as a control. If either the aneurysm or the parent vessel was occluded, the animal was excluded from the study. Seven animals served as controls. The next 12 consecutive rabbits with patent aneurysms and parent vessels were treated immediately following diagnostic angiography by endovascular packing using 0.014-inch polyester fiber-coated platinum coils (Target Therapeutics, Inc, San Jose, CA). The dimensions of these experimental aneurysms are listed in Table 1. Four coil configurations in various combinations were used for this experiment; these consist of 3 mm × 30 mm and 2 mm × 20 mm flower-petal coils, 4 mm × 30 mm complex helical coils, and 2 mm × 10 mm figure-of-eight coils. Two delivery catheter and guide wire/pusher systems were used; initially a 60-cm Tracker-18 catheter was used in conjunction with a 0.016-inch coil pusher; later on the 3.6-F diagnostic polyethylene catheter was coupled with a 0.018-inch guide wire as the delivery system. Both systems were equally effective for catherization of the aneurysm and delivery of coils.

In the first three rabbits, two coils were introduced into the aneurysm just above the neck to determine 1) stability of coils within the aneurysm, 2) whether loosely deposited coils within an aneurysm can induce progressive thrombosis, and 3) whether a partly packed aneurysm represents a potential source of cerebral emboli. All three rabbits underwent repeat angiography in 1 month. This was followed immediately by more complete packing of the residual aneurysm in two of the animals. In the remaining nine rabbits, several flower-petal coils were typically deposited within the aneurysm just distal to the aneurysm neck under roadmapping technique to create a stabilizing "safety net." Following this, the delivery catheter was then advanced through the coils, distally towards the aneurysm apex. Complex helical and figure-of-eight coils were then deposited cephalad to the flower-petal coils. The endpoint of endovascular packing was determined by real-time digital subtraction angiography. With the exception of four rabbits (rabbits 5, 7, 10, and 11), packing was stopped just short of total aneurysm obliteration. Prior to withdrawing the delivery catheter from the tightly packed aneurysm, the hockey-stick configuration at the tip of the delivery catheter was eliminated by introducing a stiff, straight 0.018-inch guide wire, thus preventing the delivery catheter from dragging any of the coils out of the packed aneurysm. An angiogram of the right common carotid artery was obtained after coil packing to document immediate treatment results. The femoral artery was then ligated with a 3.0 silk suture as the catheter was removed. The incision was closed and the rabbit was allowed to recover.

Angiographic Follow-up and Histologic Assessment

In the control animals, follow-up transfemoral angiograms of the carotid arteries were obtained 3 months after the initial angiogram. Follow-up angiography was performed in the endovascular packing group from between 1 to 3½ months. Immediately after the final angiogram, the right common carotid artery was exposed, cannulated, and perfusion-fixed with 10% neutral buffered formalin under a constant pressure of 80 mm Hg for 30 seconds, following which both common carotid arteries distal to the bifurcation aneurysm were clamped for 3 minutes to isolate the aneurysm complex. Both the brain and the bifurcation aneurysm complex were then harvested and postfixed immediately in 10% neutral buffered formalin. The aneurysms together with the platinum coils in situ were examined grossly, then processed and sectioned using a Leco VC-50 saw with a diamond wafering blade (see Appendix). The brains were sectioned at 2-mm intervals in coronal plane and stained with Luxol fast-blue/hematoxylineosin stain at 8-micron thickness for detection of clinically silent infarcts.

TABLE 1: Results of 12 rabbit carotid bifurcation aneurysms treated by endovascular packing with polyester fiber-coated platinum coils

Rabbit No.	Aneurysm Size (Length × Width)	Number and Type of Coils	% of Aneurysm Volume Packed	Interval between Rx. & F/u A-GRAM	A.D.O.	A.N.O.	Complication
1	6 mm × 3 mm	1st session Two 3 × 30[a]	0%	29 days	−	−	−
		2nd session Three 3 × 30 Four 2 × 20[b] Two 2 × 10	80.00%	65 days	±	±	−
2	6 mm × 3 mm	1st session One 4 × 30[c] One 2 × 10[d]	0%	29 days	−	−	−
		2nd session Seven 2 × 10	90.00%	59 days	+	±	−
3	8 mm × 4 mm	One 4 × 30 One 2 × 10	0%	29 days	−	−	Heel ulcer → sacrifice
4	9 mm × 3.5 mm	Three 3 × 30 Six 4 × 30	95.00%	30 days	+	−	−
5	8 mm × 4 mm	Two 4 × 30 Five 3 × 30 Three 2 × 20	>95.00%	48 days	+	+	−
6	16 mm × 6 mm	Five 3 × 30 Ten 4 × 30	75.00%	108 days	+	−	−
7	10 mm × 4 mm	Three 3 × 30 Ten 2 × 20	>95.00%	98 days	+	−	Regrowth at aneurysm neck
8	9 mm × 5 mm	Seven 3 × 30 Two 2 × 10	75.00%	100 days	+	−	−
9	12 mm × 6 mm	Six 3 × 30 Three 2 × 20 Eleven 2 × 10	75.00%	90 days	+	−	−
10	6 mm × 5 mm	Two 4 × 30 Two 2 × 20 One 2 × 10	100.00%	−	+	+	Died 1 day after Rx. Autopsy—occluded right common carotid artery
11	8 mm × 5 mm	Four 3 × 30 Five 2 × 20	>95.00%	−	+	+	Paraplegic after Rx. sacrifice 2 days later
12	6 mm × 4 mm	Five 3 × 30	75.00%	−	+	±	Right common carotid occluded during Rx. → sacrifice

Note.—Key: ADO = aneurysm dome obliteration; ANO = aneurysm neck obliteration; Rx. = treatment; F/u = follow-up; ± = subtotal obliteration; + = complete obliteration; − = incomplete obliteration.

[a] 3 × 30 = 3 mm × 30 mm flower-petal coil.
[b] 2 × 20 = 2 mm × 20 mm flower-petal coil.
[c] 4 × 30 = 4 mm × 30 mm complex helical coil.
[d] 2 × 10 = 2 mm × 10 mm figure-of-eight coil.

Results

Surgical Creation of Aneurysm

Twenty-eight rabbits were operated on for these experiments; there were 9 surgically related complications including: four aspiration pneumonias within 2 days of surgery, three intraoperative deaths due to either vocal cord paralysis and/or anesthesia overdose, and two animals with occlusion of either the aneurysm or the

parent vessels on the first postoperative angiogram. Of the 19 animals that showed both patent aneurysms and bilateral carotid arteries on the first postoperative angiogram, seven were used as controls and 12 were treated with endovascular packing. None of the seven control aneurysms showed spontaneous thrombosis, or any change in size over the 3-month follow-up period.

Outcome of the 12 rabbits treated with endovascular packing are summarized in Table 1.

Aneurysms Treated with Loosely Packed Coils

The first three rabbits were each treated initially with deposition of only two coils within the aneurysm. A combination of three coil configurations including flower-petal, complex helical, and figure-of-eight coils were used during this initial endovascular procedure. Even though flower-petal coils were inherently more stable within an aneurysm, figure-of-eight and complex helical coils can all maintain their position within a bifurcation aneurysm as long as there is a good match between the coil and the aneurysm (Fig. 1). Follow-up angiogram at 1 month showed no significant thrombosis of the aneurysm or change in its size. The results in these three rabbits with bifurcation aneurysms suggest that polyester fiber-coated platinum coils loosely packed within a bifurcation aneurysm is not sufficient to induce progressive thrombosis. Rabbits 1 and 2 subsequently underwent a second procedure for more complete packing of the aneurysm (Fig. 2). Rabbit 3 developed a foot ulcer secondary to femoral nerve injury from the cut-down procedure and was killed 29 days after initial coil placement.

Aneurysms Treated with Tightly Packed Coils

Including rabbits 1 and 2 which underwent repeat packing, eight rabbits underwent successful tight coil packing of their aneurysms. With the exception of rabbit 1 which showed subtotal aneurysm dome obliteration, the other seven rabbits all demonstrated total obliteration of the aneurysm dome. Complete angiographic obliteration of the aneurysm neck was achieved in only one out of the eight animals (rabbit 5). On the animals that underwent subtotal packing of the aneurysm neck (Fig. 2D), follow-up angiography typically showed contrast filling between interstices of tightly packed coils at or above the aneurysm neck (Fig. 2E). In spite of subtotal aneurysm obliteration in seven out of eight animals, no significant shifting of the previously tightly packed coils within the aneurysm was detected. Only one (rabbit 7) out of this group of eight showed evidence of enlargement at the aneurysm neck (Fig. 3) during the follow-up period ranging from 29–108 days. On postmortem gross examination, all eight rabbits demonstrated the presence of extensive spindle cell hyperplasia on the coil surface or in the interstices between coils with channels lined by cells resembling endothelial cells; there was a trace of hemosiderin but no evidence of organized thrombus (Fig. 4).

Complications of Endovascular Therapy

There were three significant embolization-related complications, unfortunately including two (rabbits 10 and 11) of the three rabbits that underwent the most complete packing of the entire aneurysm. In rabbit 10, the catheter was withdrawn slightly as the last coil was extruded into the aneurysm neck. This slight motion was enough to direct the tail end of the helical coil into the left common carotid artery. With much endovascular manipulation, we managed to redirect the tail end of the last coil back into the aneurysm; the postembolization angiogram demonstrated patency of the parent vessel (Fig. 5). This rabbit died from a stroke 1 day later; at autopsy, the right common carotid artery was occluded. This complication was probably due to iatrogenic intimal damage to the parent vessel by the guide wire as we tried to redirect the tail end of the last coil back into the aneurysm.

In rabbit 12, the right common carotid artery was occluded toward the end of endovascular packing as the delivery catheter was withdrawn simultaneous to the extrusion of the tail end of a coil. In this instance, the hockey-stick angulation at the tip of the 3.6-F delivery catheter was not eliminated with a stiff guide wire; as the catheter was withdrawn it also pulled an intraaneurysmal coil back into the right common carotid artery. This incident occurred during the early part of our experience; from then on, any angulation in the tip of the delivery catheter was eliminated by the introduction of a stiff, straight 0.018-inch guide wire prior to withdrawal from a tightly packed aneurysm. With that modification, we have not encountered the same problem. Rabbit 11 developed paraplegia after total aneurysm obliteration, presumably from spinal cord ische-
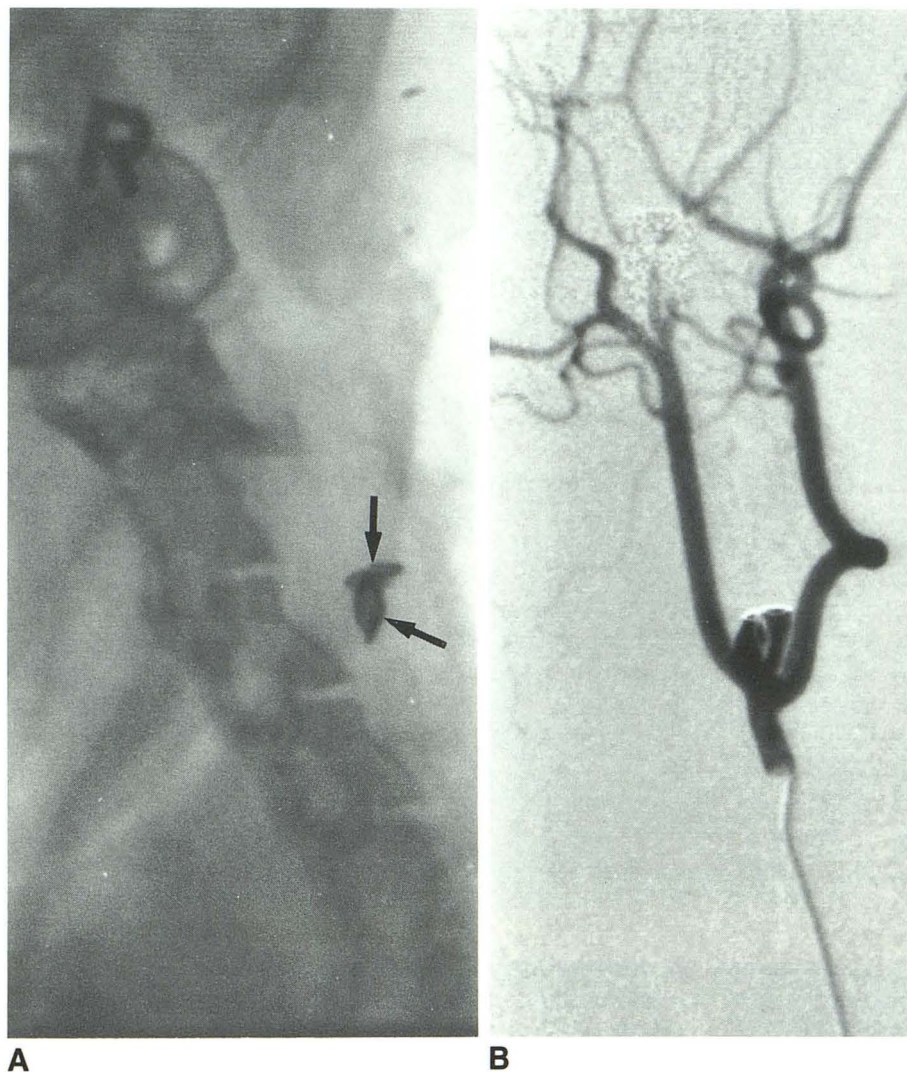
A   **B**

Fig. 1. *A*, Plain film of the neck in rabbit 2 following placement of one 4 mm × 30 mm complex helical coil (*bottom arrow*) and one 2 mm × 10 mm figure-of-eight coil (*top arrow*) within the aneurysm.

B, Follow-up right common carotid angiogram 29 days later shows stable coil configuration within the nonthrombosed bifurcation aneurysm.

mia secondary to prolonged catheter manipulation in the aorta.

With the exception of rabbit 10, there was no evidence of cerebral emboli on gross examination or histologic sections of the brain in either the treated rabbits or the control group.

Discussion

The current treatment of choice for most ruptured intradural aneurysms is surgical clipping with preservation of flow in the parent vessel. However, clipping is not always indicated in patients with unstable medical conditions, nor is it always possible in giant aneurysms with mural thrombi or a calcified neck. In this group of high-risk patients, alternative therapy is needed. Over the last decade, endovascular procedures have advanced to become an acceptable alternative to surgical clipping in selected cases.

The goal of endovascular therapy is complete aneurysm thrombosis followed by reendothelialization across the aneurysm neck; however, this is not always attainable in clinical practice. A report from Higashida et al suggests that a partially treated aneurysm with detachable silicone balloon represents an extremely high-risk situation with a mortality rate as high as 53% (2). Animal experiments using a rabbit bifurcation aneurysm model have reproduced anecdotal clinical experience of aneurysm enlargement following apparent successful intraaneurysmal balloon occlusion (Kwan et al, paper presented at the Annual Meeting of the American Society of Neuroradiology, Washington DC, June 1991). This phenomenon is primarily due to two factors: 1) the "water-hammer" effect of incessant pulsatile blood transmitted to the aneurysm dome via the 2-hydroxyethylmethacrylate (HEMA)-filled ballon, and 2) geometric mismatch between the
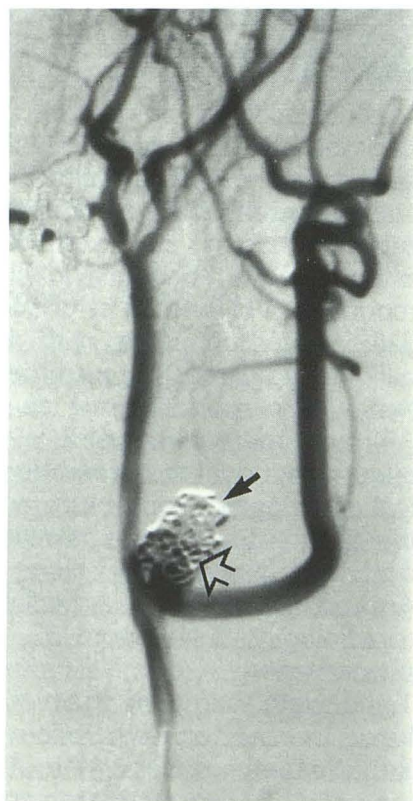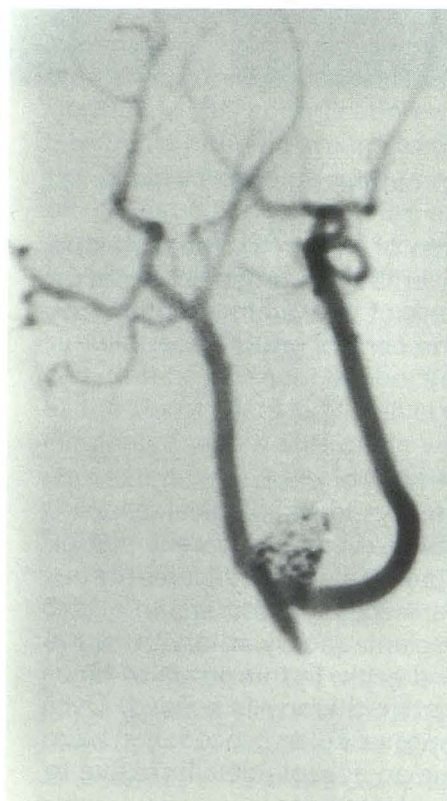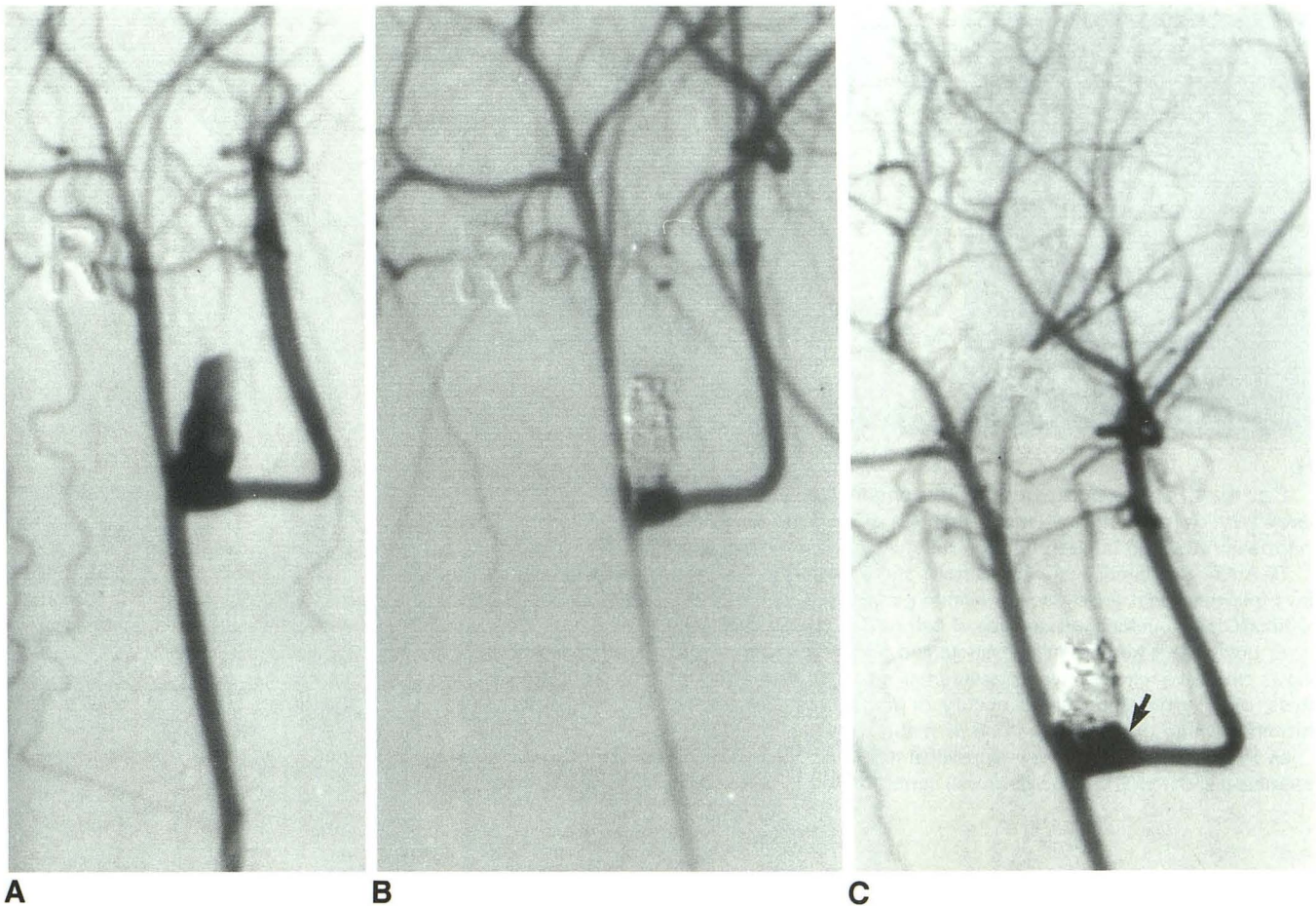
A

B

C

D

E

A   B   C
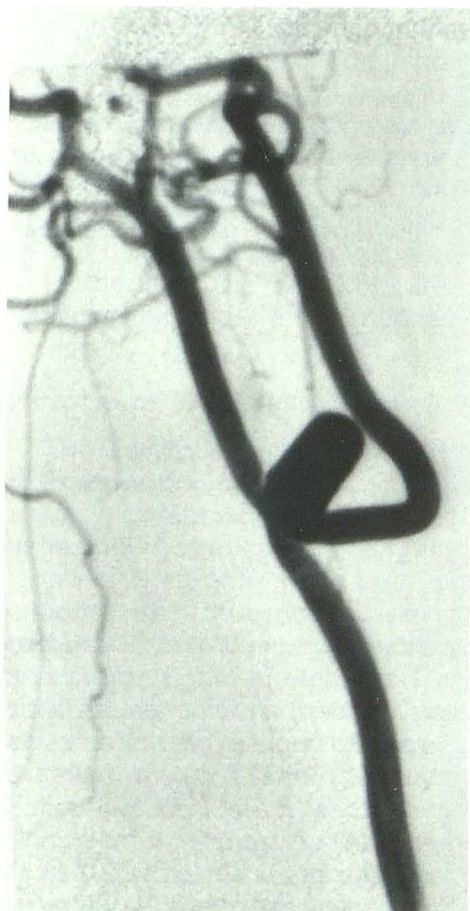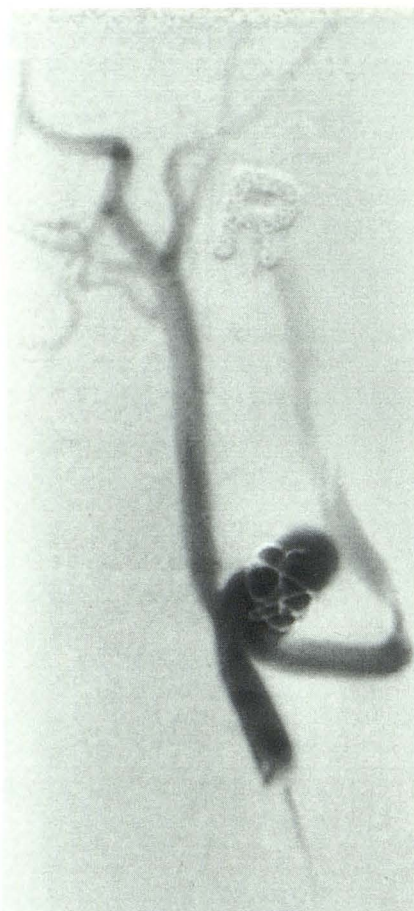
Fig. 3. *A*, Right anterior oblique projection of right common carotid angiogram in rabbit 7 prior to endovascular packing with coils.

B, Control angiogram immediately following endovascular packing. Note catheter and coil pusher induced spasm in the right common carotid artery proximal and distal to the aneurysm.

C, Repeat angiogram 98 days following treatment shows regrowth (*arrow*) at the aneurysm neck.

convex margin of the balloon collar and the aneurysm neck. There is considerable room for improvement in endovascular treatment of aneurysms. Recent experimental data in a swine side-wall carotid aneurysm model (8) has demonstrated endothelialization over aneurysm necks following endovascular packing with platinum coils and electrothrombosis. This raises the possibility that polyester fiber-coated platinum coils may also be a viable alternative to detachable balloons in the treatment of surgical unclippable aneurysm.

Historically, venous pouch side-wall aneurysms have been created experimentally in the dog carotid artery (9). Although this model can simulate cavernous internal carotid artery aneurysms and some lateral vertebral basilar artery aneurysms in humans, the major problem with this model is twofold: 1) depending on the ratio of the aneurysm orifice and volume, these aneurysms are susceptible to spontaneous thrombosis (10); 2) flow dynamics are not similar to human intracranial bifurcations aneurysms. Treatment data from the side-wall model should not be directly

Fig. 2. *A*, Right common carotid angiogram in rabbit 1, 2 weeks following surgical creation of bifurcation aneurysm.

B, Control angiogram immediately following deposition of two 3 mm × 30 mm flower-petal polyester fiber-coated coils (*arrows*).

C, Repeat angiogram 29 days following initial endovascular procedure shows no thrombosis or change in size of aneurysm. Note stability of flower petal coils within aneurysm between the two studies.

D, Control angiogram immediately after tight packing with nine additional platinum coils shows ablation of the aneurysm dome (*arrow*); contrast, however, fills interstices between coils at the aneurysm neck (*open arrow*).

E, Follow-up angiogram 36 days after *D* shows contrast continues to fill interstices between platinum coils at both the dome and the neck. Note there is no interval growth in the tightly packed aneurysm.
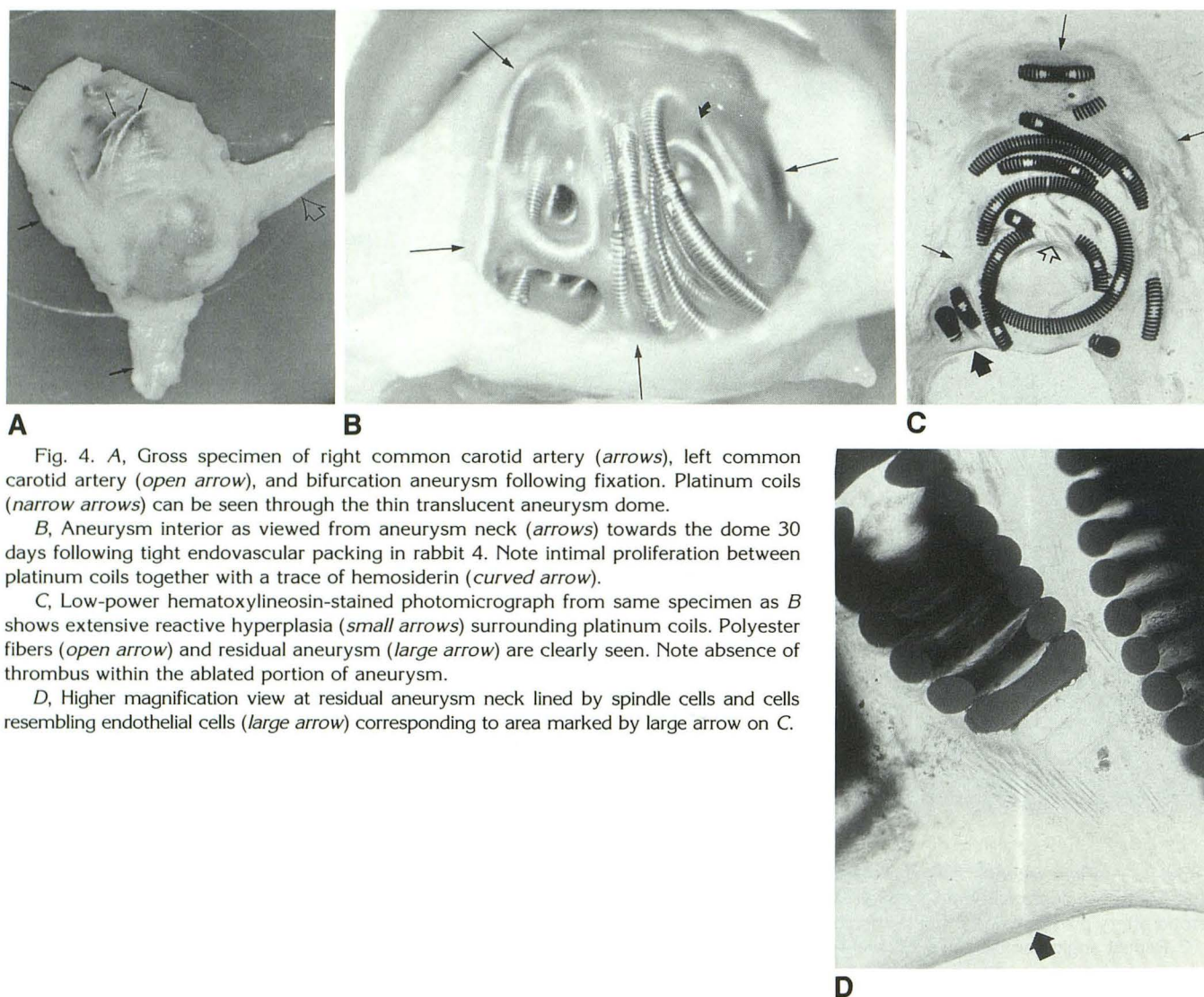
A   B   C

Fig. 4. *A*, Gross specimen of right common carotid artery (*arrows*), left common carotid artery (*open arrow*), and bifurcation aneurysm following fixation. Platinum coils (*narrow arrows*) can be seen through the thin translucent aneurysm dome.

B, Aneurysm interior as viewed from aneurysm neck (*arrows*) towards the dome 30 days following tight endovascular packing in rabbit 4. Note intimal proliferation between platinum coils together with a trace of hemosiderin (*curved arrow*).

C, Low-power hematoxylineosin-stained photomicrograph from same specimen as *B* shows extensive reactive hyperplasia (*small arrows*) surrounding platinum coils. Polyester fibers (*open arrow*) and residual aneurysm (*large arrow*) are clearly seen. Note absence of thrombus within the ablated portion of aneurysm.

D, Higher magnification view at residual aneurysm neck lined by spindle cells and cells resembling endothelial cells (*large arrow*) corresponding to area marked by large arrow on *C*.

D

transferred to human bifurcation aneurysms because of the differences in hemodynamics. While side-wall aneurysms are undoubtedly subject to increased hemodynamic stress at the in-flow and out-flow zones of the aneurysm ostium (11, 12), the side-wall model may underestimate aneurysm recurrence rate following endovascular packing when compared to bifurcation aneurysms. Even though the rabbit carotid bifurcation aneurysm model is more difficult to construct, with only one aneurysm per animal, and there is significant surgical morbidity, we believe this system offers a realistic hemodynamic model since most intradural aneurysms do occur at bifurcations and the dimensions of the rabbit common carotid artery are similar to those of human middle cerebral arteries. A notable difference between this model and human intradural aneurysms is that none of

the aneurysms in this experiment have a well-defined neck; they simply have an "open face" where the aneurysm joins directly to the parent artery.

A fundamental limitation of any experimental animal aneurysm model used for the evaluation of endovascular therapy is the difference in the coagulation profile between animals and humans. The rabbit thrombotic and thrombolytic systems have been extensively studied. Of the nonprimate animals, the rabbit has one of the thrombolytic profiles most comparable to humans and thus has been used extensively in thrombolytic research (13, 14).

Our results indicate that polyester fiber-coated platinum coils in their present form produce aneurysm ablation by spindle cell hyperplasia bridging across tightly packed coils. The exact nature of
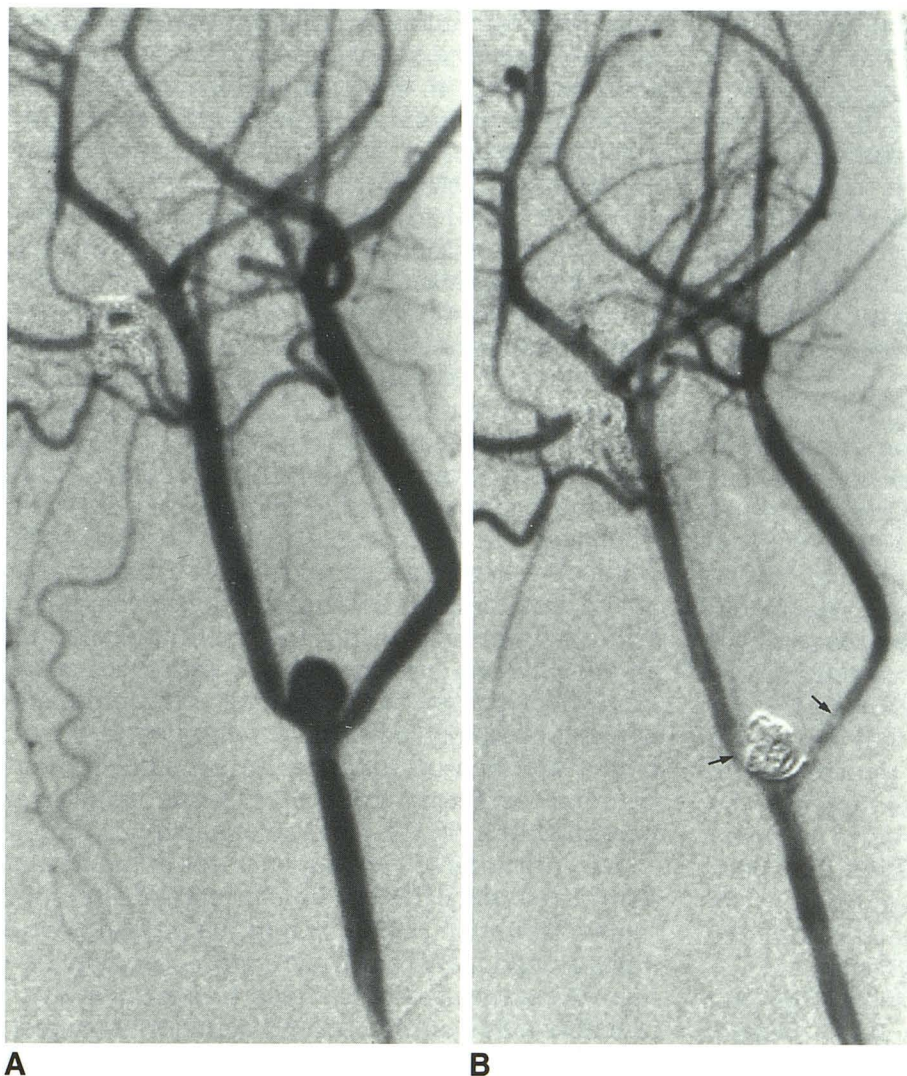
A   **B**

Fig. 5. *A*, Pretreatment right common carotid angiogram showing a broad-base bifurcation aneurysm in rabbit 10.

B, Postpacking control angiogram showing complete aneurysm ablation. Small intrluminal filling defects (*arrows*) within parent vessels are likely secondary to intimal damage during redirection of the last coil.

the spindle cells is unclear; it may represent either smooth muscle cells or intima. Accurate histologic identification of the spindle cells is difficult for the following reasons: 1) in order to cut the packed aneurysm with the platinum coils in situ, the specimens have to be relatively thick (50–100 microns), and 2) the chemical processing required for the preparation of these specimens prevents special antibody stains which could differentiate smooth muscle versus intima. This dilemma was not recognized until the histologic slides were reviewed. In retrospect, platinum coils should have been removed in some specimens prior to sectioning to allow special antibody staining on routine 8- to 10-micron histologic sections. This is a limitation of our experiment.

None of the subtotally packed aneurysms progressed to total ablation via progressive thrombosis. As a rule, we were more aggressive in tightly packing the aneurysm dome knowing the

extruded coils in this location would not migrate beyond the safety net of flower-petal coils that were initially deposited within the base of the aneurysm. As packing proceeded from the dome toward the neck, special care was taken to prevent releasing the last segment of the coil into the arterial bifurcation. Shorter coils were used as we proceeded caudally toward the neck so as to allow enough space to extrude the coil entirely within the aneurysm. Shorter coils however are inherently more unstable; a balance must be struck between the benefits of more complete packing versus the risk of releasing a coil into the parent vessels. In seven out of 10 rabbits, we opted to be conservative with the intention of evaluating whether a subtotally packed aneurysm would then go on to complete ablation. Even though subtotally packed aneurysms did not, as a rule, progress to complete thrombosis, our data indicates that by packing at least 75% of the

aneurysm volume, complete ablation of the aneurysm dome can be attained. While this technique may not be the ideal treatment of most ruptured bifurcation aneurysms, the ease with which the aneurysm dome can be reliably ablated suggests that this method may be applicable in poor clinical grade patients following subarachnoid hemorrhage. By performing this procedure acutely, these patients may be protected from acute rehemorrhage at the dome, allowing the patient to recover sufficiently to undergo definitive clipping of the remaining aneurysm necks.

Flower-petal platinum coils coupled with silk fibers have produced complete thrombosis in four out of 10 carotid side-wall venous pouch aneurysms in a canine model (15). Extraaneurysmal thrombosis extending back into the parent vessels was seen in 50% of the animals in that model, raising concern about the suitability of silk-fibered platinum coils in the endovascular packing of human aneurysms. The histologic results of our coil-packed aneurysm model differ from the canine side wall aneurysm results in that we did not see any highly organized mature thrombus. We can only speculate that the discrepancy may be due to 1) difference in flow dynamics between side-wall and bifurcation aneurysm models, 2) relative differences in thrombogenicity of silk versus polyester fibers, or 3) differences in the coagulation profile between the two species.

We perfusion-fixed the carotid bifurcations and the coil-packed aneurysms with 10% neutral buffered formalin under a constant pressure of 80 mm Hg (systolic blood pressure of rabbit) while the animals were anesthetized prior to harvesting the specimen; the rationale of this maneuver is to eliminate the presence of postmortem clot that could potentially confuse the results. Both the gross specimens and the histologic sections demonstrate only spindle cell hyperplasia over the coils with minimal amounts of hemosiderin and no organized thrombus. This finding is not unexpected as the thrombotic and thrombolytic cascades operate simultaneously within a living system.

The absence of cerebral emboli in the brain sections of all neurologically intact rabbits refutes the argument that the perfusion fixation process may flush premortem clot from the coil-packed aneurysm distally into the cerebral circulation.

In this carotid bifurcation aneurysm model, one major difference between animals treated by detachable balloons and those treated by endovascular packing with polyester fiber-coated plati-

num coils is that aneurysm regrowth in the latter group is rare (one out of eight animals) in contrast to the former, in which aneurysm enlargement occurred in nine out of 10 animals (Kwan et al, paper presented at the Annual Meeting of the American Society of Neuroradiology, Washington DC, June 1991). A possible explanation for this discrepancy is that, in the latter, the forces of arterial pulsations directed at the aneurysm neck are dissipated diffusely over the interstices between multiple coils, resulting in flow redistribution. With detachable balloons, pulsatile blood continues to strike the base of the HEMA-filled balloon with systemic artery pressures, resulting in constant hammering of the balloon into the aneurysm dome. It is of interest that the animal (rabbit 7) with the highest density of packed coils within the aneurysm is also the one that manifested aneurysm growth at 3-month follow-up (Fig. 3); thereby raising the question of ideal packing density for treating aneurysms with polyester fiber-coated platinum coil. One wonders whether a solidly coil-packed bifurcation aneurysm may then be subjected to the same "water hammer" effect at the orifice as an aneurysm treated with a HEMA-filled detachable balloon?

We encountered two major causes of morbidity associated with this aneurysm model. Hemorrhagic aspiration pneumonia in the early postoperative period was our most common complication. We suspect this was due to laryngeal dysfunction either secondary to superior laryngeal nerve injury or muscle dysfunction due to the extensive neck dissection. Early in our experience, we also encountered spontaneous thrombosis of either the aneurysm or the parent vessels in spite of a good technical surgical anastomosis. We suspect that this may have been secondary to drying of the anastomotic vessels under the high intensity light of the operating microscope; this problem was solved when we liberally irrigated the carotid arteries with papavarine solution prior to and during anastomosis.

Conclusion

The rabbit common carotid bifurcation aneurysm is a useful model for the testing and development of endovascular techniques in the treatment of human intracranial bifurcation aneurysms. It is encouraging to observe intimal hyperplasia on the coils tightly packed within the aneurysm and a low rate of aneurysm growth after subtotal endovascular packing. A major lim-

itation of this technique is that it is technically very difficult to pack reliably and tightly these commercially available coils to the aneurysm neck without leaving a portion of one in the parent vessel. Unfortunately, as long as the neck is not totally packed, progressive thrombosis following embolization is unlikely in this bifurcation aneurysm model. Perhaps by increasing the bulk of polyester fibers on the coil surface the thrombogenicity can be enhanced. This model suggests that endovascular packing of human intracranial bifurcation aneurysm with current commercially available polyester fiber-coated platinum coils may not result in complete aneurysm obliteration with reendothelialization across the aneurysm neck. Caution is therefore advised.

Acknowledgments

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APPENDIX

Specimens were processed in the following solutions at Harrington Arthritis Research Center, Phoenix, Arizona, in a Miles Scientific Tissue-Tek-VIP Processor:

70% ETOH 30 minutes
95% ETOH 30 minutes
Absolute ETOH 1 hour

Infiltration was then carried out at 4°C under vacuum in the following sequence:

Solution I
1 day — 75 mL noninhibited methyl methacrylate (MMA) and 20 mL N-butylphthalate.

Solution II
1 day — 75 mL MMA with 1 gm of Benzoyl Peroxide (BPO) and 20 mL N-butylphthalate.

Solution III
2 days — 75 mL MMA with 2.5 gm BPO and 20 mL N-butylphthalate

Specimens were embedded in solution III in jars that already had a prepolymerized layer, then allowed to stabilize at room temperature for 2–3 days. Polymerization took place at a 37°C oven until the entire polymerized methyl methacrylate (PMMA) layer hardened. Blocks were cast out by cracking the chilled jars. Thick sections of 400 microns were cut using a Leco VC-50 saw with a diamond wafering blade. Sections were polished on one surface with lapping paper mounted on a Leco VP-50 grinder. The polished surface was glued to a plastic slide with superglue. After 1–2 hours, the sections were further thinned down by grinding on silicone carbide size 600 grit paper on the grinder. They were then polished on lapping papers starting from size 23 microns down to 3 microns. The finished sections were about 50–100 microns thick. Sections were placed in a soapy solution in an ultrasonic cleaner for 5 minutes. They were rinsed in distilled water for 5 minutes with two changes, and were stained with hematoxylineosin stain.