

Intraoperative Misadventures: Complication Avoidance and Management in Aneurysm Surgery

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There are no secrets to success. It is the result of preparation, hard work, and learning from failure.

Colin Powell

This morning I am speaking on the subject of complication avoidance and management, which is the result of preparation, hard work, and learning from failure. Although aneurysm surgery is my topic, these principles apply to all areas of intracranial neurosurgery. Avoiding complications begins with appropriate patient selection and includes the prevention of a number of misadventures, and as with all neurosurgical procedures, meticulous postoperative management is essential.

PATIENT SELECTION

Figure 1A shows an angiogram from a 32-year-old woman who experienced a subarachnoid hemorrhage from a low-lying basilar bifurcation aneurysm. The decision was made to treat this aneurysm through a frontotemporal craniotomy, anticipating that the posterior clinoid process would have to be removed to obtain proximal control. After the posterior clinoid was drilled and during its removal with a curette, the carotid artery was inadvertently torn, resulting in massive bleeding. The torn carotid artery was trapped, the anterior clinoid process drilled, and the dural ring opened to obtain more proximal control, and temporary clips were placed so that the 2 ends of the carotid could be primarily reanastomosed to reconstruct the torn internal carotid artery. Once the carotid artery was reconstructed, treatment of the basilar aneurysm proceeded with temporary clipping of the basilar artery and clipping of the aneurysm with a combination of fenestrated and straight aneurysm clips. Postoperatively, the patient did well for the first 2 days and then rapidly deteriorated; a follow-up computed tomography (CT) scan demonstrated a massive infarction (Figure 1B). Despite decompressive hemicraniectomy, the patient died. This disaster may have been an error in patient selection. My colleagues with expertise in endovascular therapy thought the aneurysm was not ideal for endovascular therapy, but the added risk of drilling the posterior clinoid process may have made endovascular therapy a better option than surgery.

Patient selection involves the consideration of factors of the patient, factors of the aneurysm, factors of the surgeon, and selection of the most appropriate therapeutic modality. Factors of the patient include age, overall health status, and the psychological impact of harboring a potentially life-threatening lesion. Factors of the aneurysm include symptoms, size, location, configuration, and presence of an intracerebral hemorrhage. Factors of the surgeon to be taken into consideration are related primarily to experience. A number of aneurysms are simply not ideal for surgical management, including those in elderly patients, in patients in poor neurological condition, and in patients presenting with cerebral vasospasm; aneurysms that are difficult to surgically access; and multiple aneurysms requiring multiple craniotomies for treatment. Many of these aneurysms are better treated by endovascular therapy because of recent advances in this discipline. Many aneurysms, however, still require surgical treatment. This includes fusiform, blister-like, very small, very large, thrombotic, and wide-necked aneurysms, as well as those presenting with a clinically significant intracerebral hemorrhage. For microsurgery to remain a viable option, we must minimize risks and complications.¹ Surgery is not minimally invasive but should be minimally disruptive.

DIRECT INJURY

Figure 2 shows a contusion and associated subarachnoid hemorrhage from the craniotomy opening for an unruptured aneurysm in a 41-year-old woman. She developed a symptomatic intracerebral contusion as a result of this seemingly minor mishap during exposure. Avoiding direct injury to the brain involves the use of surgical adjuncts, appropriate exposure, and brain relaxation; minimizing the use of retractors to preserve veins; and protecting the brain during temporary occlusion. A number of surgical adjuncts minimize the risk of direct brain injury. Some of these adjuncts include skull base bony removal to minimize or eliminate brain retraction, meticulous microsurgical dissection to preserve veins, pharmacologic brain protection or bypass procedures to reduce the risk of ischemic injury, use of temporary clips to reduce the risk of intraoperative rupture, and intraoperative imaging with digital subtraction angiography or

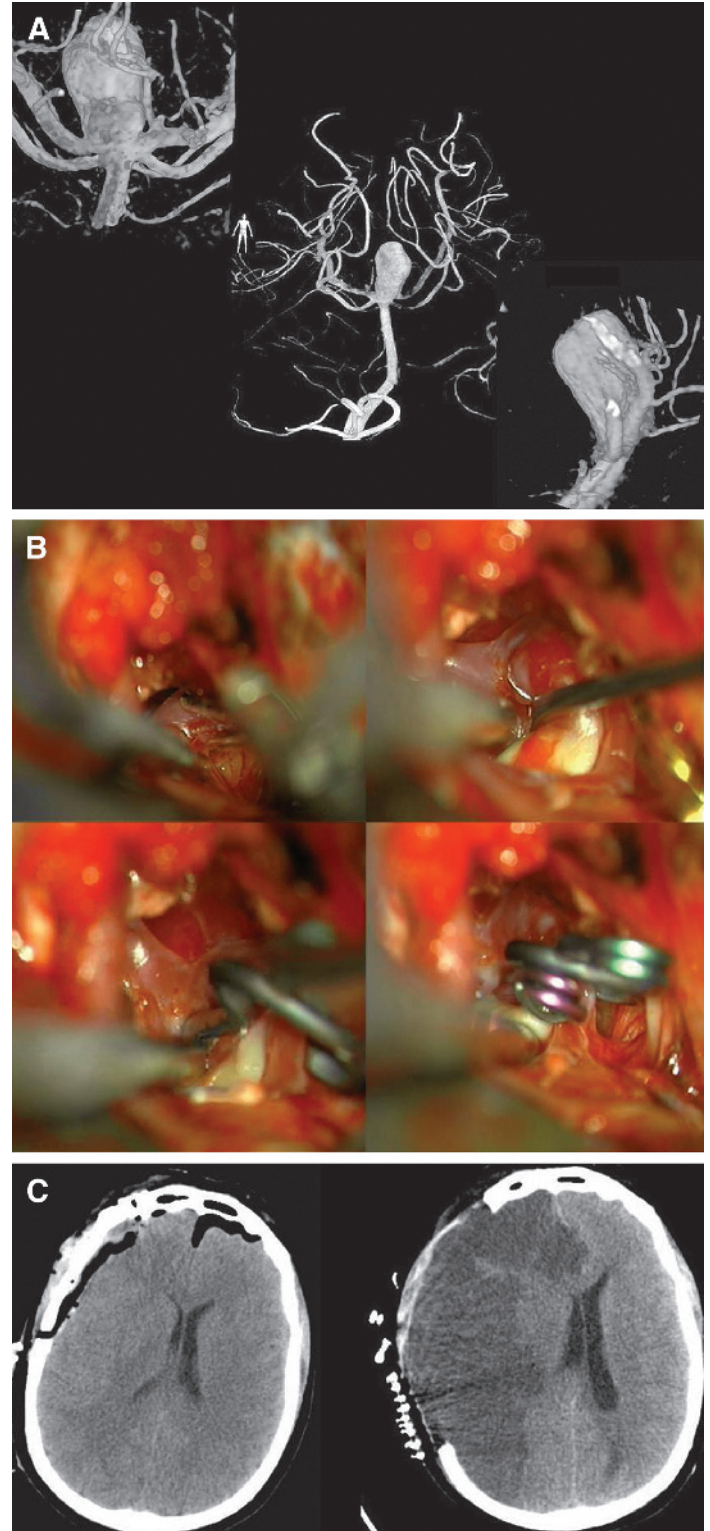


FIGURE 1. A, preoperative vertebral angiogram showing a basilar tip aneurysm that was the source of a subarachnoid hemorrhage. It was clipped through a pterional approach with drilling of the posterior clinoid to obtain proximal control and temporary clipping of the basilar artery. B, during removal of the posterior clinoid with a curette, the internal carotid artery was accidentally torn and repaired in an end-to-end fashion with 9-0 monofilament suture, re-establishing flow. C, the aneurysm was clipped uneventfully, and the patient initially did well, as indicated by the postoperative CT on the left. Two days later, she rapidly deteriorated, likely from thrombosis of the repaired internal carotid artery. Despite a decompressive hemicraniectomy, the patient died. The final CT is on the right.

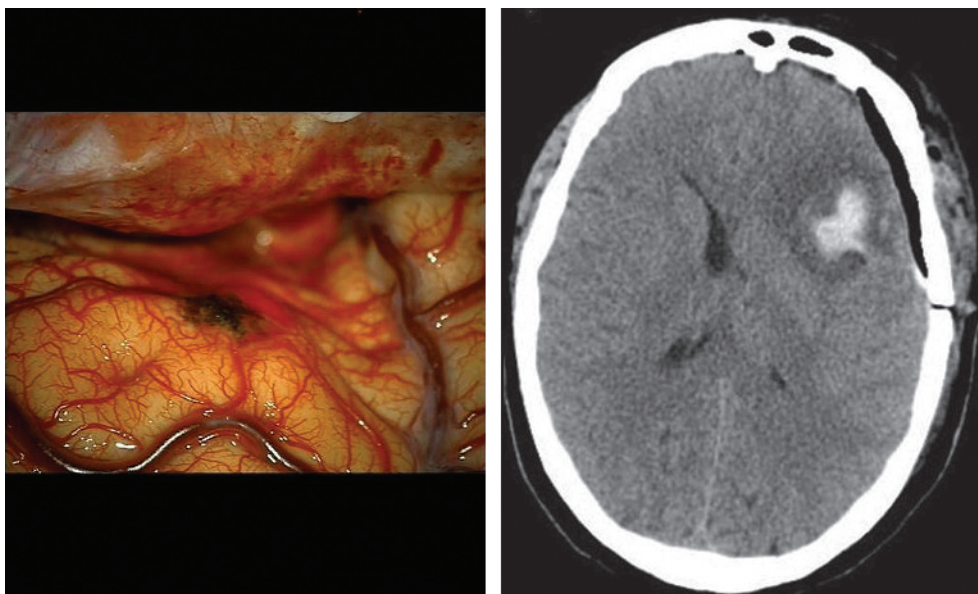


FIGURE 2. Direct injury to the brain. Left, during a craniotomy opening for elective repair of an unruptured aneurysm, the cortical surface of the brain is contused from the drill. Right, this resulted in the contusion and cerebral hemorrhage seen on the postoperative CT.

indocyanine green videoangiography to verify surgical results. The pterional craniotomy is the workhorse of aneurysm surgery. Figure 3 shows an inadequate exposure with significant portions of the lesser wing of the sphenoid remaining. Aggressive removal of the lesser wing of the sphenoid exposes the entire sylvian fissure without the need to retract the brain. Adequate brain relaxation through the use of osmotic diuretics and opening of cisterns minimizes the need for retractors, even after subarachnoid hemorrhage (Figure 4). While focusing on the arterial anatomy during aneurysm surgery, the surgeon may

overlook the importance of preserving the veins, particularly within the sylvian fissure. Meticulous preservation of all veins within the sylvian fissure maintains adequate venous drainage and eliminates potentially devastating venous congestion and infarction.^{2,3}

Selecting the most appropriate approach for the individual aneurysm is critical. The basilar aneurysm in Figure 5 was associated with a high bifurcation that was well above the sella turcica. An orbitozygomatic approach was used to visualize up into the interpeduncular fossa from the left side. A fenestrated clip

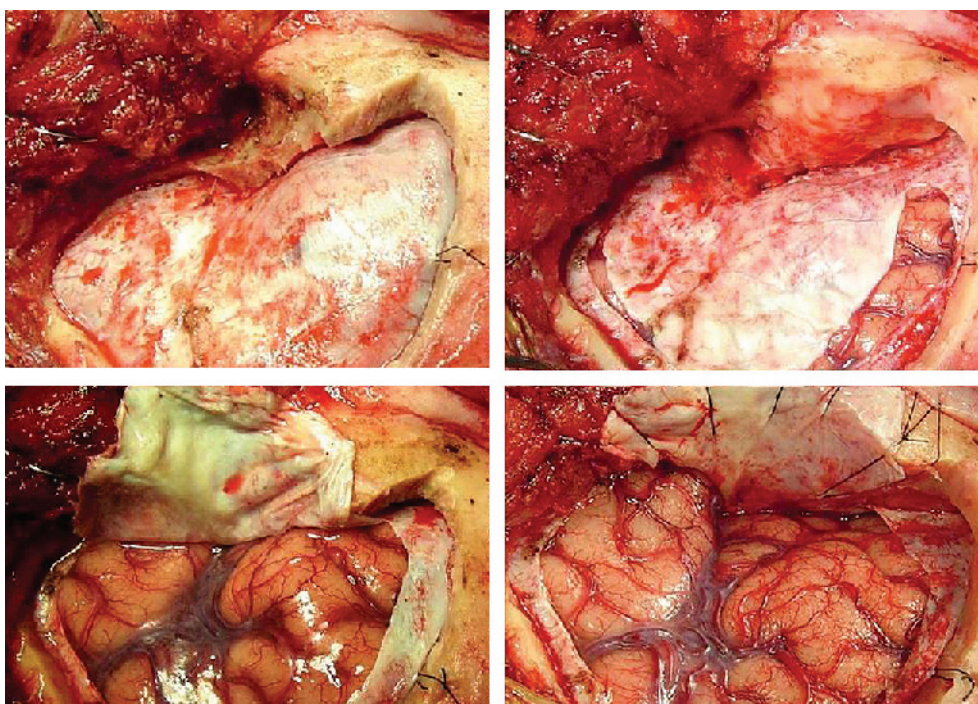


FIGURE 3. Left, inadequate bony removal on a pterional craniotomy for aneurysm. The remaining lesser wing of the sphenoid would result in the need to retract the brain to expose the entire sylvian fissure. Right, proper bony removal of the lesser wing of the sphenoid to expose the fissure and to minimize the need for retraction.

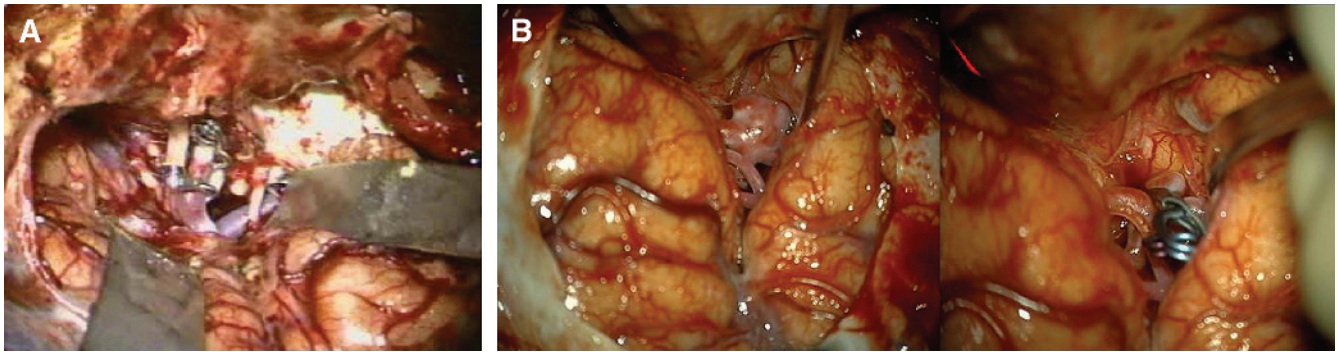


FIGURE 4. A, intraoperative photograph from early in my career shows excessive retraction to expose the proximal internal carotid artery. B, intraoperative photograph demonstrates clipping of a middle cerebral artery aneurysm without the use of retractors.

was used to obliterate the aneurysm and to reconstruct the lumen of the left P1 segment of the posterior cerebral artery. The intraoperative angiogram demonstrated complete obliteration of the aneurysm. Figure 6 also shows a basilar bifurcation aneurysm, but one associated with a very low bifurcation that would preclude adequate exposure through a frontotemporal approach. It was approached through an anterior subtemporal approach, and 2 fenestrated clips were used to reconstruct the lumen of the right posterior cerebral artery.

Intraoperative ischemic insults may result from the use of temporary clipping during aneurysm repair. Modest hypothermia, induced hypertension, and mannitol and barbiturate or propofol for burst suppression have been used to protect the brain during temporary occlusion.^{4,5} These adjuncts may prolong ischemic tolerance times. Figure 7 is an angiogram from a 22-year-old woman who presented with progressive mass effect from this giant rostral basilar aneurysm and was treated with deep hypothermic circulatory arrest for maximal brain protection and a medial petrosectomy to achieve visualization far down the clivus. After arrest, the softened aneurysm could be gathered and reconstructed with a series of aneurysm clips to decompress the brainstem. The intraoperative angiogram shows obliteration of the aneurysm.

INCOMPLETE OBLITERATION

Durability is the major advantage of surgical ligation of aneurysm⁵ over current endovascular options. With the use of modern aneurysm clips, the risk of recurrence after appropriate clipping is very low.⁶ Incomplete obliteration, however, is a potential complication of aneurysm surgery and leaves the patient at risk of future hemorrhage.⁷⁻¹¹ Figure 8 is from a 56-year-old man who had undergone surgery 15 years previously for a ruptured posterior communicating artery aneurysm and now presented with a recurrent hemorrhage resulting from inadequate clipping during his prior operation. Incomplete obliteration of aneurysms is also avoidable. Observation under the operating microscope is essential and assists the surgeon in determining whether the aneurysm appears to be completely obliterated (Figure 9). Observation alone, however, does not ensure complete

treatment. This observation can be enhanced by puncturing the dome of the aneurysm. Intraoperative angiography has become the mainstay for documenting complete obliteration.¹² A small residual anterior communicating aneurysm, shown in Figure 10, was identified after what was thought to be complete clipping. Readjustment of the clip resulted in complete obliteration of the aneurysm. More recently, indocyanine green videoangiography has provided beautiful fluorescent images of aneurysms before and after clipping (Figure 11).¹³ A variety of innovative clipping techniques have been developed to completely obliterate even complex aneurysms. Figure 12 shows a large anterior communicating artery aneurysm clipped with a combination of a fenestrated clip placed around the right A1-A2 junction and a straight clip on the portion passing through the fenestration.

Although the goal of aneurysm surgery is complete obliteration of the aneurysm, this goal has to be tempered with good judgment. Figure 13 shows a large carotid aneurysm that was secured with multiple clips, but the initial intraoperative angiogram demonstrated a small residual aneurysm. Further attempts to obliterate the aneurysm resulted in occlusion of the carotid artery, and we settled for a small residual that was wrapped with muslin.

COMPROMISE OF PARENT VESSEL

Figure 14 is a CT of a 35-year-old patient who underwent elective surgery for a carotid aneurysm and developed transient postoperative dysphasia from the inadvertent compromise of a perforating vessel, causing a small stroke. This potentially devastating complication can also be minimized by attention to detail and the use of surgical adjuncts. Although important, observation under the operating microscope can be misleading, particularly in thick-walled aneurysms. Although the surgeon may believe the clip position maintains patency of the lumen, a thickened wall may compromise the lumen without external clues. Furthermore, observation under the operating microscope can be difficult in complex aneurysms that require multiple clips that may obscure the surgeon's ability to identify the patency of parent vessels and branches (Figure 15). Postoperative angiography was, for many years, the gold standard for

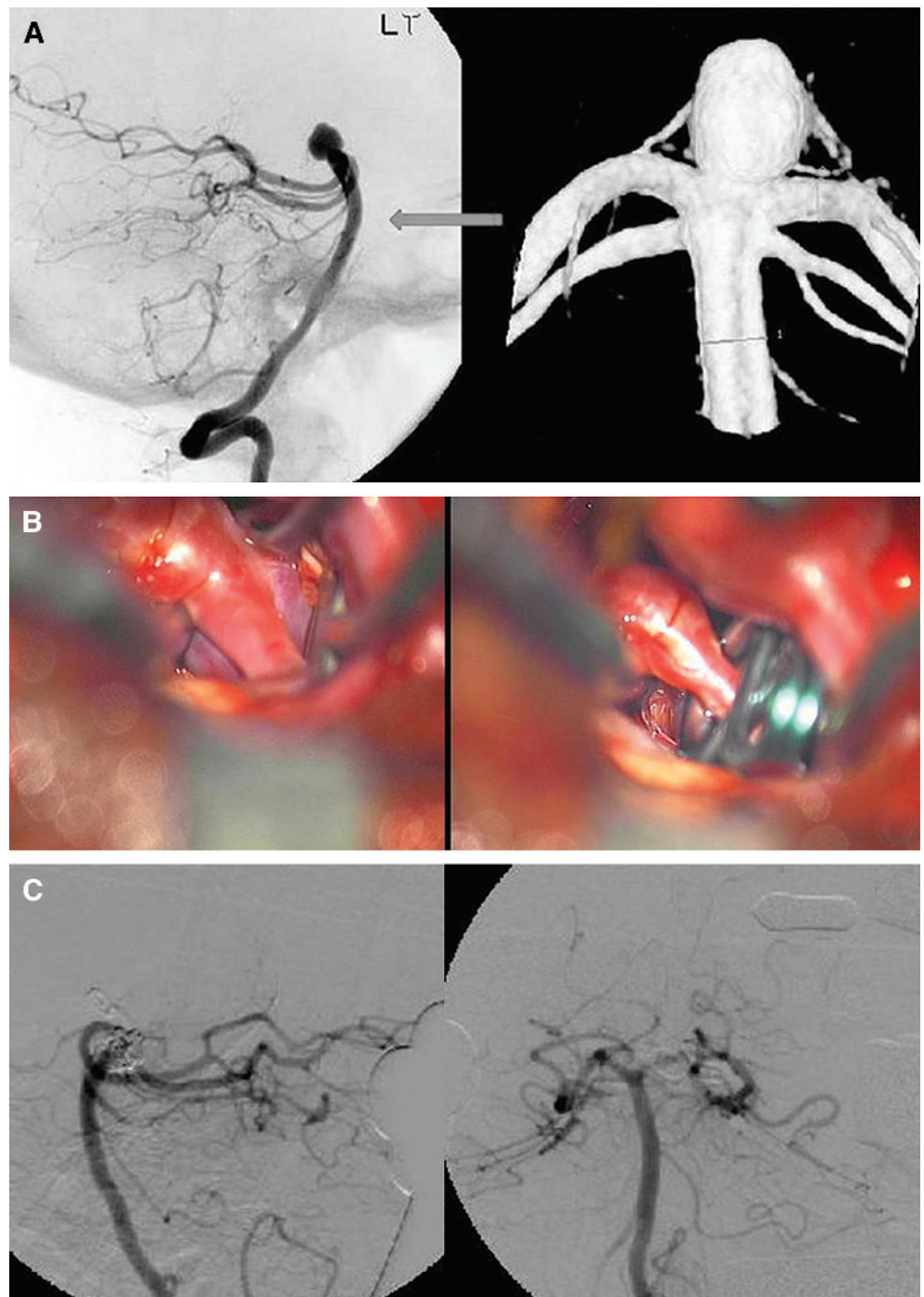


FIGURE 5. A, preoperative angiogram demonstrates a basilar tip aneurysm with a high bifurcation (arrow points to the clinoid process). B, intraoperative photograph shows the exposure from the left side up into the interpeduncular fossa (left) and the aneurysm clipped with a fenestrated clip encircling the left posterior cerebral artery (right). C, intraoperative angiogram documents complete obliteration of the aneurysm and filling of the normal vasculature.

documenting success of the operation. Unfortunately, complications seen on postoperative angiography are often identified too late to remedy the problem (Figure 16). More recently, intraoperative angiography has become the mainstay of posttreatment imaging.¹² Figure 17 shows a giant, partially thrombosed middle cerebral artery aneurysm that was clipped in which the initial intraoperative angiogram demonstrated occlusion of one of the middle cerebral branches. This was

rapidly corrected by a reconfiguration of the clips with documentation of patency of the parent vessels on an immediate repeat angiogram. Indocyanine green videoangiography is proving to be an adjunct to intraoperative angiography in identifying branch occlusion and assisting in its rapid correction. Microvascular Doppler was used in the management of the challenging case shown in Figure 18 of a large carotid aneurysm that was treated on multiple occasions with endovascular

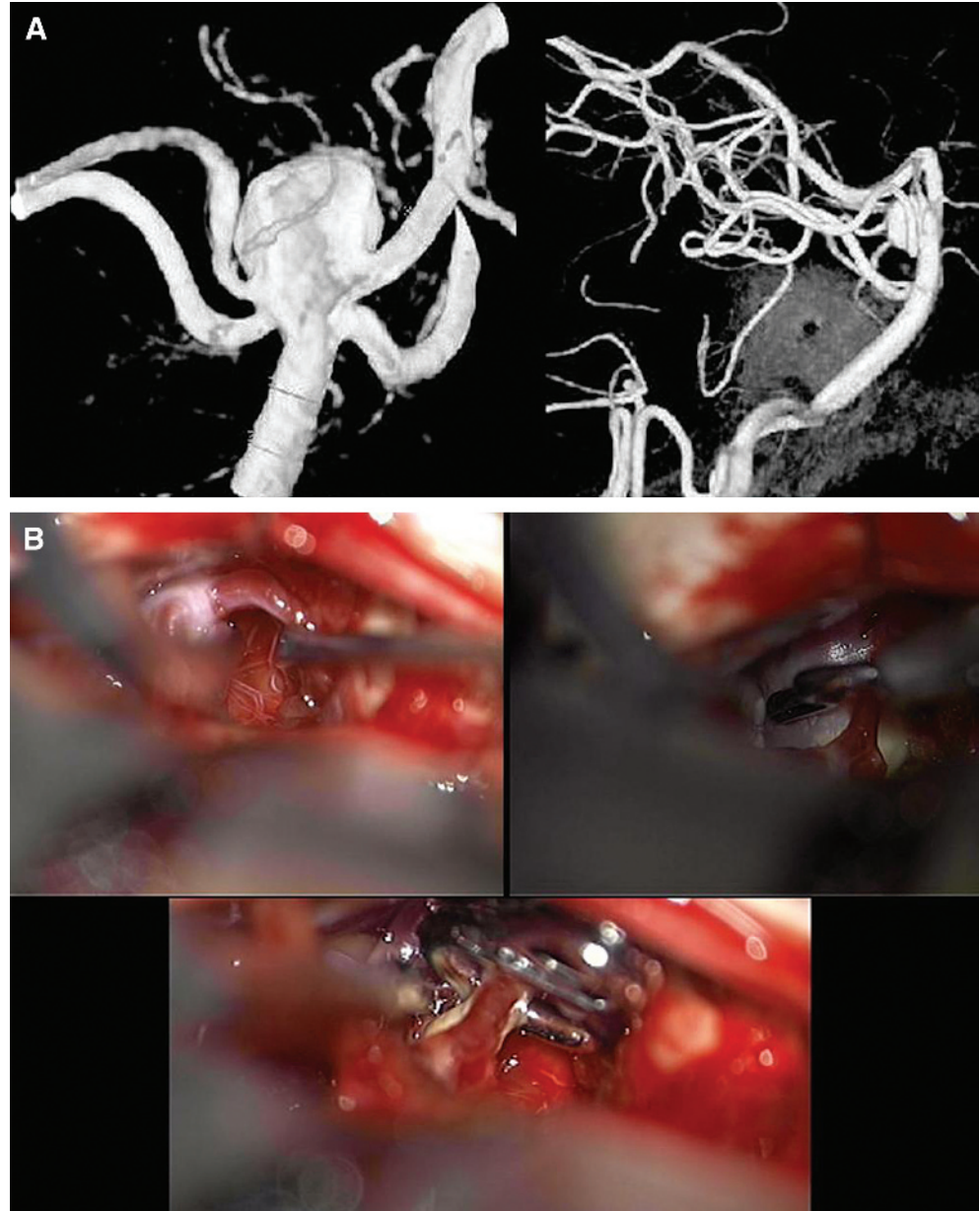


FIGURE 6. A, preoperative angiogram of a basilar tip aneurysm with a very low bifurcation. B, intraoperative photographs of the right-sided subtemporal approach. Top left, the aneurysm is being displaced anteriorly to expose the perforators behind the basilar bifurcation. Top right, a fenestrated clip is being placed across the neck of the aneurysm with the fenestration reconstructing the lumen of the right P1 segment of the posterior cerebral artery. Bottom, final result with the aneurysm clipped and basilar bifurcation reconstructed.

coiling, each time with a significant recurrence. After trapping of the internal carotid artery in the cervical region and intracranially, a series of fenestrated clips were stacked progressively more distally to increase the lumen of the internal carotid artery gradually. Microvascular Doppler was used to document flow through the carotid artery once it was completely reconstructed with the fenestrated clips. Intraoperative angiography confirmed filling through the reconstructed carotid.

Complex clipping strategies can be used to completely obliterate aneurysms and to ensure the patency of perforating vessels and parent arteries. Some aneurysms are simply not suitable for either endovascular treatment or surgical clipping and require sacrifice of the parent artery and a bypass with

either the saphenous vein or the radial artery to resupply the circulation eliminated by sacrifice.

INTRAOPERATIVE RUPTURE

Perhaps the most dramatic and potentially devastating complication of aneurysm surgery is intraoperative rupture.^{14,15} Like most surgical complications, this one is better avoided than managed, but the vascular neurosurgeon must know how to deal with intraoperative rupture because it is bound to occur. Adequate exposure, sharp dissection, proximal control, and use of temporary clips are the primary means of avoiding intraoperative rupture.^{4,15-17} For proximal

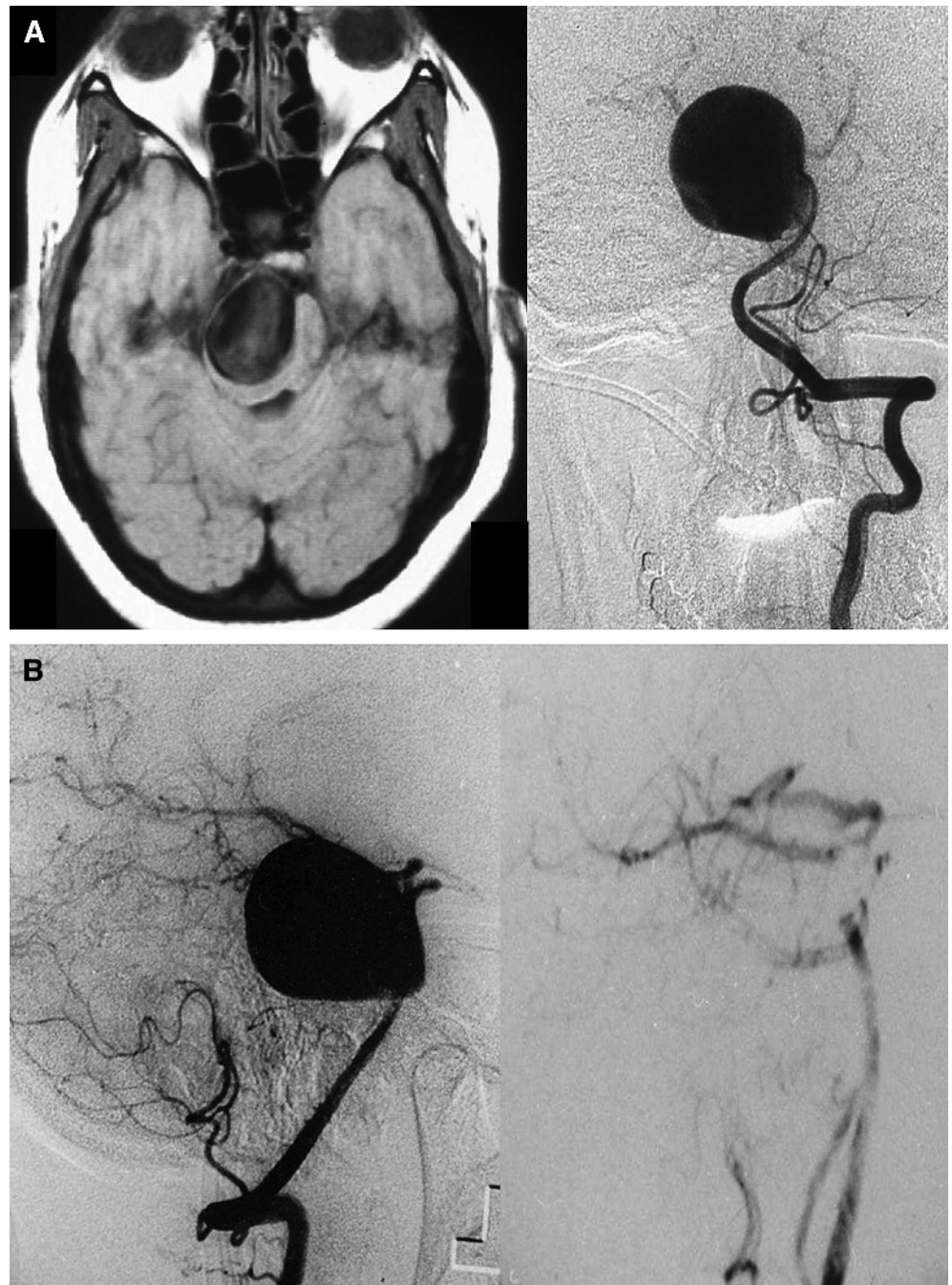


FIGURE 7. A, preoperative magnetic resonance image and angiogram show giant rostral basilar aneurysm causing significant brainstem compression. B, preoperative (left) and intraoperative (right) angiograms document obliteration of the aneurysm and filling of the basilar and its branches.

carotid aneurysms, control may require exposure of the cervical carotid, which also allows the surgeon to trap the aneurysm and to use suction decompression, as described by Drs Batjer and Sampson¹⁸ many years ago.

The surgeon should use sharp dissection around aneurysms as much as possible. Blunt dissection will transmit more pressure to the aneurysm and increase the risk of an untimely intraoperative rupture.¹⁹

Figure 19 illustrates the management of an intraoperative rupture in a woman who presented with a subarachnoid hemorrhage from this posterior communicating aneurysm. During exposure through the sylvian fissure, the aneurysm bled, likely from retraction on the temporal lobe that avulsed the aneurysm from the free edge of the tentorium. The bleeding was controlled with large-bore suctions and a small piece of cotton placed gently over the aneurysm for

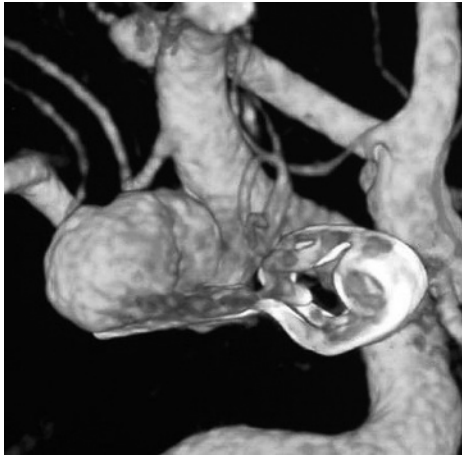


FIGURE 8. Follow-up 3-dimensional angiogram on a man who underwent clipping of a ruptured internal carotid artery aneurysm 15 years before and presented with recurrence from inadequate obliteration.

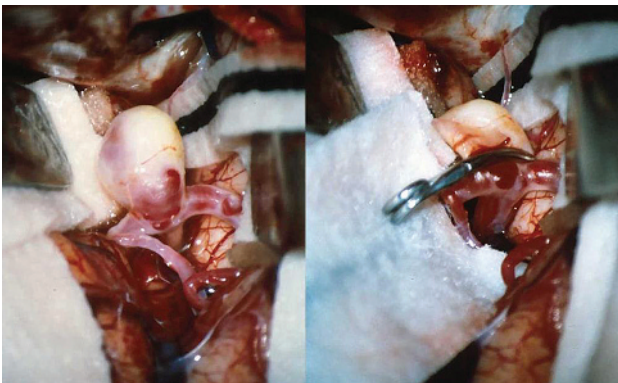


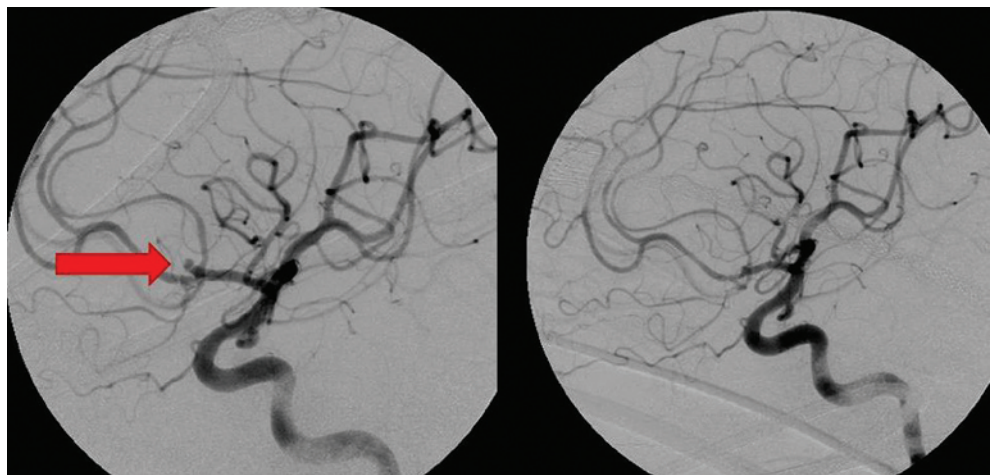
FIGURE 9. Intraoperative photographs before (left) and after (right) clipping of a middle cerebral artery aneurysm demonstrate the utility of direct observation under the operating microscope.

absorbency. A self-retaining retractor was then placed very gently on the cotton to tamponade the bleeding site, and temporary clips were placed proximally and distally to trap the aneurysm. The aneurysm was exposed and dissected away from the tentorium for placement of 2 clips to completely obliterate the aneurysm. After removal of the temporary clips, the carotid was carefully inspected both under the operating microscope and with indocyanine green videoangiography to demonstrate the patency of the posterior communicating and anterior choroidal arteries. The intraoperative angiogram demonstrated complete obliteration of the aneurysm and filling of the normal vasculature.

Figure 20 shows an intracerebral hemorrhage in this 58-year-old man who presented in very poor neurological condition. A CT angiogram was performed, and the patient was taken directly to surgery. During exposure of the aneurysm through the sylvian fissure, massive intraoperative hemorrhage occurred that could not be controlled with large-bore suctions. Adenosine was given intravenously to achieve a short period of complete circulatory arrest, allowing time to see the bleeding site and to place temporary clips. During the temporary circulatory arrest, the aneurysm was secured with a temporary clip and a permanent clip. The temporary clip was then removed, and the aneurysm was reconstructed with a series of clips to completely eliminate the aneurysm and its bleeding site, as documented by indocyanine green videoangiography. The intraoperative angiogram and postoperative CT angiogram demonstrated complete obliteration of the aneurysm.

In the event of an untimely rupture, the surgeon is faced with the dual challenges of controlling the bleeding and definitively repairing the aneurysm and arterial defect. A number of techniques for controlling the bleeding have been described, including use of a large-bore suction over the bleeding site (including a second suction handled by an assistant), tamponade with a cottonoid, proximal temporary

FIGURE 10. Left, intraoperative angiogram shows residual anterior communicating aneurysm after what was thought to be complete clipping. Right, final intraoperative angiogram after clip reconfiguration documents complete obliteration of the aneurysm.



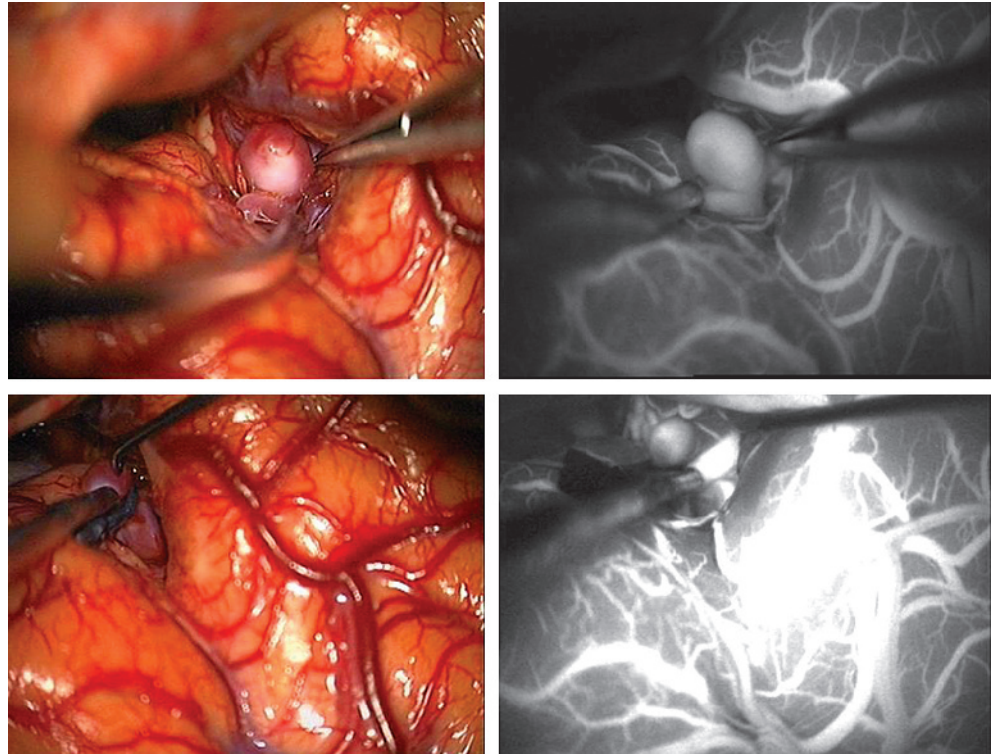


FIGURE 11. Indocyanine green videoangiography. Top left, exposure of right middle cerebral artery aneurysm before clipping. Top right, baseline indocyanine green videoangiogram shows fluorescence of the aneurysm and normal vasculature. Bottom left, intraoperative photograph after clipping of aneurysm. Bottom right, repeat indocyanine green videoangiogram shows continued filling of the middle cerebral artery aneurysm, prompting reapplication of the clip.

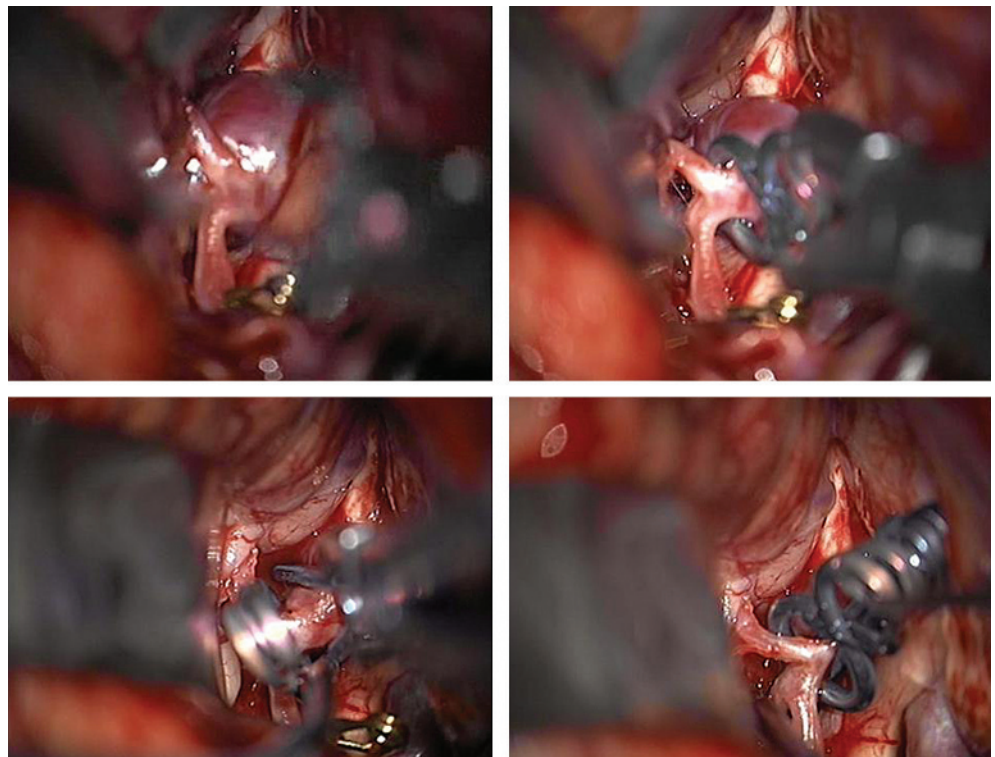


FIGURE 12. Tandem clipping technique. Top left, intraoperative photograph shows exposure of an anterior communicating aneurysm from a right pterional approach. Top right, a fenestrated clip is being placed across the neck of the aneurysm with the fenestration encircling the right A1-A2 junction. Bottom left, a straight clip is being placed across the neck that is passing through the fenestration of the first clip. Bottom right, final clip placement with complete obliteration of the aneurysm and reconstruction of the anterior communicating complex.

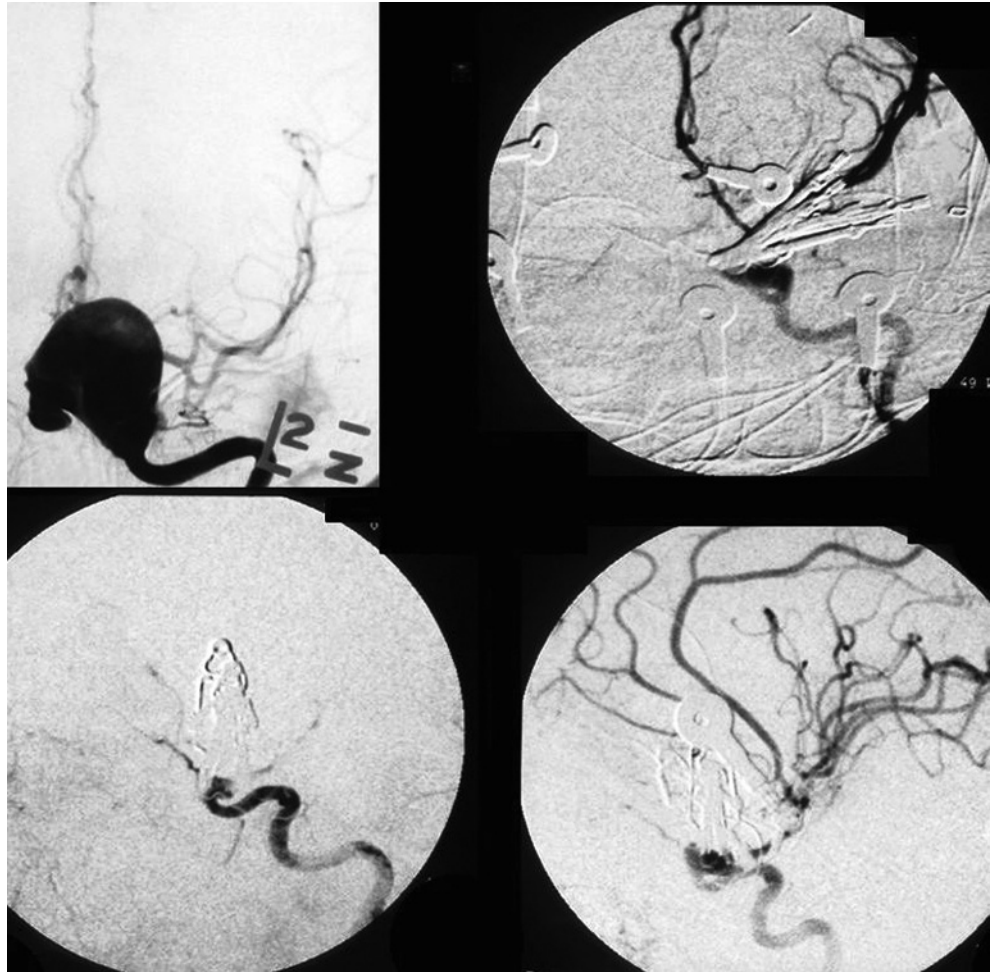


FIGURE 13. Top left, preoperative angiogram shows a giant left internal carotid artery aneurysm. Top right, after clipping, the initial intraoperative angiogram shows a small residual. Bottom left, after reconfiguration of the clips, a repeat angiogram demonstrates internal carotid artery occlusion. Bottom right, final result, settling for a very small residual that was wrapped with muslin.

occlusion or trapping, carotid compression, coagulation of the aneurysmal rent, clip application to the distal sac, and induced hypotension.^{15-17,19-24}

If an intraoperative rupture occurs on the dome of the aneurysm after it has been exposed, it can usually be readily managed by the surgeon. If the tear occurs at the neck of the aneurysm, it can be a devastating problem that is quite challenging to treat. Methods for definitive repair include microsuturing the defect, placing a Sundt clip graft, or trapping the aneurysm with or without a bypass.²⁵⁻²⁸ Figure 21 illustrates a technique using a small piece of cotton to tamponade and bolster the repair of a tear at the neck of an aneurysm.²⁸ Figure 22 is the angiogram of a patient with a left middle cerebral artery bifurcation aneurysm. The aneurysm was exposed through the left sylvian fissure with a temporary clip on the M1 segment. A fenestrated clip was placed around the most lateral M2 segment, obliterating the lateral part of the neck, and the temporary clip was removed. The portion of the aneurysm passing through the fenestrated clip was then secured with a straight clip. In exploring the clip placement to

ensure that the aneurysm was completely obliterated, I inadvertently tore the aneurysm at the neck. Placing another clip would compromise the middle cerebral bifurcation. Therefore, the temporary clip was replaced, a small piece of cotton was placed near the tear in the aneurysm neck, the original clip was opened, and the cotton was used as a bolster to obliterate the aneurysm and the tear within the neck without compromising the lumen of the middle cerebral artery bifurcation.

CONCLUSIONS

Through careful patient selection, the use of appropriate exposures, and adherence to the principles of microsurgery, surgical management of aneurysms will remain an important therapeutic tool for the foreseeable future. Less invasive techniques are available for many aneurysms, and new additions to the endovascular armamentarium will be developed. Surgery is not minimally invasive, but to remain a viable option, surgery must be minimally disruptive. It is



FIGURE 14. Postoperative CT from patient undergoing elective surgical clipping of an unruptured internal carotid artery aneurysm shows a small infarct (arrow).

important that the surgeon leave a minimal trace. Our goal should be to achieve a result in which it is difficult to determine which scan is the preoperative image and which is the postoperative image (Figure 23).

Disclosure

The author has no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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FIGURE 15. Intraoperative photographs of (left) a complex internal carotid artery aneurysm after placement of a proximal temporary clip but before and (right) after clipping. The complex nature of the clipping obscures the surgeon’s ability to accurately determine the patency of the parent artery and branches by observation alone.

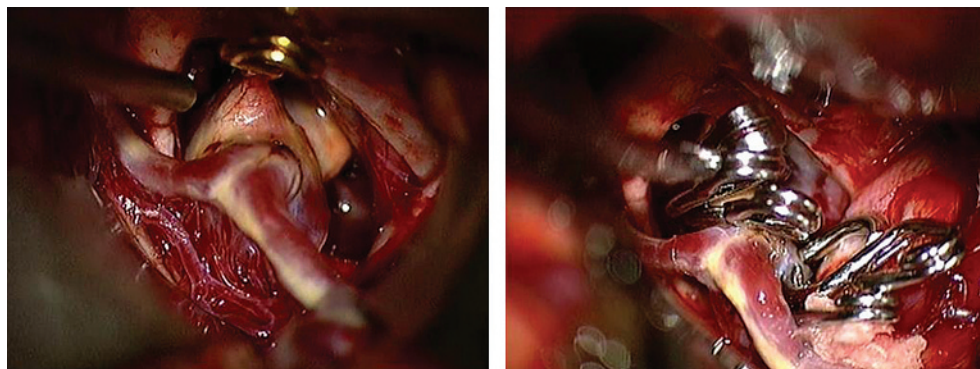
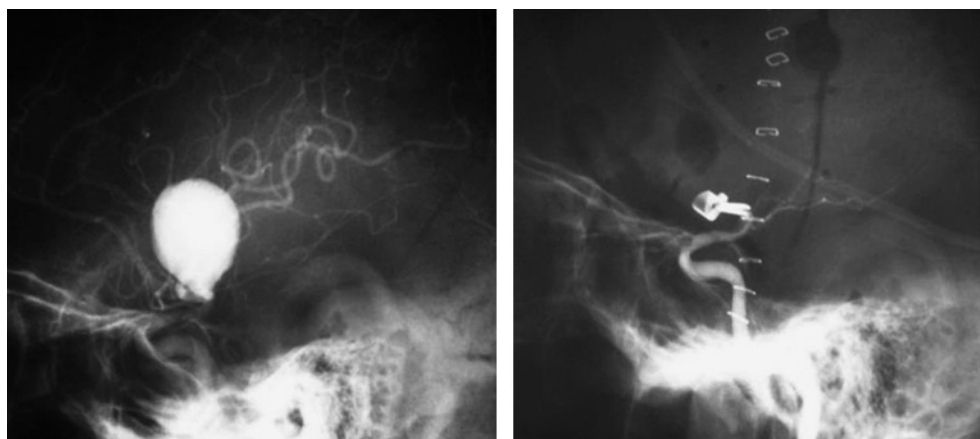


FIGURE 16. Postoperative angiography. Left, preoperative angiogram shows a large left internal carotid artery bifurcation aneurysm. Right, postoperative angiogram shows complete occlusion of the internal carotid artery from the clip having slid down the neck of the aneurysm. By the time the postoperative study was completed, the patient had suffered a stroke.



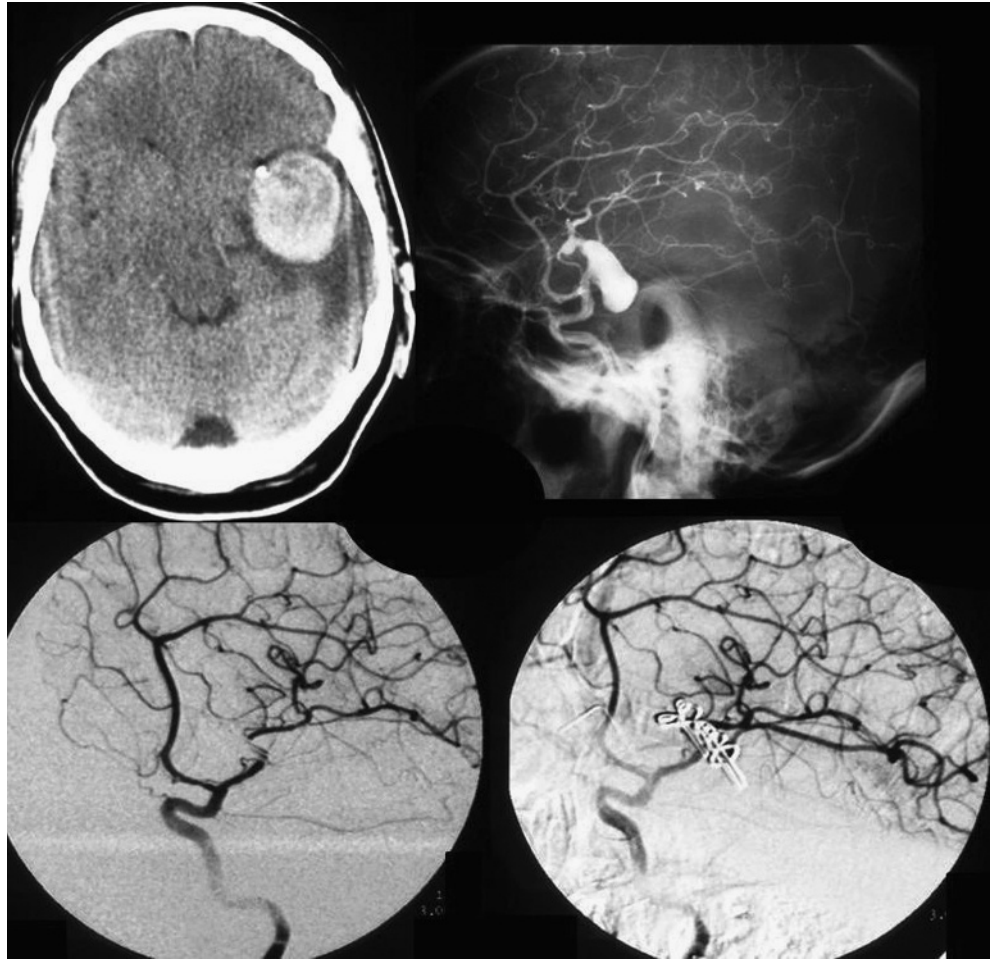


FIGURE 17. Intraoperative angiography. Top row, preoperative CT and angiogram demonstrate a giant partially thrombosed middle cerebral artery aneurysm. Bottom left, initial intraoperative angiogram after clipping reveals a missing branch of the middle cerebral artery. Bottom right, final intraoperative angiogram after the clips were reconfigured and intraoperative ischemia was avoided.

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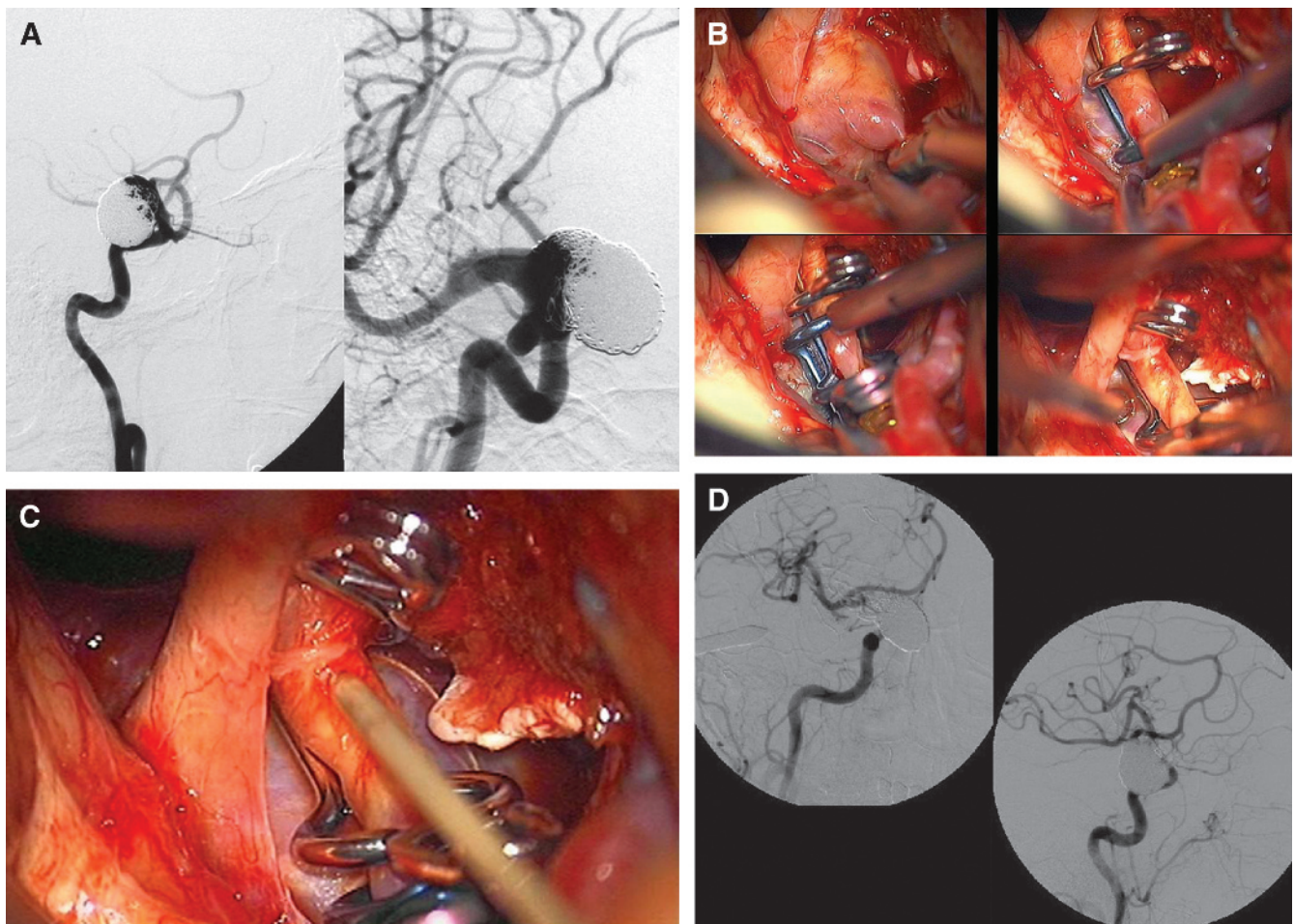


FIGURE 18. Transcranial Doppler. A, right carotid angiogram shows a large proximal carotid aneurysm previously coiled on 3 occasions with recurrence and associated visual loss. B, top left, intraoperative photograph while a temporary clip is being put on the distal internal carotid artery to trap the aneurysm (proximal occlusion was obtained in the cervical region). Coils within the aneurysm can be seen, as can compression of the optic nerve. Top right, fenestrated clips are used to reconstruct the lumen of the internal carotid artery. Bottom bank, to enlarge the lumen of the carotid, fenestrated clips are progressively placed more distally over the original clips and the first clips removed. C, microvascular Doppler is used to determine when normal flow is established through the carotid. D, intraoperative angiogram documents obliteration of the aneurysm and normal filling of the internal carotid artery.

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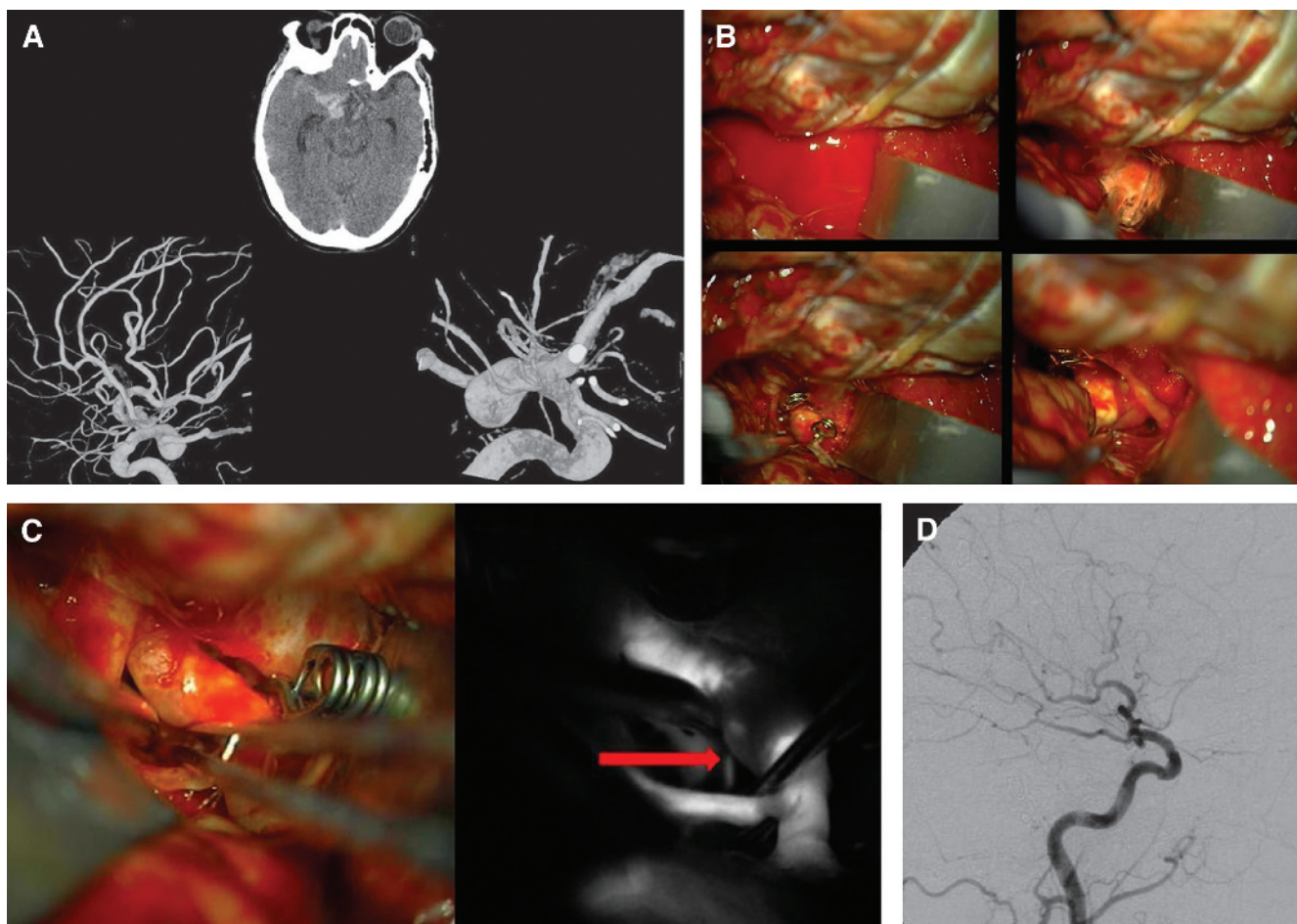


FIGURE 19. A, preoperative CT and angiogram show intracerebral and subarachnoid hemorrhage from an internal carotid artery aneurysm. B, top bank, during exposure, the aneurysm bled and was controlled with large-bore suctions and a cotton ball placed over the hole to tamponade the bleeding. The self-retaining retractor was then gently placed on the cotton to halt the bleeding while the dissection proceeded. Bottom bank, temporary clips are placed to trap the aneurysm, and the cotton is removed to expose the aneurysm. C, the aneurysm is clipped, and an indocyanine green videoangiogram documents obliteration of the aneurysm and filling of branches, including the anterior choroidal (arrow). D, intraoperative angiogram documents obliteration of the aneurysm.

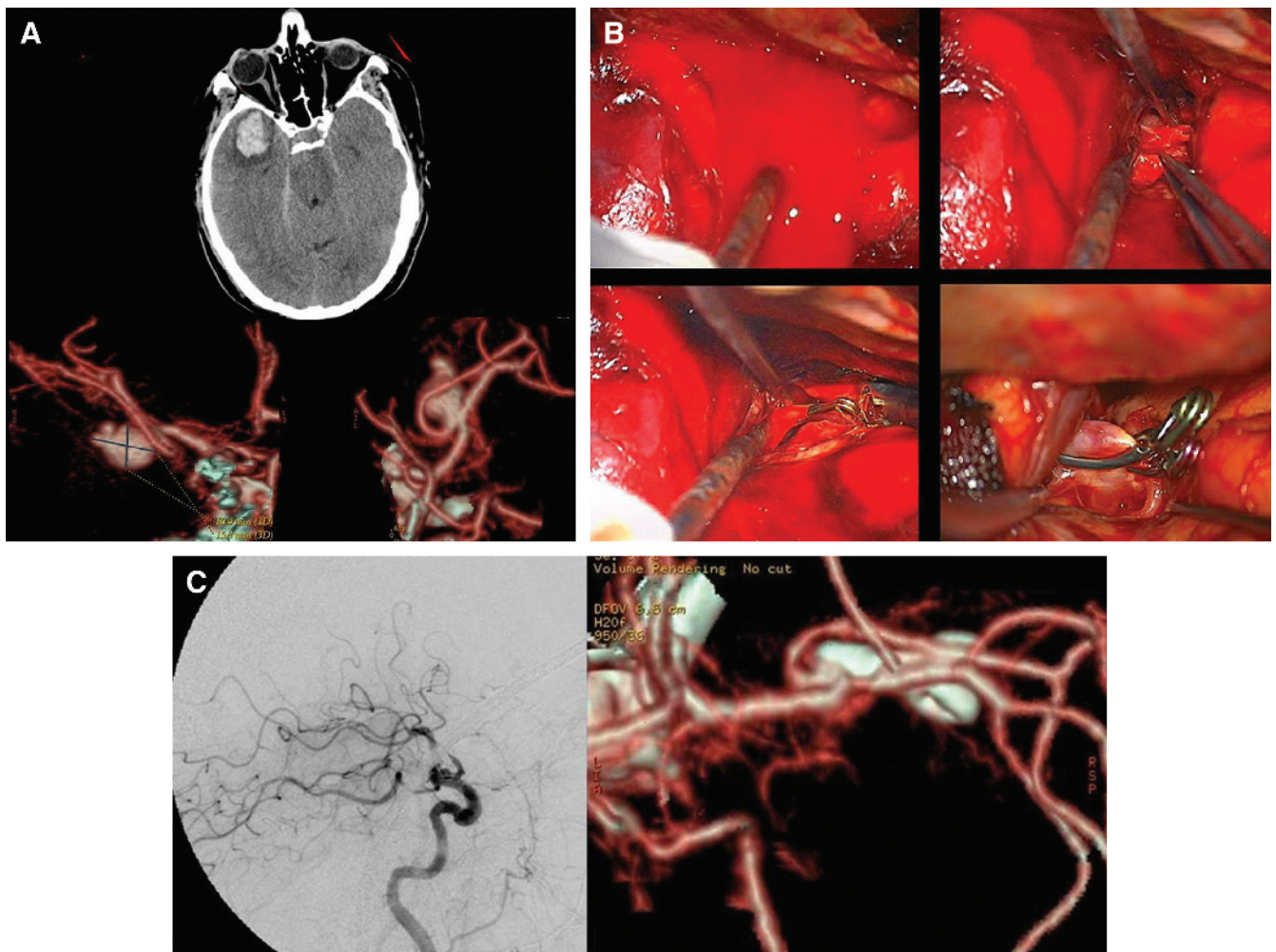


FIGURE 20. A, preoperative CT and CT angiogram from a 58-year-old man presenting in poor neurological condition from an intracerebral and subarachnoid hemorrhage resulting from a middle cerebral artery aneurysm. B, top left, during exposure of the aneurysm through the sylvian fissure, the aneurysm bled vigorously and could not be controlled by suction. Top right, the patient was given intravenous adenosine in escalating doses until transient cardiac arrest occurred, halting the bleeding long enough for the surgeon to see the aneurysm. Lower bank, initially a temporary clip and permanent clips were used to reconstruct the middle cerebral bifurcation. C, intraoperative angiogram and postoperative CT angiogram document complete obliteration of the aneurysm and normal filling of the middle cerebral artery.

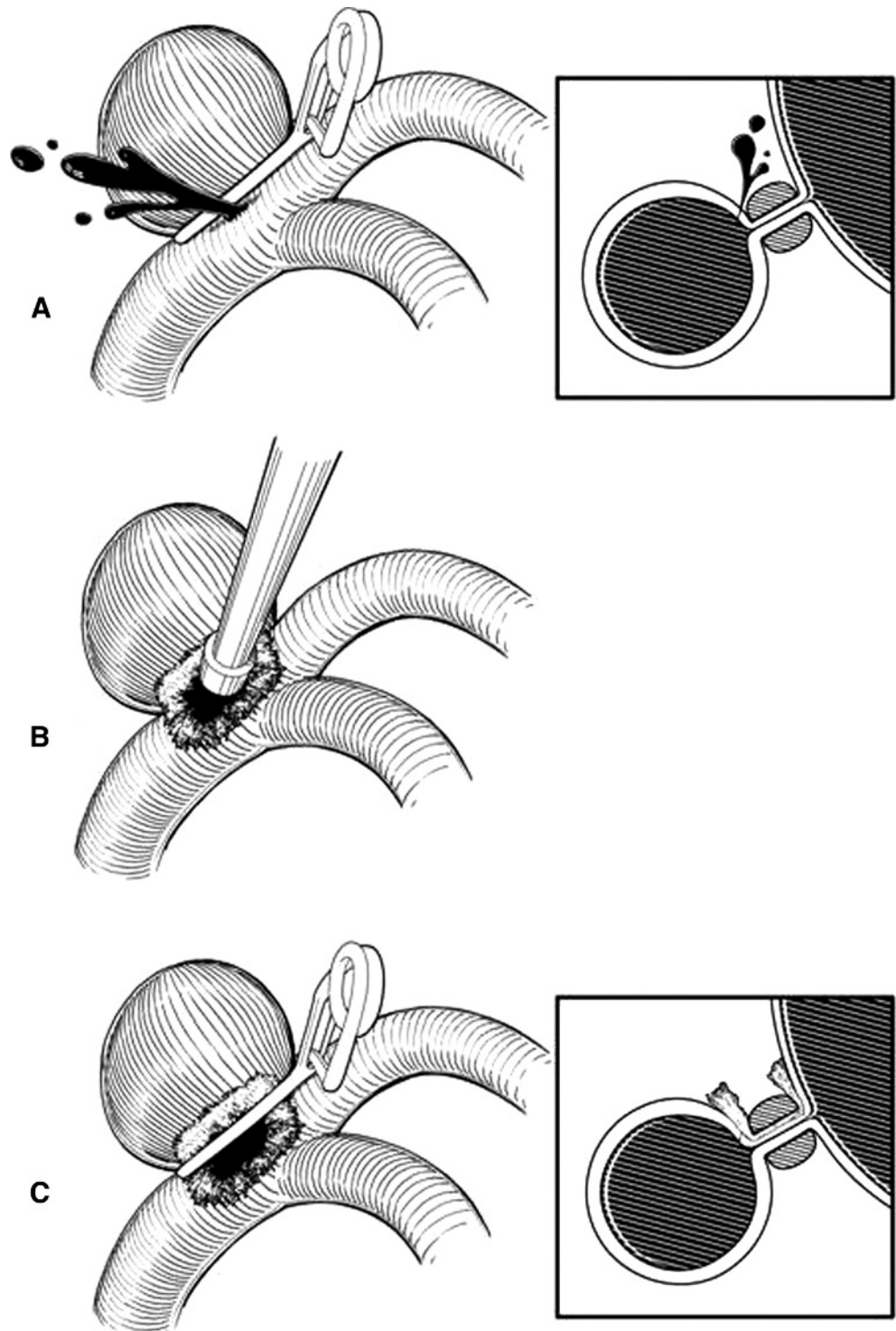


FIGURE 21. Artist's illustration of technique for repairing a tear at the neck of an aneurysm. A, a tear at the neck cannot be clipped without compromising the parent artery. B, a small piece of free cotton is placed over the tear to halt the bleeding. C, the clip is placed just above the tear, clipping the cotton as a bolster to tamponade the tear. From Barrow and Spetzler.²⁸

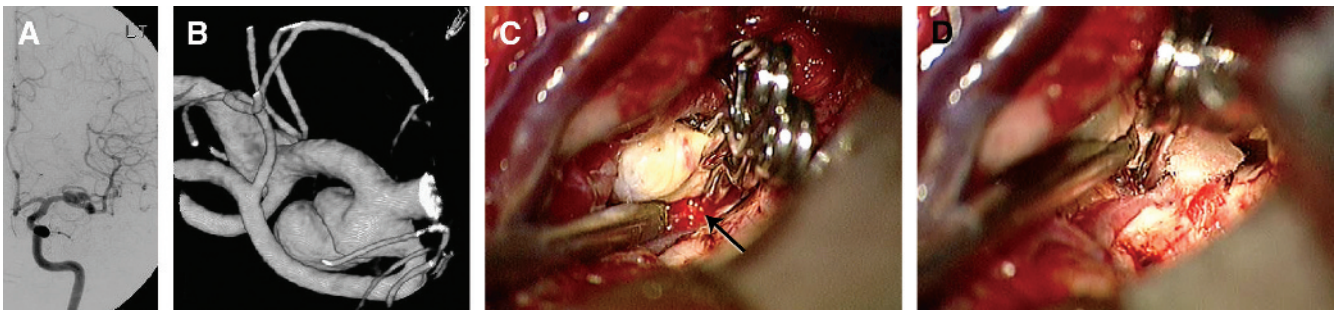


FIGURE 22. Preoperative digital subtraction angiogram (A) and 3-dimensional angiogram (B) show a left middle cerebral artery aneurysm. C, the middle cerebral artery bifurcation aneurysm has been clipped with a straight fenestrated clip encompassing the lateral portion of the neck with a straight tandem clip obliterating the portion that passes through the fenestration. A tear (arrow) is seen at the junction of the aneurysm neck and the medial M2 branch. D, intraoperative photograph shows the cotton now beneath the fenestrated clip to tamponade the tear. From Barrow and Spetzler.²⁸

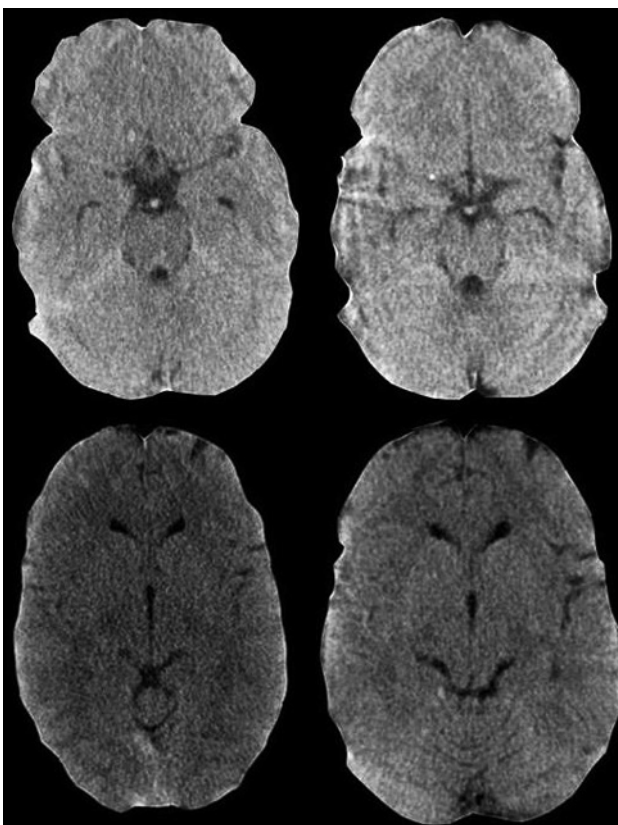


FIGURE 23. Which is the preoperative scan and which is the postoperative scan?