Neurosurgical management of cerebral aneurysms following unsuccessful or incomplete endovascular embolization

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Modern endovascular techniques permit treatment of intracranial aneurysms in many circumstances when surgery is associated with significant morbidity. Occasionally, embolization of aneurysms is unsuccessful or incomplete or followed by complications, in which case surgical management is required. Since 1986, 196 patients have undergone embolization of intracranial aneurysms at the authors’ institution and 21 (11%) required subsequent surgical treatment. Attempted embolization failed in five patients (Group A). Ten patients (Group B) had only partial occlusion of the aneurysm or demonstrated recanalization on follow-up studies. Eight of these Group B patients underwent embolization with Guglielmi detachable coils (GDCs), representing 5.7% of the 141 GDC-treated patients in this experience. Surgical treatment in these two groups consisted of clipping (eight cases), surgical parent vessel occlusion (one case), and parent vessel occlusion with extracranial–intracranial bypass (six cases). Fourteen (93%) of the 15 patients in these two groups had an excellent or good outcome with complete aneurysm occlusion. Six patients underwent surgery to treat complications related to the endovascular procedure (Group C). Of these, four patients had neurological improvement compared to their preoperative state, and two died. This series of cases demonstrates that surgical treatment of aneurysms is usually possible with good results following incomplete embolization and emphasizes the need for close and continued neurosurgical involvement in the endovascular management of intracranial aneurysms.

KEY WORDS • cerebral aneurysm • coil • embolization • endovascular therapy • surgery • complication

ENDOVASCULAR techniques have shown promise in the treatment of cerebral aneurysms. Recent advances in the embolization of aneurysms have led to increased use of this treatment option in select instances in which direct surgical clipping has not been desirable or feasible. As the number of patients treated with endovascular methods grows, it is important to emphasize the role of neurosurgical management in the care of these patients. Surgical aneurysm treatment may be necessary after endovascular treatment (or attempted treatment) in several circumstances. The attempt at endovascular treatment may be unsuccessful due to aneurysm configuration or to intolerance to planned parent artery occlusion. Despite advances in endovascular treatments, aneurysm embolization may be associated with serious complications, some of which require surgical intervention. Finally, growth of small residual aneurysm necks has been a risk of all embolization techniques developed so far. Prior embolization does not necessarily preclude surgical treatment of a residual aneurysm; previous case reports have addressed this issue in patients with detachable balloon embolization.16–24

We report our experience in 21 cases in which surgical intervention has been necessary following embolization procedures, either due to incomplete aneurysm obliteration or for the purpose of managing acute complications.

Clinical Material and Methods

Patients and Embolization Procedures

From 1986 to 1994, 200 aneurysms in 196 patients were treated by endovascular means. Embolization is performed in those patients who either refuse surgery or are considered (usually by the referring clinician) to be at high risk from surgery. Multiple follow-up angiograms are then performed to assure continued exclusion of the aneurysm from the cerebral circulation. The hospital records and radiographic studies of 21 consecutive patients requiring either acute or elective surgery (performed by one neurosurgeon, N.A.M.) following embolization of cerebral aneurysms were reviewed. These patients were divided into three groups: Group A (five patients) consisted of those patients in whom an attempt at embolization failed; Group B (10 patients) required elective surgery for definitive treatment following incomplete embolization or regrowth of the aneurysm; and Group C (six patients) required emergency surgery for treatment of complications related to the embolization. The clinical data are summarized in Table 1.

The most frequent aneurysm locations were carotid-ophthalmic (six patients) and intracavernous (five patients). Seventeen lesions were in the anterior circulation.
and four in the posterior circulation. Ten aneurysms were classified as giant (one dimension ≥25 mm), eight as large (< 25 mm but ≥ 10 mm), and three as small (< 10 mm in all dimensions). Thirteen patients initially presented with subarachnoid hemorrhage (SAH); three were Hunt and Hess25 Grade II, seven Grade III, two Grade IV, and one Grade V. Other presenting symptoms included visual acuity changes (three patients), ophthalmoplegia (three), headache (three), and epistaxis (one).

Transfemoral embolization was performed in the neuroangiography suite with neuroleptic anesthesia and systemic heparinization. Endosaccular embolization was performed with isobutyl cyanoacrylate (IBCA) liquid adhesive in one case and with silicone balloons (Interventional Therapeutics Corp., South San Francisco, CA) in three cases. These were performed prior to the development of the Guglielmi electrolytically detachable platinum coils (GDCs; Target Therapeutics, Fremont, CA). The remaining endosaccular embolizations were performed with GDCs. Latex balloons were used for parent vessel sacrifice in three cases. Details of these procedures have been published previously.12,15

During parent vessel sacrifice, a test occlusion was performed prior to permanent balloon detachment to determine the adequacy of collateral blood flow. Detailed serial neurological testing and electroencephalographic (EEG) analysis was performed by a neurologist over a 30-minute interval. If the patient failed the test occlusion, an extracranial–intracranial (EC–IC) bypass was performed with surgical occlusion of the parent vessel at the time of bypass.

Surgical Considerations

All patients underwent preembolization, preoperative, and postoperative (or adequate intraoperative) angiography. Group A patients had undergone attempted embolization that had failed for several reasons (Table 1) whereas, in Group B, surgical treatment was performed after follow-up angiography demonstrated a significant recurrent or residual aneurysm lumen. These patients were judged to be an acceptable risk for surgery despite initial selection for embolization; those considered to have an unacceptable risk–benefit ratio for surgery continue to be followed clinically and radiographically (see Discussion). In four of the 10 Group B patients, multiple unsuccessful attempts were made to reembolize the residual lumen prior to surgical treatment. Group C patients were operated on for declining neurological status following embolization; five of the six patients required emergency surgical procedures. Nonoperative therapy was attempted prior to neurosurgical intervention. This included hypertensive and hypervolemic therapy in patients experiencing delayed ischemic deficits and ventriculostomy placement following intraprocedural aneurysm rupture. In all Group C patients, initial head computerized tomography (CT) was performed following onset of the neurological deficit. One patient also underwent magnetic resonance (MR) imaging to document increased mass effect from her giant aneurysm.

Whenever possible, direct clipping of the aneurysm was preferred to aneurysm trapping and revascularization. Barb比特ure cerebral protection was administered routinely during temporary vessel occlusion. Intraoperative angiography was used in most patients following clipping, unless the aneurysm and surrounding vascular anatomy were exceedingly well delineated under the operating microscope.

Overall, eight EC–IC bypass procedures were performed. A saphenous vein graft was placed from the external carotid artery to a middle cerebral artery (MCA) branch (the M2 segment) in four patients. This technique has been described elsewhere.39 A superficial temporal artery (STA) to MCA anastomosis was performed in three patients and the occipital artery was used in one case.

The outcomes were defined as follows: “excellent,” no detectable neurological deficit at last follow up; “good,” mild hemiparesis, cranial nerve palsy, or other deficit that does not interfere with daily functioning or work; “fair,” significant hemiparesis, aphasia, confusion, or other deficit that interferes with daily activities or prevents a return to work; “poor,” coma or severe neurological deficit rendering the patient totally dependent; and “death.”

Results

Overall Complications of Embolization

Of 141 aneurysms originally embolized with GDC coils, a total of 10 (7.1%) required surgical procedures after embolization. Following one or more embolizations in eight patients (5.7%), significant aneurysm remnants warranted the risk of surgical treatment. Two (1.4%) required emergency or urgent surgical treatment. Endosaccular embolization failed in five additional patients (3.4% of 145 attempts): two were treated by endovascular parent vessel sacrifice and three by surgery. Complications not requiring surgery included eight patients (5.7%) who experienced transient neurological symptoms that resolved with medical management. Five (3.5%) had a permanent neurological deficit resulting from the embolization. There were two deaths (1.4%) directly related to the procedure; these were both from aneurysm perforation early in our experience, in patients with high-grade SAH.

Forty-one patients were initially treated with balloon occlusion of a parent artery. Two (4.9%) experienced minor transient neurological changes; one of these was iatrogenic, due to a rapidly acting antihypertensive agent administered by a covering physician unfamiliar with the patient. One (2.4%) had an SAH shortly after embolization and recovered after medical management. Two (4.9%) developed hemispheric ischemia requiring emergency EC–IC bypass surgery.

Of 14 patients undergoing endosaccular embolization with balloons (prior to the development of GDCs), four experienced serious immediate complications; all four died. Two suffered aneurysm rupture during or shortly after the procedure. Of these, only one survived to operation, but died postoperatively. In two patients the balloon shifted into the parent vessel, resulting in critical ischemia. Again, only one survived to operation, but died in the postoperative period. One patient required eventual operation for regrowth of the aneurysm. One patient whose aneurysm was embolized with IBCA required an operation for regrowth of the lesion. The results of the subgroup of 21 patients who went on to surgery are detailed below.
<table>
<thead>
<tr>
<th>Group A</th>
<th>Case</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>Presenting Symptoms†</th>
<th>Size (mm)</th>
<th>Location of Aneurysm</th>
<th>Reason for Embolization</th>
<th>Embolic Agent</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>65</td>
<td>F</td>
<td>CN III palsy</td>
<td>30</td>
<td>intracavernous ICA</td>
<td>location of aneurysm</td>
<td>referred from outside institution due to size</td>
<td>balloon</td>
<td>failed test occlusion; embolization not performed</td>
</tr>
<tr>
<td>2</td>
<td>39</td>
<td>F</td>
<td>monoclonal loss</td>
<td>27</td>
<td>suprachordoid ICA</td>
<td></td>
<td></td>
<td>GDC</td>
<td>attempted embolization resulted in unstable placement of coils due to wide neck of giant aneurysm; embolization not performed</td>
</tr>
<tr>
<td>3</td>
<td>63</td>
<td>F</td>
<td>headache; diplopia; CN VI palsy</td>
<td>30</td>
<td>intracavernous ICA</td>
<td>location of aneurysm</td>
<td></td>
<td>balloon</td>
<td>failed test occlusion; embolization not performed</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>F</td>
<td>Grade III SAH</td>
<td>10</td>
<td>lt carotid-ophthalmic</td>
<td>patient refused surgery</td>
<td></td>
<td>GDC</td>
<td>unable to catheterize aneurysm due to severe tortuosity of cavernous carotid &amp; siphon; not embolized</td>
</tr>
<tr>
<td>5</td>
<td>69</td>
<td>F</td>
<td>Grade III SAH</td>
<td>12</td>
<td>basilar apex</td>
<td>coronary artery disease; COPD; peripheral vascular disease</td>
<td></td>
<td>GDC</td>
<td>embolization attempt resulted in dissection of dominant vertebral artery; further attempts risked basilar occlusion because contralateral vertebral ended in PICA &amp; both PCoAs were small</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group B</th>
<th>Case</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>Presenting Symptoms†</th>
<th>Size (mm)</th>
<th>Location of Aneurysm</th>
<th>Reason for Embolization</th>
<th>Embolic Agent</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>49</td>
<td>F</td>
<td>epistaxis</td>
<td>12</td>
<td>intracavernous carotid eroding into sphenoid sinus</td>
<td>location of aneurysm</td>
<td></td>
<td>IBCA</td>
<td>80% occluded at 1 mos with recurrent epistaxis</td>
</tr>
<tr>
<td>7</td>
<td>50</td>
<td>F</td>
<td>Grade IV SAH</td>
<td>5</td>
<td>PICA</td>
<td>poor neurological status</td>
<td></td>
<td>balloon</td>
<td>80% occluded at 3 mos</td>
</tr>
<tr>
<td>8</td>
<td>30</td>
<td>F</td>
<td>Grade IV SAH</td>
<td>10</td>
<td>PICA</td>
<td>cardiac dysfunction; neurogenic pulmonary edema; poor neurological status</td>
<td></td>
<td>GDC</td>
<td>85% occluded at 2.5 mos</td>
</tr>
<tr>
<td>9</td>
<td>41</td>
<td>M</td>
<td>Grade III SAH</td>
<td>25</td>
<td>suprachordoid ICA incorporating PCoA origin</td>
<td>failed clipping attempt at referring hospital</td>
<td></td>
<td>GDC</td>
<td>65% occluded at 4 mos</td>
</tr>
<tr>
<td>10</td>
<td>57</td>
<td>F</td>
<td>Grade III SAH</td>
<td>13</td>
<td>basilar apex</td>
<td>clipped ×2 with residual neck; regrowth ×2</td>
<td></td>
<td>GDC</td>
<td>embolization ×3 over 11 mos with recurrent neck; 60% occluded at 11 mos after last embolization</td>
</tr>
<tr>
<td>11</td>
<td>63</td>
<td>M</td>
<td>Grade III SAH</td>
<td>25</td>
<td>ICA bifurcation</td>
<td>patient refused surgery</td>
<td></td>
<td>GDC</td>
<td>embolization ×3 over 8 mos, then balloon occlusion of ICA; 60% occluded at 8 mos, incomplete thrombosis after balloon occlusion</td>
</tr>
<tr>
<td>12</td>
<td>41</td>
<td>F</td>
<td>lt eye: light perception only; rt eye: visual field cut</td>
<td>30</td>
<td>lt carotid-ophthalmic</td>
<td>patient refused surgery</td>
<td></td>
<td>GDC</td>
<td>85% occluded at 5 mos</td>
</tr>
<tr>
<td>13</td>
<td>56</td>
<td>F</td>
<td>Grade V SAH; SDH contralateral to aneurysm</td>
<td>12</td>
<td>carotid-ophthalmic</td>
<td>poor clinical grade; cerebral swelling on CT; SDH</td>
<td></td>
<td>GDC</td>
<td>80%–85% occluded at 3 mos</td>
</tr>
<tr>
<td>14</td>
<td>44</td>
<td>F</td>
<td>Grade II SAH</td>
<td>11</td>
<td>carotid-ophthalmic</td>
<td>presence of vasospasm</td>
<td></td>
<td>GDC</td>
<td>60%–70% occluded at 5 mos</td>
</tr>
<tr>
<td>15</td>
<td>72</td>
<td>F</td>
<td>headache; lt eye blindness</td>
<td>26</td>
<td>lt carotid-ophthalmic</td>
<td>referred from outside hospital due to advanced age &amp; aneurysm size</td>
<td></td>
<td>GDC</td>
<td>80%–85% occluded at 3 mos</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group C</th>
<th>Case</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>Presenting Symptoms†</th>
<th>Size (mm)</th>
<th>Location of Aneurysm</th>
<th>Reason for Embolization</th>
<th>Embolic Agent</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>74</td>
<td>F</td>
<td>headache</td>
<td>7</td>
<td>PICA</td>
<td>patient refused surgery; advanced age</td>
<td></td>
<td>balloon</td>
<td>slippage of balloon into ICA &amp; PCoA at 2 wks with ACA embolus, PCA occlusion, hemiparesis</td>
</tr>
<tr>
<td>17</td>
<td>75</td>
<td>F</td>
<td>Grade II SAH</td>
<td>25</td>
<td>intracavernous</td>
<td>location of aneurysm</td>
<td></td>
<td>balloon</td>
<td>successful parent vessel occlusion, developed mild hemiparesis, 1 facial weakness, &amp; neglect 24 hrs after embolization</td>
</tr>
<tr>
<td>18</td>
<td>52</td>
<td>F</td>
<td>Grade II SAH</td>
<td>7</td>
<td>PICA</td>
<td>patient refused surgery</td>
<td></td>
<td>balloon</td>
<td>intraprocedural rupture during attempted endosaccular embolization with massive IVH &amp; SAH; two additional balloons immediately placed in neck of aneurysm &amp; ICA, occluding parent vessel</td>
</tr>
<tr>
<td>19</td>
<td>73</td>
<td>F</td>
<td>CN III palsy</td>
<td>26</td>
<td>intracavernous</td>
<td>location of aneurysm</td>
<td></td>
<td>balloon</td>
<td>successful parent vessel occlusion; developed aphasia; rt hemiparesis 24 hrs after embolization; unresponsive to hypertensive &amp; hypervolemic therapy</td>
</tr>
<tr>
<td>20</td>
<td>45</td>
<td>F</td>
<td>Grade III SAH</td>
<td>27</td>
<td>basilar apex</td>
<td>poor neurological grade; location &amp; size of aneurysm</td>
<td></td>
<td>GDC</td>
<td>100% occluded after two embolizations; neurological deterioration without improvement due to increasing mass effect from thrombosing aneurysm</td>
</tr>
<tr>
<td>21</td>
<td>64</td>
<td>F</td>
<td>Grade III SAH</td>
<td>10</td>
<td>carotid-ophthalmic</td>
<td>patient refused surgery</td>
<td></td>
<td>GDC</td>
<td>herniation of coils into ICA with occlusion; hemiparesis; aphasia</td>
</tr>
</tbody>
</table>

* Group A: failed attempt at endovascular treatment; Group B: incompletely treated or residual/recurrent aneurysms; Group C: complications after embolization. CN = cranial nerve; ICA = internal carotid artery; GDC = Guglielmi detachable coil; SAH = subarachnoid hemorrhage; PICA = posterior inferior cerebellar artery; PCoA = posterior communicating artery; COPD = chronic obstructive pulmonary disease; IBCA = isobutyl cyanoacrylate; SDH = subdural hematoma; CT = computerized tomography; ACA = anterior cerebral artery; PCA = posterior cerebral artery; IVH = intraventricular hemorrhage.
† Grading of SAH according to Hunt and Hess.25
Patients whose embolization failed were treated with standard surgical techniques as appropriate to the particular aneurysm (Table 2). As would be expected, the attempt at embolization did not interfere with surgical exploration, because no embolic materials were deposited. For example, three patients with wide-necked giant internal carotid artery (ICA) aneurysms (Cases 1, 2, and 3), in whom attempts at endovascular treatment were unsuccessful, were not embolized at all and were referred for surgical treatment (trapping and saphenous vein bypass in two cases and STA bypass in one). Figure 1 shows an example of a wide-necked aneurysm in which a stable coil position could not be achieved. Four of the five patients in this group had a good or excellent outcome.

The single death (Case 5) was related to a ruptured posterior fossa aneurysm in an elderly woman with severe atherosclerotic disease. It is worthwhile to note that the severity of the patient’s vascular disease made both embolization and surgery difficult: her sole vertebral artery was dissected while trying to catheterize extremely tortuous vessels, and an atherosclerotic neck made clip application difficult.

**Group B: Residual and Recurrent Aneurysms**

**Surgical Technique.** The surgical procedures and results in Group B patients are listed in Table 2. Of the 10 patients in this group, seven had aneurysms that could be successfully clipped with preservation of the parent vessel. In five

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**TABLE 2**

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Aneurysm Location</th>
<th>Surgical Technique</th>
<th>Clinical Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Intracavernous ICA trapping: saphenous vein graft bypass to MCA with clip occlusion of ICA origin and proximal to PCoA</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>2</td>
<td>Supraclinoid ICA trapping: saphenous vein graft bypass to MCA with clip occlusion of ICA distal to ophthalmic and proximal to AChA</td>
<td>Good: transient postop CN III palsy due to aneurysm thrombosis</td>
<td>Excellent</td>
</tr>
<tr>
<td>3</td>
<td>Intracavernous ICA trapping: STA bypass to M2 segment, with clip occlusion at ICA origin and proximal to PCoA</td>
<td>Good: subtle new hemiparesis, but aneurysm only 75% occluded at 26-mo angiogram; no rehemorrhage</td>
<td>Excellent</td>
</tr>
<tr>
<td>4</td>
<td>Lt carotid-ophtalmic clipping</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>5</td>
<td>Basilar apex clipping (aneurysm grossly atherosclerotic)</td>
<td>Postop thalamic infarct; died of pulmonary complications 2 mos later</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

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*Group A: failed attempt at endovascular treatment; Group B: incompletely treated or residual/recurrent aneurysms; Group C: complications after embolization.*

ICA = internal carotid artery; MCA = middle cerebral artery; PCoA = posterior communicating artery; AChA = anterior choroidal artery; STA = superficial temporal artery; CN = cranial nerve; PICA = posterior inferior cerebellar artery; ACA = anterior cerebral artery; SAH = subarachnoid hemorrhage.

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*TABLE 2*

**Technique and results of neurosurgery after embolization**

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<td>4</td>
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ICA = internal carotid artery; MCA = middle cerebral artery; PCoA = posterior communicating artery; AChA = anterior choroidal artery; STA = superficial temporal artery; CN = cranial nerve; PICA = posterior inferior cerebellar artery; ACA = anterior cerebral artery; SAH = subarachnoid hemorrhage.
of these cases, the aneurysm neck was patent and pliable because the embolic agent (balloon or GDCs) had been compacted into the fundus and dome. In three patients (Cases 12, 13, and 14) with carotid–ophthalmic aneurysms packed with coils several months earlier, the aneurysm dome was incised after clipping. This was done to remove coils from the dome to decrease pressure and distortion of the optic nerve and chiasm. It was not possible to remove the coils in these cases, as they were found to have formed a densely fibrotic mass with surrounding thrombus. Any pulling on the coils caused excessive traction and displacement of the dome, which was transmitted to the adherent nerve or chiasm.

In one of these patients (Case 14), complete aneurysm neck occlusion could not be achieved with one clip because a coil had herniated into the neck and the parent vessel. An attempt to remove this coil after opening the dome of the aneurysm was unsuccessful because it was fibrosed to the vascular wall. Placement of a second clip adjacent to the first succeeded in closing the neck completely (Fig. 2). In one patient (Case 11), a giant ICA bifurcation aneurysm was explored with the intent of clipping. This was prevented by the presence of many coils at the neck of the aneurysm. Temporary trapping and removal of the coils were not attempted because one long loop of coil could be seen to herniate into the proximal MCA trunk where it seemed to be incorporated into the intima. It appeared that removal of this loop risked damage to the MCA. The coils were left in place, and the aneurysm was occluded by permanent trapping (in conjunction with a saphenous vein bypass graft from the external carotid artery to the MCA). Two other patients (Cases 6 and 9) had recurrent aneurysms not inherently amenable to clipping and were treated with trapping and bypass procedures (Fig. 3). One patient with a wide-necked basilar apex aneurysm that recurred after two attempts at clipping and multiple embolizations was treated by surgical occlusion of the basilar artery trunk.

**Outcome**

Complete occlusion of the aneurysm was achieved in nine of the 10 Group B cases, the single exception being the multiply recurrent basilar apex aneurysm treated by basilar trunk occlusion (Case 10). This aneurysm showed only 75% occlusion due to filling via one large posterior communicating artery. It was refractory to two prior clipping attempts and three prior embolization attempts. Thus, the inability to occlude this aneurysm was unrelated to prior embolizations. This patient sustained the only permanent postoperative neurological deficit: a hemiparesis that was subtle and nondisabling at her 6-month follow-up examination. The clinical outcome was excellent in five patients, and good in five. Of the seven patients in this group who presented with SAH (six Grade III or higher), four had an excellent outcome, whereas the remaining three had a good outcome at last follow-up review. None of the patients who experienced SAH and underwent emergency embolization with GDCs had rebleeding from the aneurysm before definitive operative treatment, despite partial recanalization (detected by routine follow-up angiography) after embolization.

**Group C: Postembolization Complications**

**Surgical Technique.** The surgical procedures and results in Group C patients are listed in Table 2. Two patients underwent emergency craniotomy for removal of the embolic agent when a balloon (Case 16) or GDCs (Case 21) herniated from the aneurysm into the parent artery (the ICA in both cases) and caused hemispheric ischemia. The balloon in Case 16 had been inserted 2 weeks prior to the onset of ischemic symptoms and was extracted easily after temporary clipping of the ICA, and opening of the aneurysm fundus. After balloon removal the neck of the aneurysm was clipped without difficulty. The coils in Case 21, placed in a carotid–ophthalmic aneurysm, slipped into the ICA during the initial endovascular procedure, and the emergency craniotomy was performed within 2 hours. The coils with associated fresh thrombus could be removed easily through an incision in the dome after temporary ICA occlusion (Fig. 4).

One patient (Case 20) with a giant wide-necked basilar apex aneurysm required removal of GDCs and associated thrombus which had caused brainstem compression (Fig. 5). The procedure was performed 2 weeks after the second and 3 weeks after the first embolization. The manipulation and displacement of the aneurysm required to expose its neck was made more challenging by the presence of the dense, nonpliable combination of coils and thrombus within the fundus and neck. Even with the use of hypothermic circulatory arrest, clipping was quite difficult. After clipping, the fundus of the aneurysm was opened, and many meters of embolic coil material were extracted. The coils were tightly interwoven and held in place by organizing thrombus. The procedure involved 3 hours of gentle, careful coil extraction because more vigorous pulling caused traction and movement of both the aneurysm dome and the adherent brainstem. Most of the
embolic coils had to be left in place because they were densely adherent high in the dome.

Two patients (Cases 17 and 19) developed delayed hemispheric ischemia after balloon occlusion of the ICA for treatment of intracavernous aneurysms. Both patients had passed the clinical balloon occlusion test before permanent detachment. In one case the deficit appeared in stepwise fashion within 24 hours of ICA occlusion. In the other the deficit appeared and progressed slowly more than 24 hours after embolization. In neither case did the deficit resolve with hypervolemic, hypertensive therapy. Emergency STA–MCA bypass procedures were performed in both cases.

One patient (Case 18) experienced posterior communicating artery aneurysm rupture during placement of a balloon within the sac. The massive subarachnoid, intracerebral, and intraventricular hemorrhage was treated by craniotomy for clot removal, external ventricular drainage, and intensive medical support.

**Outcome.** The patient who had emergency removal of GDCs that had herniated into the ICA (Case 21) recovered completely. The patient who developed embolic infarcts from the balloon that had herniated into the ICA (Case 16) died. After surgery, this patient developed massive fatal hemispheric swelling, presumably due to reperfusion edema.

The patient (Case 20) who required microcoil extraction from the giant basilar aneurysm was initially more severely quadriparetic after surgery. After prolonged hospitalization and rehabilitation, she improved substantially and is much less impaired than immediately before surgery. She is awake, alert, and cognitively intact, with a residual hemiparesis. Both patients who underwent emergency STA–MCA bypass after balloon carotid occlusion (Cases 17 and 19) showed improvement in their symptoms of cerebral ischemia. The patient with craniotomy for clot removal (Case 18) died.

**Discussion**

The endovascular occlusion of cerebral aneurysms was first described in 1974. In the ensuing 20 years, steady advances have been made in the techniques and materials used in endovascular therapy. This has been accompanied by a decrease in the morbidity and mortality rates associated with such procedures. Although surgical treatment is still the procedure of choice for most uncomplicated aneurysms, endovascular methods remain an effective alternative for selected patients. As with all procedures, complications and treatment failures occur. Our purpose in this report is to focus on the subset of patients who subsequently required surgical intervention. As these techniques become more widespread, it will be increasingly important for all neurosurgeons to be familiar with such interventions.
At our institution, we have assembled a neurovascular team consisting of neurosurgeons experienced in neurovascular surgery, interventional neuroradiologists, and neurologists with expertise in neurophysiological monitoring. We have found that this leads to optimal patient care, as the increasing sophistication and complexity of procedures and patient management issues involved make it difficult for one physician to be skilled in all areas. Treatment decisions regarding surgery or embolization are made at a weekly neurovascular conference. All services involved are available 24 hours a day for emergency procedures or consultation.

Selection of Patients for Embolization or Surgery

Selection of patients for embolization or surgery is conducted on an individual basis. However, the relative indications for embolization of aneurysms at our institution include: 1) medically unstable condition (for example, cardiac or pulmonary failure); 2) advanced patient age (greater than 75 years “physiologically”); 3) significant cerebral swelling or vasospasm on radiographic studies necessitating delay in surgery for ruptured aneurysms; 4) poor neurological status after SAH (Grade IV or V status); 5) recurrent or residual aneurysm after unsuccessful surgical clipping; 6) patient refusal of surgery; and 7) relative surgical contraindication due to difficult aneurysm location or configuration. These indications are somewhat imprecise and open to variations in application among physicians of different specialties or with different levels of experience with aneurysms. The last listed indication is most subjective. An aneurysm that is difficult or presents a high risk in the view of one physician (a giant carotid–ophthalmic aneurysm, for instance) may seem operable with acceptably modest risk to a highly experienced or specialized colleague.

How can aneurysms selected for endovascular treatment (therefore presumably “inoperable” or high-risk) later be treated surgically with the low morbidity seen in this series? In some cases the condition responsible for the high surgical risks (for example, medical instability, neu-
rological impairment, or vasospasm) resolved between the time of endovascular treatment and surgical treatment. In several cases aneurysms were referred initially for endovascular treatment because their surgical treatment would require the use of specialized techniques that are not routinely used by many neurosurgeons (for example, EC–IC saphenous vein bypass and trapping for unclippable aneurysms, anterior clinoid resection for carotid–ophthalmic aneurysms, or hypothermic circulatory arrest for giant aneurysms). After aneurysm recurrence, the use of the relevant “specialized” technique permitted safe surgical treatment. In some cases, after failure of endovascular techniques, patients who initially refused surgery reconsidered and requested treatment via craniotomy.

Surgical Treatment After Unsuccessful Attempt at Endovascular Therapy

Failure of embolization may be related to the inability to safely occlude a parent vessel by balloon embolization in the setting of a failed test occlusion. Treatment with EC–IC bypass followed by occlusion of the parent vessel is an accepted method in such cases. Utilization of a vein graft may be preferable in this situation, as greater blood flow is available immediately compared with an STA–MCA bypass. This may reduce the incidence of ischemic deficits that occur following STA–MCA bypass and ICA occlusion. Although embolization may then be performed after surgery, we prefer to sacrifice the parent vessel at the time of surgery, after intraoperative test

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Fig. 4. Case 21. Left: Preembolization lateral angiogram showing a multilobulated carotid–ophthalmic artery aneurysm. Center: Immediate postembolization angiogram showing the coil mass in the aneurysm, with stenosis of the internal carotid artery (ICA) resulting in very slow flow. Right: Postoperative angiogram showing occlusion of the aneurysm, with restoration of flow in the ICA.

Fig. 5. Case 20. Left: Preembolization angiogram, Towne’s projection, showing a giant basilar apex aneurysm. Center: Angiogram, Towne’s projection, obtained after two embolizations with Guglielmi detachable coils showing a coil mass with patent base incorporating the posterior cerebral arteries. Right: Postoperative skull film, anteroposterior view, obtained after aneurysm clipping, aneurysmorrhaphy, and decompression with use of hypothermic circulatory arrest. A gap is present between the clips across the aneurysm neck and the remaining coils; several meters of coil have been removed from this area. Note that the remaining coils are less densely packed.
occlusion with EEG and evoked potential monitoring. This allows for distal trapping of the aneurysm, reducing the risk of embolic events by eliminating the distal stump. It also eliminates the risk of aneurysm rupture, which may occur following EC–IC bypass. While the aneurysm may be trapped with balloons, navigating a balloon distal to the aneurysm may be technically difficult and increases the risk of embolism from thrombus within the aneurysm.

Failure of embolization may be secondary to difficulty in positioning the microcatheter within the aneurysm in elderly, hypertensive patients with tortuous, atherosclerotic vessels. Usually, a direct carotid artery puncture will allow access to the aneurysm by bypassing a tortuous aorta but, in our Case 14, the tortuousity was located in the ICA at the skull base.

Surgical Treatment of Remnant Aneurysm Necks After Endovascular Treatment

All techniques developed to date for the intravascular occlusion of aneurysms, whether relying on balloons or coils, may result in incomplete occlusion. This is particularly evident in giant aneurysms or those with wide necks. A significant risk of recurrent SAH is present in these cases, based on extrapolation of data from recurrent aneurysms following surgical clipping and on reports of regrowth and rebleeding following incomplete endovascular occlusion. Even small remnants may grow into large aneurysms over time and present with recurrent SAH. Feuerberg, et al. calculated an annual risk of rebleeding for residual aneurysms that may be as high as 0.79% per year, less than the risk from an unclipped aneurysm but still significant. They also confirmed that small remnants can enlarge and rebleed. Thus, an attempt at complete extirpation of residual aneurysms would seem justified if the procedure can be performed with acceptably low risk.

We usually attempt repeat embolization prior to considering a patient for surgical treatment. However, this is not always effective or possible due to the geometry of the residual aneurysm, which may preclude safe catheterization or further coil deposition. For example, in some cases further embolization may risk branch vessel occlusion. In these circumstances, surgical clipping may still be possible despite an initial classification as a high-risk lesion. We were willing to accept higher surgical risk to treat a clipped aneurysm but still significant. They also confirmed that small remnants can enlarge and rebleed. Thus, an attempt at complete extirpation of residual aneurysms would seem justified if the procedure can be performed with acceptably low risk.

We usually attempt repeat embolization prior to considering a patient for surgical treatment. However, this is not always effective or possible due to the geometry of the residual aneurysm, which may preclude safe catheterization or further coil deposition. For example, in some cases further embolization may risk branch vessel occlusion. In these circumstances, surgical clipping may still be possible despite an initial classification as a high-risk lesion. We were willing to accept higher surgical risk to treat a large neck remnant, or one that was enlarging on serial angiograms, because we considered that the risk of rerupture was high in such cases. The decision to operate in this group of patients is subjective and depends on multiple factors, including the location of the aneurysm, the age and condition of the patient, and the size of the remnant aneurysm. It may be best to follow conservatively a stable 4-mm remnant basilar aneurysm in an elderly patient, whereas surgery may be more appropriate for such a remnant in the anterior circulation in a younger patient.

The major considerations when attempting to clip a partially embolized aneurysm are the degree of occlusion of the aneurysm neck, the elapsed time from the last embolization, and the neurological status of the patient. We believe that, if there is residual filling of the aneurysm, it is best to wait until the patient’s neurological condition following SAH has stabilized before operating. The small risk of aneurysm rupture incurred by waiting the necessary few weeks or months for recovery from SAH is probably outweighed by the lower surgical risk that results. The risk of immediate rebleeding following coil embolization would appear to be low, as the majority of aneurysms bleed from the dome or fundus, and these regions are usually protected even with an incomplete embolization. Nevertheless, more data need to be acquired before this can be stated with certainty.

If the aneurysm base is free of coils, as is often the case in wide-necked aneurysms that have experienced compaction of platinum coils, there is little extra impediment to clip application. Balloon embolization may also leave a widely patent neck, as balloons may migrate distally into or through the aneurysm dome, presumably from the effect of constant arterial pulsations. Larger aneurysms may offer more of a problem, as the aneurysm cannot be collapsed for better visualization and clip adjustment with a fibrotic mass of coils present. We experienced this difficulty only in Case 20, the giant basilar apex aneurysm causing mass effect. In such cases, intraoperative angiography can be invaluable in detecting improper clip placement. Others have noted fibrosis surrounding the neck of aneurysms treated with balloons, but this did not occur to any significant extent in our three cases. This appears to be more frequent with latex than with silicone balloons. We did not find unusual perianeurysmal fibrosis in aneurysms treated by the GDC technique.

Smaller remnants may prove more difficult to clip due to the presence of the embolic material in the neck region (see below). Observation may be preferable in these cases, as their small size presumably results in a relatively lower risk of rupture. If a decision is made to proceed surgically, waiting a few months may result in further coil compaction and easier clip application at operation while subjecting the patient to an acceptably small risk of hemorrhage.

If considerable time has passed since embolization (on the order of a few weeks), the thrombus surrounding the platinum coils organizes into a fibrotic mass. We observed this in several of our cases. This becomes an issue only if an attempt is made to remove the mass of coil to decrease the mass effect of large aneurysms or to remove coils that may have herniated into the parent vessel. Two observations are pertinent. First, coil extraction may not be necessary for decompression, because exclusion of the aneurysm lumen from the circulation decreases aneurysm pulsation and may thereby decrease its mass effect. We have seen improvement of symptoms following endoscopic obliteration of aneurysms. Second, we have observed that one or two loops of coil may prolapse into the parent vessel, without causing thrombus or generating emboli. It is probably not necessary to remove the coils in these cases. However, such coil positioning may hinder complete clip closure; this was observed in Case 14, but placement of another clip sufficed to occlude the neck. It may be hazardous to attempt to remove a long loop of coil that has herniated into the parent artery. In such cases the coil may become incorporated into the vessel wall, and extraction might cause intimal damage, as in Case 11. A large number of coils may prolapse into the parent vessel,
especially in cases in which vessel origins are incorporated into the aneurysm. It is unlikely that adequate clip placement can be achieved in this situation, and trapping of the aneurysm with possible bypass in cases of inadequate collateral flow may be necessary. Incising the dome of the aneurysm to withdraw coils may be attempted, but vigorous efforts to extract the coils should be avoided if they have become fibrosed in place and the aneurysm is adherent to surrounding structures. The task of removing the microcoils is made considerably easier if the operation is performed shortly after the embolization. One patient (Case 21), with coil herniation from a carotid–ophthalmic aneurysm into the ICA, was operated on immediately after embolization, and it was possible to remove all the coils from the ICA without difficulty. However, another patient (Case 20), with a giant basilar apex aneurysm, was operated on 3 weeks after the first GDC embolization and 2 weeks after the second embolization. It was rather difficult to extract the coils because they were fixed in place by tenacious thrombus. Only 30% of the coils in the fundus could be removed.

Our results suggest that planned, staged endovascular and surgical procedures may be of benefit in certain patients, such as those presenting with high-grade SAH. Endovascular embolization may be performed as an emergency to seal the immediate rupture site within the aneurysm. If it is not possible to completely occlude the aneurysm safely at the time of embolization, the patient may be operated on electively following recovery from the acute event.

Management of Complications After Endovascular Treatment

Complications associated with embolization of aneurysms include intracranial hemorrhage from aneurysm rupture or vessel perforation, and ischemic symptoms. Intracranial hemorrhage may occur following perforation of the aneurysm or an intracranial vessel with the microcatheter or guidewire. We have also seen instances of aneurysm rupture secondary to the force of the coils being deposited into the aneurysm (V Watson, et al., unpublished data). The rupture can frequently be sealed with the immediate administration of protamine and with the rapid deposition of further coils into the aneurysm lumen. The outcome is usually dependent on the patient’s overall condition prior to the complication. The hemorrhage, although usually subarachnoid, may be parenchymal, intraventricular, or subdural. Surgical evacuation may be necessary in extreme situations, as in Case 17, in which removal of massive intraventricular clot was necessary in an attempt to control severe intracranial hypertension. We have experienced several other cases of rupture during endovascular treatment in which ventriculostomy placement followed by medical management in a neurosurgical intensive care unit has sufficed.

Ischemic symptoms following embolization may be either acute or delayed. They may result from thromboembolic phenomena or from hemispheric hypoperfusion secondary to parent vessel occlusion. We initially treat the patient with anticoagulation and/or antiplatelet therapy, and begin hypertensive and hypervolemic therapy. Lack of response to this regimen requires more aggressive intervention.

In the setting of an endovascular embolization, a stroke syndrome may result from occlusion of a branch vessel during or following the procedure. This may be caused by thrombus propagation from the catheter or guidewire, from thrombosis in the aneurysm lumen, or from herniation of the coils into the parent vessel. When a vessel is occluded due to thrombus propagation, emergency diagnostic angiography with superselective thrombolytic therapy may reestablish patency. Symptomatic vessel occlusion caused by herniation of coils or balloons into the parent vessel occurred in two of our cases. This situation is difficult to resolve by endovascular methods and requires surgical removal of the embolic material provided that there is no evidence of distal thrombosis. Surgical reestablishment of flow is urgent and must be accomplished before brain infarction occurs. In one patient (Case 16) balloon embolectomy was too late, and the patient died. In Case 21, immediate coil extraction restored ICA patency and reversed the ischemic deficit.

Following parent vessel occlusion, transient neurological deficits may occur in up to 12% of cases, with permanent deficits in 1.5% to 4.4%. This occurs despite various protocols developed for assessing the adequacy of collateral cerebral blood flow during test occlusion. Transient ischemic attacks in this setting may be related to formation of emboli in the distal stump of the occluded vessel and are treated with antiplatelet therapy.

Hemispheric ischemia related to hypoperfusion may also occur. Although the indications for EC–IC bypass remain controversial, if there is no response to initial medical management, emergency EC–IC bypass may be indicated to restore cerebral blood flow in the presence of delayed hypoperfusion. The likelihood of a successful outcome increases if the patient is operated on within 6 hours, or immediately following intraprocedural occlusion. Two of our patients (Cases 17 and 19) required emergency bypass for evolving hemispheric ischemia following ICA occlusion. Both patients experienced an improvement in their neurological function compared to their preoperative state. It appears that STA–MCA bypass grafts have a lower incidence of intracerebral hemorrhage than saphenous vein interposition grafts and may be preferable in this situation as the lower initial blood flow limits the possibility of reperfusion hemorrhage.

Conclusions

Neurosurgical management continues to play a role in cerebral aneurysms treated by endovascular methods. Although remarkable advances have been made in the endovascular treatment of aneurysms, follow-up studies of these patients are necessary to document continued aneurysm exclusion from the cerebral circulation. Many factors need to be taken into account when determining the necessity for surgery in those patients left with aneurysm remnants, including the size of the remnant, the location of the aneurysm, and the patient’s age and medical condition. With proper patient selection, we have found surgical treatment of postembolization remnants to be quite satisfactory. It should be remembered that many of these patients were initially classified as “high risk” due to the size or location of the lesion and that operating on this subgroup of patients may incur greater risks than normal...
Neurosurgery after unsuccessful aneurysm embolization
due to the nature of the aneurysm. Such operations may also require advanced neurovascular techniques.

A neurosurgical team should be on standby to perform emergency procedures following possible endovascular complications. Surgical embolectomy with concurrent clipping of the aneurysm or EC–IC bypass grafting may be necessary to treat hemispheric ischemia. Decompression may be required if thrombosis of the lumen of a giant aneurysm results in increased mass effect on critical structures, such as the brainstem.

References


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