Spontaneous rupture of cerebral aneurysms typically results in subarachnoid hemorrhage. The primary goal of treatment of cerebral aneurysms is to prevent future rupture. Surgical clipping had been the mainstay of treatment of both ruptured and unruptured cerebral aneurysms. In 1991, Guglielmi detachable coil (GDC) embolization was introduced as an alternative method for treating selected patients with aneurysm. The goal of the treatment is to prevent the flow of blood into the aneurysm sac by filling the aneurysm with coils and thrombus. Theoretically, there are several advantages of GDC over surgery. These procedures are performed under general anesthesia with the standard transfemoral approaches used in diagnostic angiography. Since its inception, GDC embolization has evolved as a result of both clinical experience and the introduction of technological improvements. We are now better at selecting aneurysms appropriate for coiling, which also have wide necks. Advances in GDC technology have also improved this method of treatment. Over the last several years, the number of coil sizes has been increased, multidimensional coils allowing safer initial coil placement have become available, and, more recently, softer coils have been introduced. Our current approach is to have both surgical and endovascular options for patients.

Endovascular therapy (EVT) continues to evolve and is now challenging surgical clipping as a genuine alternative therapy for intracranial aneurysms. The management of subarachnoid hemorrhage (SAH) and its associated complications remains a problem, and the need for a new relatively atraumatic treatment option has generated much interest. The Guglielmi detachable coil (GDC) has been particularly promising. This platinum coil is detached by electrolysis of the stainless steel delivery wire. The coil has proved simpler to deploy than earlier techniques and is safer because it deforms more easily to the lumen of the aneurysm. The GDC has been studied in the treatment of acutely ruptured aneurysms and unruptured aneurysms with a variety of morphologic features and locations. The outcome of surgical treatment for acutely ruptured aneurysms has remained fairly constant for the past 20 years, with only 30% of patients regaining their premorbid neurological status. It was hoped that the use of EVT in aneurysmal SAH would reduce the risks and harvest the benefits of early surgical intervention. The geometry and location of the aneurysm and the clinical status of the patient affect the indication for and likely success of EVT.

Although comparison is theoretically invalid given the different patient populations, EVT has tended to be reserved for poor surgical candidates, those with poor Glasgow Outcome Scale scores after SAH, or those with high surgical risks due to position or morphologic features, and the results have been similar to those of surgical series.

Criticism of EVT has resulted from the potential for rebleeding from partially occluded aneurysms. The need to demonstrate complete obliteration of the sac has...
been emphasized, and the terms dog-ears, neck remnants, and residual aneurysms have been used to describe the angiographic appearance when partial occlusion occurs. The long-term natural history of partially occluded aneurysms is not yet clear. As the pool of data for EVT increases, it is becoming clear that EVT is a viable alternative to surgical clipping. Moreover, in certain situations, EVT might be regarded as the treatment of choice. To our knowledge, there are no randomized controlled trials directly comparing surgery with EVT, but the criteria for the ideal “EVT candidate” are beginning to emerge. The aim of this review is to discuss the current literature that is concerned with the comparison of surgical treatment and EVT, detailing population demographics; outcomes; and morbidity, mortality, rebleeding, and complication rates. In light of this, we attempted to clarify the indications for choosing EVT for intracranial aneurysms in what is now an established multidisciplinary approach using the expertise of neurosurgeons and neuroradiologists.

**SUMMARY OF DATA FROM THE LITERATURE**

Several studies assess the use of EVT in the treatment of ruptured and unruptured intracranial aneurysms. Five recent studies are worthy of more detailed attention. The summarized results of these and other studies are shown in Table 1. In Table 2, for comparison, a selection of surgical series is highlighted.

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**Table 1. Summary of Coiling Series**

<table>
<thead>
<tr>
<th>Study, y</th>
<th>Patients, No.</th>
<th>No. With SAH</th>
<th>Hunt and Hess Grade, %</th>
<th>Complete Occlusion, %</th>
<th>Outcome, %</th>
<th>Morbidity, %</th>
<th>Mortality, %</th>
<th>Rate of Rebleeding, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>I: 24</td>
<td>Group 1: 56</td>
<td>Excellent:</td>
<td>SAH: 7.2 overall</td>
<td>Nonacute: 2.2</td>
<td>SAH: 17.8 overall</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>II: 29</td>
<td>Group 2: 77</td>
<td>Nonacute: 90</td>
<td>overall</td>
<td>Nonacute: 7.8</td>
<td>overall</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>III: 25</td>
<td></td>
<td></td>
<td>SAH: 74.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IV: 14</td>
<td>Complete occlusion: 40</td>
<td>Good: 78</td>
<td>Procedure related: 9.1</td>
<td>7.8 (related to aneurysm perforation, CVA, or delayed hemorrhage)</td>
<td>At 1.9 y: 2.6 (near complete occlusions; no complete occlusions)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>V: 7</td>
<td>Near complete occlusion: 52</td>
<td>Procedure related: 8</td>
<td>0.9 (1/103 had neck remnant)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>II: 0</td>
<td></td>
<td>Procedure related: 1.4</td>
<td>0.9 (3 with incomplete occlusion, 1 with anticoagulation)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>III: 16</td>
<td>Complete occlusion: 40</td>
<td>Good (GOS score 1 or 2): 82</td>
<td>Procedure-related mortality/ morbidity: 8</td>
<td>8.9 (related to aneurysm perforation, CVA, or delayed hemorrhage)</td>
<td>At 6-mo follow-up: 2.2 (no complete occlusions)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IV: 32</td>
<td>Small neck: 70.8</td>
<td>Improved or remained neurologically the same: 84.9</td>
<td>Overall: 6.2</td>
<td>Overall: 6.2</td>
<td>Overall: 2.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>V: 0</td>
<td>Large: 35</td>
<td>Overall: 8.9</td>
<td>Overall: 6.2</td>
<td>Overall: 6.2</td>
<td>Overall: 2.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>I: 61</td>
<td>Giant: 50</td>
<td>Overall: 8.9</td>
<td>Overall: 6.2</td>
<td>Overall: 6.2</td>
<td>Overall: 2.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>II: 17</td>
<td>90%-100% occlusion: 85</td>
<td>Good (GOS score 1): 83</td>
<td>Procedure related: 8</td>
<td>0</td>
<td>At 3-mo follow-up: 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>III: 9</td>
<td></td>
<td>Procedure related: 8</td>
<td>0</td>
<td>At 3-mo follow-up: 0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IV: 3</td>
<td>Cure in 21/24 who made it to follow-up: 87.5</td>
<td>Overall: 3.5</td>
<td>Overall: 7</td>
<td>Overall: 7</td>
<td>Overall: 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>V: 9</td>
<td>(WFNS)</td>
<td>Overall: 8.9</td>
<td>Overall: 6.2</td>
<td>Overall: 6.2</td>
<td>Overall: 6.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>I: 24</td>
<td>79</td>
<td>Good (GOS score 1 or 2): 87</td>
<td>Procedure-related mortality/ morbidity: 4.8</td>
<td>0.9 (1/103 had neck remnant)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>II: 17</td>
<td></td>
<td>Procedure-related mortality/ morbidity: 8</td>
<td>0.9 (3 with incomplete occlusion, 1 with anticoagulation)</td>
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<td></td>
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<td></td>
<td>III: 3</td>
<td></td>
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<td>0.9 (3 with incomplete occlusion, 1 with anticoagulation)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>I: 32</td>
<td>84.5</td>
<td>Good: 84.5</td>
<td>Overall: 4.2</td>
<td>Overall: 11.3</td>
<td>Overall: 4.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>II: 38</td>
<td></td>
<td>Overall: 4.2</td>
<td>Overall: 11.3</td>
<td>Overall: 4.2</td>
<td>Overall: 11.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>III: 17</td>
<td></td>
<td>Overall: 4.2</td>
<td>Overall: 11.3</td>
<td>Overall: 4.2</td>
<td>Overall: 11.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IV: 13</td>
<td></td>
<td>Overall: 4.2</td>
<td>Overall: 11.3</td>
<td>Overall: 4.2</td>
<td>Overall: 11.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>V: 0</td>
<td></td>
<td>Overall: 4.2</td>
<td>Overall: 11.3</td>
<td>Overall: 4.2</td>
<td>Overall: 11.3</td>
</tr>
</tbody>
</table>

*SAH indicates subarachnoid hemorrhage; ADL, activities of daily living; CVA, cerebrovascular accident; GOS, Glasgow Outcome Scale; WFNS, World Federation of Neurological Surgeons; and ellipses, mortality data are combined with morbidity data and given in column 7.

†Group 1 represents their early experience, in which patients were chosen for Guglielmi detachable coiling based on surgical exclusion; group 2 represents their late experience, in which patients were chosen based on aneurysm geometry.
Debrun et al\textsuperscript{6} present data from 144 patients split into groups 1 and 2 representing their early and late experience, respectively. The former group was chosen for GDC based on surgical exclusion and the latter based on aneurysm geometry (specifically, dome-to-neck ratios >2). For 55 patients with SAH (Hunt and Hess grade I, 24%; II, 29%; III, 25%; IV, 14%; and V, 7%), an excellent outcome (Glasgow Outcome Scale score 1) was seen in 74%, with procedure-related morbidity and mortality of 3.6% and 1.8%, respectively (overall morbidity and mortality, 7.2% and 17.8%, respectively). For 89 patients who presented nonacutely, an excellent outcome (Glasgow Outcome Scale score 1) was observed in 90%, with procedure-related morbidity of 2.2% and no procedure-related mortality (overall morbidity and mortality, 3.6% and 1.8%, respectively) (overall morbidity and mortality, 8.9% and 2.2%, respectively). The significance of subgrouping into those treated based on aneurysmal geometry is addressed later in this article.

Kuether et al\textsuperscript{16} published their data from 74 patients—40% presented with SAH over a 4\textfrac{1}{2}-year period. After coiling, they found that of patients with Hunt and Hess grade I/II, 81% were independent; of those with grade III, 100% were independent; and of those with grade IV/V, 50% were independent. Procedure-related morbidity and mortality were 9.1% and 7.8%, respectively.

Cognard et al\textsuperscript{17} performed EVT on 182 patients, 150 of whom had SAH (Hunt and Hess grade I, 61%; II, 17%; III, 9%; IV, 3%; and V, 9%) and 38 of whom had unruptured aneurysms. Of 167 patients who survived to long-term follow-up, 83% had Glasgow Outcome Scale scores of 1, with overall morbidity and mortality of 6.5% and 8.7%, respectively.

Vinue\textsuperscript{13} treated 403 patients with GDC divided into Hunt and Hess grade I, 20.3%; II, 26.1%; III, 30.0%; IV, 17.1%; and V, 6.5%. They found that 84.9% of patients improved or remained neurologically unchanged, with overall morbidity and mortality of 8.9% and 6.2%, respectively. In discussing these results they were compared with previous surgical series with similar distributions of Hunt and Hess grades and overall morbidity and mortality of 23% and 21%, respectively,\textsuperscript{18} and 14% and 27%, respectively,\textsuperscript{20} and 16% mortality.\textsuperscript{17-25}

Raymond and Roy\textsuperscript{12} treated 75 patients with EVT, with a Hunt and Hess grading distribution of I, 24%; II, 17%; III, 40%; IV, 15%; and V, 4%. They found that 82% of patients with grades I through III had good outcomes, with procedure-related morbidity and mortality of 8%.

Although these populations are different from those of surgical series, their results compare favorably.\textsuperscript{17-20, 23-25} It seems that overall the ability of EVT to secure aneurysms after hemorrhage (thus preventing rebleeding and allowing treatment of associated vasospasm) and achieve high good outcome scores is similar to that of surgical clipping. The tabulated surgical results (Table 2) are by no means comprehensive but give an idea of figures obtained through the late 1980s and 1990s. The discussion and comparison of these 2 treatments is complicated not only by the differing nature of the population characteristics but also by the presentation of variable outcome measures and morbidity and mortality rates: overall rates and procedure-related rates can only be compared with like rates. Furthermore, these observational comparisons are hardly scientific, and more detailed analysis requires a randomized controlled trial.

**DRAWBACKS AND REASONS FOR EVT FAILURE**

Drawbacks of EVT include the potential for bleeding from nonobliterated aneurysms after the procedure, its effect on the incidence of vasospasm, and the inherent complications of the technique.

**Remnant Rebleeding**

Experience from surgical clipping has shown that aneurysmal neck remnants seen on the postoperative angiogram might dilate to form another aneurysm and repre-
sent a significant risk for rebleeding. In view of this, the aim of EVT has been to achieve total occlusion. Total occlusion rates of 70% to 85% have been quoted, sometimes requiring more than one procedure. Generally, it has been easier to achieve total occlusion in aneurysms with small necks, and aneurysmal geometry is emerging as an important predictive factor.

In the study by Keuther et al of 74 patients, 40% of aneurysms exhibited complete occlusion (100%), 52% near complete occlusion (90%-99%), and 8% incomplete occlusion (<90%). They reported after 1.9 years of follow-up that no completely occluded aneurysm hemorrhaged after GDC treatment, and of near complete occlusions, 2.6% hemorrhaged at a rate of 1.4% per year. In the incomplete occlusion group, 16.7% (1 of 6 patients) bled after 2.3 years at a rate of 7.3% per year. In the context of acutely ruptured aneurysms, other studies have quoted rebleeding rates from partially occluded residual aneurysms (which are presumably <90% occluded) of 6.25%, 27.0%, and 25.0%.

In the study by Raymond and Roy, the angiographic terms dog-ears and residual necks are used to differentiate incomplete occlusion from residual aneurysms, which are classified as any opacification of the sac. It was from the residual aneurysms that the rebleeding occurred. They also note that at angiographic follow-up, 12 patients had recurrences from coil compaction that was more commonly associated with narrow necks than wide necks. Recurrences during this short period were not associated with hemorrhage, mortality, or morbidity. We need to determine whether patients who rebleed from the features of their postprocedure angiography (ie, dog-ears, residual necks, or percentage of incomplete occlusion) can be predicted so that in these patients further embolization or surgical clipping can be performed prophylactically. This information will come to light as long-term follow-up studies are published.

Vasospasm

The incidence of vasospasm in patients treated with EVT is a controversial issue. A recent study by Gruber et al suggests an increase in infarction rates after acute SAH in those treated with EVT compared with those treated with surgery. However, the increased rate of infarction is only significant in patients with Fischer grade 4 and Hunt and Hess grade V. They conclude that the presence of retained intracerebral clots in patients treated with EVT increases the delayed ischemic infarction rate secondary to vasospasm. In patients without intracerebral clot, there was no significant difference between those treated with surgery or EVT, although there was a trend toward higher rates in the EVT-treated group. Theoretically, even in groups with less severe grades of SAH, early surgery has been suggested to reduce the incidence of vasospasm by removal of vasoactive blood products at the time of surgery using cisternal lavage. This was not confirmed in the International Cooperative Study on the Timing of Aneurysm Surgery, in which early surgery did not seem to affect the incidence of morbidity and mortality from chronic cerebral vasospasm. Murayama et al studying a group of patients with Hunt and Hess grades I through III treated with EVT, found the incidence of symptomatic vasospasm to be 23%, which compares favorably with conventional surgical series and is confirmed by other EVT studies. More recently, Yalamanchili et al compared patients of similar Hunt and Hess and Fischer grades treated with surgery or EVT within 48 hours of aneurysmal SAH. They found that 22% of the EVT group developed vasospasm, whereas 74% of the surgical group developed vasospasm. Those in the EVT group responded to maximal medical management with significant improvement or resolution of their deficit; in the surgical group, 3 patients (30%) required endovascular angioplasty; ultimately, 2 died and 1 experienced a residual hemiparesis. They suggest, in contrast to Gruber et al, that blood, lipid peroxides, and free radicals released into the subarachnoid space because of surgical trauma, in addition to the spastic response of the cerebral vasculature to manipulation, predisposes craniotomy patients to vasospasm. The study by Yalamanchili et al consisted of a small number of patients, and, in the face of this conflicting data, it is clear that further study is required.

Technical Considerations

Complications are well documented in all the published series and include aneurysmal rupture, artery occlusion and thromboemboli, and coil migration. These complications have been reported at rates of 2.1% to 8.0% for aneurysmal perforation, 1.6% to 6.5% for thromboemboli, 3.2% to 5.0% for parent vessel occlusion, and 1.1% to 1.3% for coil migration.

Vessel Tortuosity

A possible cause of failure is the inability to gain a stable position of the microcatheter in the aneurysm for coil delivery because of tortuosity of the access vessel.

Mass Effect

Another problem encountered is increasing mass effect after coiling of large or giant aneurysms, which might require subsequent decompression of the surrounding structures. In a series of 9 patients, Tsuura et al performing serial magnetic resonance images after embolization of large or giant aneurysms, found that shrinkage of approximately 30% tended to occur 2 to 12 months after treatment. Only 2 patients were coiled, however (the rest had balloon occlusion), and these tended to shrink more slowly, they believed, because balloon occlusion allowed thrombosis of capillary channels within the aneurysm wall. Growth of thrombosed aneurysms has been recorded after treatment, possibly secondary to hemorrhage of vasa vasorum, but in each case after balloon occlusion. It is possible that the presence of coils might produce the same effect in addition to an inflammatory reaction and associated edema.

As experience increases and microcatheter and coil technology improves, many of these drawbacks will become less significant, and complication rates should decline.
ANEURYSM MORPHOLOGY AND LOCATION

It is well known that the results of EVT in large and giant aneurysms are less favorable than those in small aneurysms, with a commonly accepted classification of small (4-10 mm), large (>10-25 mm), and giant (>25 mm). Occlusion rates in these studies have consistently been better for small aneurysms, as defined by the previous dimensions: occlusion rates decreased for aneurysms larger than 10 mm, and for very small aneurysms (<4 mm), packing became technically difficult. The width of the neck has also been critical. There is inherent logic in the statement that small necks are easier to pack with coils than wide necks, and a width of less than 5 mm has been suggested as a cutoff point. This simple principle for EVT suitability has recently been refined by Debrun et al, who examined aneurysmal geometry. Based on the observation that a 5-mm aneurysm with a 2-mm neck would be easier to pack than a 5-mm aneurysm with a 4-mm neck, they propose dome-to-neck ratio as a more effective measurement. In their study, group 1 patients with dome-to-neck ratios of less than 2 (ie, relatively wide necks) had complete occlusion rates of 58%, whereas group 2 patients with dome-to-neck ratios of greater than 2 (ie, narrow necks relative to aneurysmal sac width) had complete occlusion rates of 80%. They point out, however, that any aneurysm with a neck wider than 5 mm is unlikely to be packed effectively because of coil prolapse, regardless of the dome-to-neck ratio.

For the early studies, patients were recruited on the basis of surgical exclusion. This could be for a variety of reasons, including poor clinical grade after SAH, general lack of fitness for surgery, and surgical inaccessibility. As a result, the published data contained a predominance of posterior circulation aneurysms. This in itself was not a problem, and in fact some groups report easier catheterization of posterior circulation aneurysms because the vessels are less tortuous; however, it made comparison of EVT and surgical series less valuable. Although this bias is now less marked, and in some cases even reversed, in all of these more recent series the most common individual locations were the basilar tip or parapyramidal aneurysms. This confirms that surgical inaccessibility remains an important factor in the choice of EVT. As experience of coiling at other sites grows, previously unknown situations that make coiling unsuitable have come to light: Debrun et al found that aneurysms in which multiple branches arose were particularly difficult (eg, at the middle cerebral artery bifurcation) because the vessels obscured the aneurysm neck, increasing risk of coil protrusion, and thus thrombosis, in the parent artery. This observation reiterates the importance of meticulous pretherapeutic angiography and planning before opting for EVT.

SUMMARY

There are now 2 options for the treatment of intracranial aneurysms, and available data suggest that the outcomes for each are similar. In certain circumstances each one has an advantage over the other, and different patients might be more suited to one but not the other. Endovascular therapy lends itself to small aneurysms (diameter, 4-10 mm), with neck widths less than 5 mm and dome-to-neck ratios greater than 2, in which the chances of total angiographic occlusion are highest. The most common individual locations treated in the published data are the basilar tip and parapyramidal aneurysms. Most of cerebral aneurysms in the posterior circulation and a few in the anterior circulation are better treated using endovascular coiling technique rather than surgically. A multidisciplinary approach with free communication between the interventional neuroradiologist and the neurosurgeon should be emphasized, with meticulous planning on the basis of pretherapeutic angiography. We need to continuously evaluate the data from surgical and endovascular series and any randomized trials to ensure the continued optimal management of patients with intracranial aneurysms. New technology will continue to make advances in this field.

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Corresponding author and reprints: James I. Ausman, MD, PhD, Department of Neurosurgery (M/C 799), University of Illinois at Chicago, 912 S Wood St, Chicago, IL 60612 (e-mail: jausman@uic.edu).

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