Intraoperative angiography during aneurysm surgery: a prospective evaluation of efficacy

GORDON TANG, M.D., C. MICHAEL CAWLEY, M.D., JACQUES E. DION, M.D., AND DANIEL L. BARROW, M.D.

Departments of Neurological Surgery and Radiology, Emory University School of Medicine, Atlanta, Georgia

Object. Indications for intraoperative angiography during aneurysm surgery remain unclear. To define its use, the authors report the results of a prospective study in which this modality was used in all patients undergoing surgery for intracranial aneurysms.

Methods. Intraoperative angiography was performed prospectively in the surgical treatment of 517 consecutive aneurysms regardless of the lesion’s location, size, or complexity. In 64 (12.4%) of 517 aneurysms intraoperative angiography findings prompted a change in surgical treatment. Residual aneurysm (47%) was the most frequent finding leading to clip revision. In 44% of cases, intraoperative angiography revealed vessel compromise. Surgery for aneurysms of the proximal internal carotid artery (ICA) was the most frequently altered, with lesions located at the superior hypophyseal artery (SHA) and clinoidal region having the highest revision rates, eight (40%) of 20 and eight (44%) of 18, respectively. Aneurysm size predicted the need for revision; giant aneurysms (>24 mm) underwent revision in nine (29%) of 31 cases, whereas large aneurysms (15–24 mm) were revised in 12 (22%) of 54 cases. In a multivariate logistic regression model, factors related to increased revision rates included the SHA and clinoidal locations, as well as giant and large size. Ninety-five patients underwent both intraoperative and postoperative angiography. Five discrepancies were noted (95% accuracy); four were flow-related and one involved a previously unrecognized residual aneurysm. Complications attributable to intraoperative angiography occurred in 0.4% of cases.

Conclusions. Proximal ICA location and large aneurysm size significantly predicted revision of surgery following intraoperative angiography. Unexpected findings, even in less complex locations, are frequently identified on intraoperative angiography. Low complication rates, high accuracy, and the unexpected need for clip readjustments favor a more widespread use of intraoperative angiography.

KEY WORDS • intracranial aneurysm • intraoperative angiography • clipping

The surgical repair of intracranial aneurysms may be complicated by residual lesion or vascular compromise following clip ligation. In many medical centers, the use of postoperative angiography has become standard practice to confirm that the goals of surgery have been achieved. Since the 1960s, intraoperative angiography has been available to provide feedback during surgery, while the aneurysm remains exposed. Revision can be undertaken before ischemic deficits occur and without an additional operation. Few debate the theoretical advantage of using intraoperative angiography to improve the outcome of aneurysm surgery, yet guidelines for its practice remain uncertain. Some investigators have advocated its use in the majority of cases, although most have suggested that it be limited to selected ones. Recommendations differ regarding which locations should be the subject of routine study. Meanwhile, refinement of portable DS technology and increasing expertise on the part of angiography teams continue to decrease operative time and improve image quality.

In this study we will evaluate the key issues surrounding the routine use of intraoperative angiography. Our consecutive prospective use of intraoperative angiography reduces the selection bias inherent in past studies in which factors predictive of surgical revisions were examined. The large number of patients undergoing postoperative angiograms has afforded an opportunity to compare the results of intraoperative with postoperative angiography, and the large number of angiograms provides the basis for an accurate assessment of safety.

Clinical Material and Methods

Patient Population

Since January 1995, intraoperative angiography has been the standard of care for surgical treatment of aneurysms at our institution. Data on all patients who underwent this
procedure were maintained prospectively. Because we have viewed intraoperative angiography as a standard of care and it did not represent application of a new technology, approval from the institutional review board was not sought. At the study’s end point in December 2000, a total of 714 aneurysms had been surgically treated by two surgeons (D.L.B. and C.M.C. at Emory University Hospital; aneurysms treated at other hospitals in our system were excluded from this analysis). Due to the lack of availability of neuroradiological support during a 6-month period in 1996, 36 patients did not undergo intraoperative angiography. Therefore, to minimize selection bias, all aneurysms treated before 1997 have been excluded from the study. All cases in which aneurysms were intentionally trapped or deemed unclippable were also excluded. Of the remaining 523 aneurysms treated with surgical clipping, intraoperative angiography was not performed in six cases. In two of these, technical difficulties related to obtaining the angiogram with the patient in the lateral or prone position precluded its completion; our current use of an extra-long metal reinforced sheath has corrected this problem. In one of the cases in which intraoperative angiography was not performed, surgical treatment was combined with tumor resection, and an unexpected incidental aneurysm was identified and clipped. In the other three cases, the lack of available radiology staff prevented us from obtaining the angiogram.

Between January 1997 and December 2000, 517 aneurysms treated by clip ligation in patients ranging in age from 2 to 78 years were studied. Seventy-two percent of aneurysms were found in female patients, demonstrating a strong sex predilection. Fifty-six percent of patients presented with SAH; other presentations included the following: incidental (16%), headache (10%), ophthalmoplegia (5%), intracerebral hemorrhage (4%), and visual deficits (4%). The MCA and ACoA complex locations were the most common.

**Angiography Procedure**

All patients, regardless of aneurysm morphology, size, or location, underwent intraoperative angiography. A radiolucent headholder and a radiolucent operating table were used for intraoperative angiography studies. A portable intraoperative DS angiography unit was used. The femoral artery was the point of access in all patients. If the positioning of the patient precluded later femoral catheter placement, a long femoral catheter introducer was placed beforehand. The angiography team was called during the dissection of the aneurysm. Once the aneurysm was clipped, at least two views of the area in question were obtained in all cases. When no unexpected findings were encountered, intraoperative angiography rarely added more than 20 minutes to the operating time. Nevertheless, there was considerable variability in the amount of additional time necessary, depending on both the difficulty encountered in obtaining optimal views and the need for clip revisions. Estimates of the additional operative time were based on the average of 30 index cases. At present, there is no difference between intraoperative and postoperative angiography as far as patient charges are concerned. Postoperative angiography was not routinely performed; 95 patients underwent follow-up studies after intraoperative angiography, typically for the diagnosis and treatment of cerebral vasospasm.

**Data Analysis**

All pertinent patient data, including the role of intraopera-

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**TABLE 1**

*Intraoperative angiographic findings leading to revision in 64 aneurysms* 

<table>
<thead>
<tr>
<th>Finding</th>
<th>No. of Lesions (%)</th>
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<tbody>
<tr>
<td>residual aneurysm</td>
<td>30 (47)</td>
</tr>
<tr>
<td>vessel compromise</td>
<td>28 (44)</td>
</tr>
<tr>
<td>new aneurysm</td>
<td>3 (5)</td>
</tr>
<tr>
<td>bypass occlusion</td>
<td>5 (8)</td>
</tr>
<tr>
<td>unclippable (endovascular</td>
<td>2 (3)</td>
</tr>
<tr>
<td>treatment)</td>
<td></td>
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* In four cases there was more than one revision.

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**Fig. 1.**  *Left:* Preoperative angiogram demonstrating an aneurysm arising from the ventral surface of the ICA near the origin of the SHA, extending anteriorly and inferiorly into the region of the superior cavernous sinus.  *Center:* Although the clip appeared to be positioned entirely across the aneurysm neck, intraoperative angiography documents persistent filling of the aneurysm through the clip blades.  *Right:* The dural ring was opened closer to the clinoidal segment and the clip blades were repositioned superiorly to complete obliteration of the aneurysm.
ative angiography, were prospectively maintained in a computer database. Factors considered to have a potential role in revision, including aneurysm location and size, were entered into a multivariate logistic regression model, with revision as the independent variable. Significance was defined at probability values of less than 0.05.

Sources of Supplies and Equipment

The Mayfield radiolucent headholder was purchased from Ohio Medical Instruments, Cincinnati, OH, and the radiolucent operating table was obtained from Skytron, Grand Rapids, MI. The portable DS angiography unit was manufactured by OEC Diagnostics, Salt Lake City, UT. The Filemaker Pro version 4.1 software used for the database was produced by Filemaker, Inc., Santa Clara, CA. The statistical software (SPSS 9.0) was acquired from SPSS, Inc., Chicago, IL.

Results

Intraoperative Angiographic Findings

As shown in Table 1, intraoperative angiography findings led to modifications in aneurysm surgery in 64 cases (12.4%). Residual aneurysm was the most common finding (Fig. 1); in 47% of cases, the aneurysm was incompletely clipped. In all cases in which residual aneurysm was detected on intraoperative angiography, the lesion was reexplored. In 17 cases, the clip was repositioned and an optimal, angiographically confirmed result was obtained. In the remaining 13 cases, various strategies were used. In one case, the aneurysm was trapped. In another, the calcified fusiform neck was wrapped. In four cases, only the subarachnoid component of the aneurysm was treated because the residual lesion was reduced to the extradural component. In the seven remaining cases, the residual aneurysm could not be treated safely by clip ligation, and postoperative embolization was planned. In two of those cases, the patients’ poor neurological condition precluded further treatment.

Angiographic evidence of vessel compromise was observed in 28 cases (44%). In 12 instances (19%), branch vessel compromise was noted (Fig. 2). In 16 cases (25%), there was parent vessel compromise; clip revision restored flow in each circumstance. In three cases, a previously unrecognized aneurysm was identified on intraoperative angiography that was obscured from view in the preoperative study. In cases in which bypass grafts were applied as an adjuvant to the treatment of aneurysms, intraoperative angiography demonstrated occlusion of the bypass graft in five instances, thereby allowing revision in the same setting. Intraoperative angiography may also reveal that attempts at clip revision compromise the parent vessel.

Aneurysm Location

The proximal CA location demonstrated the highest rates of revision following intraoperative angiography (Table 2). Clinoidal segment and SHA aneurysms underwent revisions most frequently after intraoperative angiography; their revision rates were 44.4% and 40%, respectively. Thirteen percent of OphA segment aneurysms underwent clip readjustment after intraoperative angiography. Although the revision rates in the remainder of the anterior circulation were lower, they continued to be significant, ranging from 4.3% in PCoA aneurysms to 16.7% at the ICA terminus. The only location that did not appear to benefit from intraoperative angiography was the small number of aneurysms of the anterior choroidal artery. Aneurysms of the posterior circulation had higher revision rates compared with the anterior circulation, except for the proximal CA segment.

Aneurysm Size

Revision rates were directly correlated with aneurysm size (Table 3). There were 31 giant aneurysms in this series (> 24 mm); within this group, intraoperative angiography led to surgical revision in nine cases (29%). In the 54 large aneurysms (15–24 mm), surgical revisions were undertaken in 22% of cases. There was no difference in revision rates between medium (5–14 mm) and small (< 5 mm) aneurysms: both were 9%.

Statistical Analysis

Patient age, aneurysm location, aneurysm size, and the incidence of SAH were entered into a stepwise multivariate
logistic regression model to study their individual contribution to revision rates. Age and the incidence of SAH were not significantly associated with clip revision. On univariate analysis, the clinoidal and SHA locations were significantly associated with clip revision (p < 0.001). After controlling for size in multivariate analysis, however, the relationships became less significant (p = 0.11 in SHA and p = 0.08 in clinoidal lesions). Similarly, whereas the PCoA location demonstrated significantly lower revision rates on univariate analysis (p = 0.016), controlling for the higher proportion of smaller aneurysms eliminated any relationship on multivariate analysis (p = 0.35). Giant (p = 0.004) and large aneurysms (p = 0.008) were significantly associated with clip revision on both univariate and multivariate analyses.

### Accuracy of Intraoperative Angiography

Ninety-five patients underwent both intraoperative and postoperative angiography. Patients in our series did not routinely undergo postoperative angiography, and of those who did, additional studies were obtained because of new neurological deficits or for the management of cerebral vasospasm. Five patients had discrepancies between the intraoperative angiography and the postoperative study, for a 95% accuracy rate. In three of these instances, the postoperative study was performed to evaluate a new neurological deficit after surgery. In each of these instances, there was compromise of ICA or MCA flow that was not apparent on the preoperative angiogram. In a retrospective review of one of the cases, impending ischemia may have been anticipated because of the slow, asymmetrical filling of the anterior cerebral artery system. In one other discrepancy, an external CA–P2 vein graft bypass proved to be occluded, whereas intraoperative angiography had demonstrated patency. In another instance, intraoperative angiography had demonstrated complete obliteration of a posterior inferior cerebellar artery aneurysm. Nonetheless, while angioplasty for vasospasm was being performed, the angiogram demonstrated residual aneurysm. The patient underwent a second craniotomy, with successful clip ligation of the residual aneurysm.

### Complications Related to Intraoperative Angiography

Complications from intraoperative angiography were few; of 517 aneurysms treated, there were only two strokes attributable to intraoperative angiography; the calculated stroke risk is 0.4%. One patient experienced expressive aphasia after an intraoperative angiogram that included temporary balloon occlusion; this patient made a full recovery. In another case, a patient suffered vertebrobasilar infarction and quadriplegia. No patient developed a groin hematoma that required surgical intervention.

### Discussion

The goal of aneurysm surgery is the complete obliteration of the lesion without compromise of normal vascular anatomy. In discussions in which aneurysm surgery is compared with alternative treatments and natural history studies, it is often assumed that surgery affords a complete cure and eliminates the risk of future SAH. Nevertheless, it is not well documented how frequently these surgical goals are achieved. Numerous reports of routine postoperative angiography indicate that incomplete treatment may occur more often than previously suspected. Macdonald, et al.,9 reported on 66 patients harboring 78 cerebral aneurysms who underwent postoperative angiography. Unexpected residual aneurysms were seen in three (4%) of the 78, and three more aneurysms were observed to be completely unclipped. Of the nine unexpected major vessel occlusions noted, three were not associated with infarction. Six of the nine patients suffered strokes, and two died. In a study of routine postoperative angiography after surgical treatment in 597 consecutive aneurysms, Le Roux, et al.,4 reported a 5.7% incidence of residual aneurysm and a 5.7% incidence of major vessel compromise. Similarly, Rauzzino, et al.,12 described postoperative angiographic results in a study of 228 patients harboring 313 aneurysms, in which 13 cases of residual aneurysm (4.2%) and one major vessel occlusion (0.32%) were noted. Additionally, three cases of aneurysm were found that were not identified on the preoperative angiogram. An incompletely clipped aneurysm entails significant risk. Drake and Vanderlinden9 reported a 33% rehemorrhage rate in patients with small residual lesions, and a 54% rehemorrhage rate (seven of 13) in patients with large residual aneurysms. In addition, these authors noted a rehemorrhage rate of 28% (12 of 43) in the 13% of patients whose aneurysms were incompletely clipped. Giannotta and Litofsky4 reported on 19 patients with residual aneurysm after surgery; five patients presented with rehemorrhage and six

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**TABLE 2**  
Revision rates by lesion location

<table>
<thead>
<tr>
<th>Location</th>
<th>Revision Rate (%)</th>
<th>Total No. of Lesions</th>
</tr>
</thead>
<tbody>
<tr>
<td>cavernous sinus</td>
<td>22.2</td>
<td>9</td>
</tr>
<tr>
<td>clinoidal region</td>
<td>44.4</td>
<td>18</td>
</tr>
<tr>
<td>OphA</td>
<td>13.5</td>
<td>52</td>
</tr>
<tr>
<td>SHA</td>
<td>40.0</td>
<td>20</td>
</tr>
<tr>
<td>ICA bifurcation</td>
<td>16.7</td>
<td>24</td>
</tr>
<tr>
<td>ICA, NOS</td>
<td>10.0</td>
<td>10</td>
</tr>
<tr>
<td>ACoA</td>
<td>9.5</td>
<td>95</td>
</tr>
<tr>
<td>PCoA</td>
<td>4.3</td>
<td>69</td>
</tr>
<tr>
<td>MCA</td>
<td>8.4</td>
<td>95</td>
</tr>
<tr>
<td>AChA</td>
<td>0.0</td>
<td>15</td>
</tr>
<tr>
<td>ACA</td>
<td>11.1</td>
<td>27</td>
</tr>
<tr>
<td>BA apex</td>
<td>18.8</td>
<td>32</td>
</tr>
<tr>
<td>SCA</td>
<td>6.3</td>
<td>16</td>
</tr>
<tr>
<td>PCA</td>
<td>25.0</td>
<td>8</td>
</tr>
<tr>
<td>VB</td>
<td>7.4</td>
<td>27</td>
</tr>
</tbody>
</table>

* A CA = anterior cerebral artery; AChA = anterior choroidal artery; NOS = not otherwise specified; PCA = posterior cerebral artery; SCA = superior cerebral artery; VB = vertebrobasilar.

**TABLE 3**  
Revision rates by lesion size

<table>
<thead>
<tr>
<th>Size Category</th>
<th>Revision Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>giant (&gt;24 mm)</td>
<td>29</td>
</tr>
<tr>
<td>large (15–24 mm)</td>
<td>22</td>
</tr>
<tr>
<td>medium (5–14 mm)</td>
<td>9</td>
</tr>
<tr>
<td>small (&lt;5 mm)</td>
<td>9</td>
</tr>
</tbody>
</table>
presented with mass effect. The average time from treatment to recurrent hemorrhage or mass effect was 10.5 and 9.75 years, respectively. Because the latency period between incomplete treatment and its clinical manifestations can be lengthy, instances of incomplete treatment are likely to be underreported in the literature.

To minimize the risks associated with aneurysm surgery and to improve rates of complete obliteration, the use of intraoperative angiography has been discussed since the 1960s. The theoretical advantages are clear: intraoperative feedback from the vascular anatomy optimizes aneurysm obliteration while allowing immediate revision in the event of major vessel compromise. Early attempts at intraoperative angiography yielded poor-quality images and added considerable time to the operative procedure. Consequently, intraoperative angiography had been reserved for difficult aneurysms. Improved user expertise, portable DS units, and radiolucent operating tables and headframes now can provide images comparable to angiograms obtained in dedicated suites. Once integrated into the routine of aneurysm surgery, intraoperative angiography has had minimal impact on operative times if a dedicated team of interventional neuroradiologists is available. In our series, the additional time incurred rarely exceeds 20 minutes. The minimal increase in operative time is facilitated by the preoperative placement of femoral sheaths in elective cases and their placement in the intensive care unit in patients who present with SAH. The neuroradiologist is contacted when the final stages of aneurysm dissection have begun, so that all members of the angiography team are in position to obtain the angiogram as soon as the surgeon has completed inspection of the clip.

The benefits of intraoperative angiography have been reported in numerous studies. Alexander, et al., reported on 100 consecutive craniotomies for the treatment of 107 aneurysms in which intraoperative angiography was used. Their cases, however, were not strictly consecutive because 16 patients during the study period did not undergo angiography due to technical difficulties and the surgeon's preference. These exclusions may have introduced some degree of selection bias. Nonetheless, intraoperative angiography led to clip revision in 12 (11%) of 107 cases. Derdeyn, et al., also reported on 199 patients undergoing intraoperative angiography for the surgical treatment of 234 aneurysms; findings with this modality resulted in clip repositioning in 16.8% of 273 studies. In a smaller series, Origzano, et al., reported 18 clip revisions in 42 surgical procedures for 54 aneurysms. In a selected series, Payner, et al., reported on the use of intraoperative angiography in 70 patients; because of selection criteria, their revision rate was higher (27%) than in our study.

Our report contains both the largest series and the largest consecutive series in which intraoperative angiography was used during aneurysm surgery. Unlike previous series, the percentage of revisions is unlikely to reflect selection bias, because of the large series size as well as the fact that only six of 523 patients underwent clip ligation without intraoperative angiography. The size of our series also allows detailed statistical analysis that is not possible with smaller studies. The large number of patients who underwent both intraoperative angiography and postoperative studies provides stronger support for the accuracy of the former compared with the latter.

As with other investigations of intraoperative angiography, aneurysms of the proximal CA were found to benefit most from this procedure. Because of the technical complexity of the clip ligation of SHA and clinoidal segment aneurysms, revisions were undertaken in more than 40% of these cases. In most instances, residual aneurysm complicated initial clip placement; OphA aneurysms also had a high revision rate.

Clip ligation of giant and large aneurysms has been found to benefit uniformly from intraoperative angiography. Origitano, et al., reported errant clip placement in 64% of 25 large and giant aneurysms. Payner, et al., noted clip revision in five (42%) of 12 giant aneurysms. Difficulty in reconstructing the parent vessel lumen, concomitant atherosclerotic disease, and infolding of the thickened aneurysm neck wall may contribute to vessel compromise or residual lesion during clip ligation of giant aneurysms. In our series, giant aneurysms underwent revision after intraoperative angiography in 29% of cases, whereas treatment in 22% of large aneurysms was influenced by intraoperative angiography. Both findings were statistically significant on multivariate analysis.

Although most practitioners agree that intraoperative angiography should be routinely used in patients harboring large aneurysms and aneurysms of the proximal CA, restricted use of intraoperative angiography is commonly advocated in other circumstances. There is no consensus in the literature regarding the indications for intraoperative angiography in these other circumstances. Alexander, et al., noted increased rates of unexpected radiographic findings at the BA apex and PCoA locations. Other researchers have not singled out the PCoA location. In fact, Derdeyn, et al., reported significantly lower rates of unexpected findings in 50 PCoA aneurysms and concluded that intraoperative angiography could be avoided in this location.

The most important finding in our series, a finding not emphasized in other studies, is that surgical management of aneurysms of nearly all locations and sizes may benefit from intraoperative angiography. Clip ligation of aneurysms of the ICA bifurcation was associated with a surprisingly high revision rate (16.7%). Likewise, aneurysms of the BA apex underwent revision in 18.8% of cases. In the most common aneurysm locations, the ACoA and the MCA, one in 10 clipping procedures benefited from intraoperative angiography. Similarly, one in 10 small- and medium-sized aneurysms also benefited from intraoperative angiography. The only locations that appeared to have lower revision rates were in the PCoA and the anterior choroidal artery. Other than in the clinoidal and SHA locations, in no area was the revision rate statistically higher or lower than another on multivariate analysis. In contrast with findings in earlier series, no aneurysm location appears to be immune from revision based on the findings of intraoperative angiography. Given the large size of this series, this conclusion is less likely to result from a sampling error.

Intraoperative angiography can also be invaluable whenever a high-flow bypass is planned. This modality can identify kinking of the vessels and stenosis at the suture line, as well as intraluminal thrombus. Recently, Sekhar, et al., reported the use of intraoperative angiography in 62 patients who underwent bypass procedures; in 20 patients (32%) 23 graft problems were found. In this series, five bypass procedures benefited from intraoperative angiography, which
allows immediate recognition of graft failures and permits revision when success is most likely, while reducing the likelihood of stroke.

This series of patients highlights the use of intraoperative angiography to complement endovascular management. In circumstances in which an aneurysm may be impossible to cure with clipping alone, intraoperative angiography can provide guidance in the use of clipping to change the anatomy of a complex aneurysm to one that is more readily treatable with endovascular management. This approach avoids the risks involved with heroic clipping attempts or deconstructive procedures by providing an end point for surgical management at which complete clipping is impossible. Aneurysms that may not be treatable with endovascular or surgical means alone may then be treated with a combination of the two modalities.

Heros\textsuperscript{6,7} has noted that revision rates after intraoperative angiography may be artificially high. He notes that surgeons who routinely use intraoperative angiography may curtail their efforts to ensure adequate clip placement and rely on radiographic findings rather than methodical inspection. Before the current series, the selection biases of other series have hampered the ability to address this issue. The results of our study, however, can be compared with results from a consecutive series of postoperative angiograms. The rate of unexpected findings in our study (12.4\%) is nearly identical to the 11.4\% reported by Le Roux, et al.\textsuperscript{,8} in a large series of patients who underwent postoperative angiography. The similarity of the rates suggests that intraoperative angiography principally identifies problems that cannot be easily detected by inspection. Despite this similarity between the findings of intraoperative and postoperative angiography, there is little doubt that routine intraoperative angiography may change a surgeon’s habits. Especially in the setting of limited exposure and a difficult clipping procedure, waiting for the results of intraoperative angiography may prove to be more attractive than continued exploration. It is difficult to estimate how these changes in habits may affect the rate of revisions found in this series. Although these modifications may increase the frequency of unexpected findings on the intraoperative angiogram, the new regimen may also reduce unnecessary dissection and aneurysm and clip manipulation, which may have resulted in greater morbidity.

With improvements in technology, the quality of most intraoperative angiograms compares favorably with studies obtained in the angiography suite. Insistence on multiple views and a reading by a neuroradiologist familiar with the case improves overall accuracy. In this report, 95 patients underwent both intraoperative and postoperative angiography. Unfortunately, most postoperative angiograms obtained in this setting were limited studies intended to evaluate and treat cerebral vasospasm, and they do not provide an ideal standard against which the intraoperative angiogram should be compared. Nonetheless, it is worthwhile to note that there were only five discrepancies, for an overall accuracy of 95\%. In four of the five instances, intraoperative angiography demonstrated patent flow, whereas occlusion was identified on the postoperative angiogram. In these circumstances, it is likely that the intraoperative angiogram provided an accurate impression of the vascular anatomy at the time of surgery and that the occlusion occurred later. Although they did not contribute to the accuracy of intraoperative angiography as a procedure, these discrepancies underscore that findings on this modality do not preclude all ischemic complications: clip slippage, progressive thrombosis, and embolism remain unaccounted for. Excluding the four flow-related discrepancies, intraoperative angiography was accurate in 99\% of cases.

Despite the unexpected findings on intraoperative angiography and the resulting corrective surgical maneuvers, our study does not prove that the use of this modality improves outcomes. Patients with unexpected vessel compromise on intraoperative angiography may suffer ischemic complications even after clip revision. Intraoperative angiography may yield false-negative results in which all vessels appear to fill normally, although the patient experiences a stroke. Persistent filling into the aneurysm dome may become thrombosed over time and not require clip revision. A trial in which patients with aneurysms are randomly assigned to groups in which clipping is performed with or without intraoperative angiography would address this question.

Selective use of intraoperative angiography may be an attractive means to limit costs and improve convenience. A study of the cost-effectiveness of the routine use of this modality in aneurysm surgery has recently been completed.\textsuperscript{14} Using decision tree and Markov analyses, it was found that intraoperative angiography adds approximately 0.126 QALYs, principally by reducing the incidence of stroke. Because the cost of caring for a patient who suffers a major stroke is $35,800 per year, the cost savings achieved by reducing its incidence offset the estimated $3200 additional charge for intraoperative angiography for the large number of patients in whom normal results were found. The cost per QALY for the patients who underwent intraoperative angiography was no different from the cost per QALY for those who did not. With regard to convenience, routine intraoperative angiography relies heavily on the availability and enthusiasm of the neuroradiology team. With adequate planning, the impact on operative time can be minimized.

The most common strategy of selective use of intraoperative angiography for aneurysm surgery is partially based on the belief that one can predict when these studies will be useful and when they will not. Although large lesion size and paraclinoid location predict a higher revision rate, the literature as well as our analysis of more than 500 cases reveals no criteria that reliably identify situations in which surgical treatment of aneurysms is immune from error. To minimize the risks associated with aneurysm surgery and to assure the greatest likelihood of complete treatment, we advocate intraoperative angiography for all but the simplest aneurysms.

Conclusions

Intraoperative angiography frequently reveals radiographic findings that lead to alterations in aneurysm surgery. There are significantly higher rates of revision in the paraclinoid region and in large aneurysms. Nonetheless, no location was immune from complications associated with aneurysm surgery. Intraoperative angiography can be performed safely and accurately, in comparison with conventional angiography. We advocate routine intraoperative
Efficacy of intraoperative angiography during aneurysm surgery

angiography during surgery in all but the simplest aneurysms.

References


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Address reprint requests to: Sherry A. Ballenger, Editor, Department of Neurological Surgery, Emory University, 1365-B Clifton Road, Suite 6400, Atlanta, Georgia 30322. Email: sherry_ballenger@emory.org.