See the Editorial and the Response in this issue, pp 979–980.

J Neurosurg 96:988–992, 2002

Routine intraoperative angiography during aneurysm surgery

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Object. The routine use of intraoperative angiography as an aid in the surgical treatment of aneurysms is uncommon. The advantages of the ability to visualize residual aneurysm or unintended occlusion of parent vessels intraoperatively must be weighed against the complications associated with repeated angiography and prolonged vascular access. The authors reviewed the results of their routine use of intraoperative angiography to determine its safety and efficacy.

Methods. Prospectively gathered data from all aneurysm cases treated surgically between January 1996 and June 2000 were reviewed. A total of 303 operations were performed in 284 patients with aneurysms; 24 patients also underwent postoperative angiography. Findings on intraoperative angiographic studies prompted reexploration and clip readjustment in 37 (11%) of the 337 aneurysms clipped. Angiography revealed parent vessel occlusion in 10 cases (3%), residual aneurysm in 22 cases (6.5%), and both residual lesion and parent vessel occlusion in five cases (1.5%). When compared with subsequent postoperative imaging, false-negative results were found on two intraoperative angiograms (8.3%) and a false-positive result was found on one (4.2%). Postoperative angiograms obtained in both false-negative cases revealed residual anterior communicating artery aneurysms. Both of these aneurysms also subsequently rebled, requiring reoperation. In the group that underwent intraoperative angiography, in 303 operations eight patients (2.6%) suffered complications, of which only one was neurological.

Conclusions. In the surgical treatment of intracranial aneurysms, the use of routine intraoperative angiography is safe and helpful in a significant number of cases, although it does not replace careful intraoperative inspection of the surgical field.

KEY WORDS • residual aneurysm • arterial occlusion • intraoperative angiography • aneurysm clip

AFTER surgical obliteration of an aneurysm, it is important to obtain angiographic studies for evaluation of clip placement and to rule out either residual aneurysm or parent or branch vessel occlusion. In several series focused on postoperative angiography, up to a 12% incidence of residual aneurysm and a 19% incidence of parent vessel or branch occlusion have been shown, for a possible combined total of a 31% incidence of unexpected findings after aneurysm clipping.[19] Intraoperative angiography provides this information during surgery so that clip placement can be modified immediately. Although intraoperative angiography has been used selectively during surgery for technically challenging aneurysms,[3,10,18,20] it has not been used routinely in all cases. Since 1996, we have obtained these studies routinely after aneurysm clipping and before wound closure. We report our experience in this prospective series of intraoperative angiography studies performed in 303 consecutive operations over 4.5 years.

Abbreviations used in this paper: ACoA = anterior communicating artery; FA = femoral artery; ICA = internal carotid artery; MCA = middle cerebral artery; OphA = ophthalmic artery; OR = odds ratio; PCoA = posterior communicating artery; SAH = subarachnoid hemorrhage.

Clinical Material and Methods

Data Collection

A policy of routine intraoperative angiography after aneurysm clipping was implemented at the Johns Hopkins Hospital on January 1, 1996. The data on all patients admitted due to a diagnosis of intracerebral aneurysm between January 1, 1996 and June 30, 2000 were entered prospectively into a database collected by one of the authors (R.J.T.). Information from the database, along with medical records, intraoperative records, and radiographic reports on all patients treated surgically for their aneurysms were then reviewed to investigate the risks and benefits of the routine practice of post-clipping intraoperative angiography at this institution. Patient follow up was available for a minimum of 6 months and a maximum of 4.5 years. Patients who were treated medically and with surgical procedures not involving clipping (that is, trapping, parent vessel ligation, or endovascular methods) were not included in this study. Also excluded were a small number of patients treated by surgeons other than the authors, because none of these patients underwent intraoperative angiography.

Surgical Management

After induction of general anesthesia, a No. 5 French

sheath introducer was placed in the patient's left groin for selective transfemoral arterial catheterization before their final positioning was completed. In patients admitted with SAH, the sheath used for diagnostic angiography remained in the groin until the time of surgery. Heparin (2000 U in 500 ml normal saline at 30 ml/hour) was infused continuously through the sheath to maintain its patency.

After heparin infusion, all patients were placed in a headholder with radiolucent carbon fiber pins in preparation for intraoperative angiography before positioning for surgery. Surgical clipping of all aneurysms was performed by two of our authors (R.J.T. and D.R.). After the aneurysm had been clipped to the surgeons' satisfaction, angiographic images were obtained. If an unexpected occlusion of a parent or branch vessel or an aneurysm remnant was detected, the surgical clip was repositioned and repeated angiography was performed. Occasionally, angiography would have to be repeated several times until the result of clipping was satisfactory. The time required for the performance of intraoperative angiography (from the time of clip placement to the completion of angiography) was as little as 20 minutes in several of the most recent cases. On satisfactory completion of aneurysm clipping, the dome of the lesion was punctured and careful inspection of the operative site was performed before the wound was closed. The groin sheath was removed postoperatively in the intensive care unit.

Angiographic Procedure

A portable digital subtraction angiography unit (OEC 9600; Diasonics, Salt Lake City, UT), consisting of a mobile C-arm image fluoroscope, a real-time digital image processor and storage unit, and a video monitor, was used in all cases. After aneurysm clipping, No. 5 French catheters were introduced under fluoroscopic guidance into the common carotid artery, followed by 7 to 9 ml of nonionic contrast dye (concentration 300 mg/ml) injected by hand for digital subtraction angiography. Two views of the vessel of interest were routinely obtained, including anterior, lateral, or oblique views, depending on which were noted to be useful preoperatively. The amount of time needed for intraoperative angiography ranged from 15 to 35 minutes. All catheters were removed immediately after completion of intraoperative angiography.

Statistical Analysis

All data were considered nonparametric except for patient age. Univariate and multivariate analyses were then performed using stepwise logistic regression to determine if any of the recorded factors were significantly predictive of residual aneurysm or vessel occlusion. A two-sided alpha level of 0.05 was considered statistically significant.

Results

Patient Data

During the 4.5 years of the study, a total of 303 operations were performed to secure 337 aneurysms in 284 patients; 206 (72%) of the patients were female and 78 (27%) were male. Patient ages ranged from 14 to 85 years (median 51 years). Seventy-eight (27%) were African-American and 192 (68%) were caucasian.

Multiple aneurysms that were clipped at the time of surgery were present in 34 patients (12%). Fifty-seven aneurysms (17%) were large or giant lesions (> 10 mm in diameter), and 37 (11%) were posterior circulation ones. There was no obvious sex or race predominance among those harboring larger or posterior circulation aneurysms. One hundred ninety-one (63%) of the 303 operations were performed after SAH.

Of the patients studied, all but four underwent intraoperative angiography; this procedure was not performed because of technical difficulties in one patient, the presence of severe ulcerated carotid plaque in one patient, and dye allergy in two patients. Because of severe peripheral vascular disease in the FAs, two angiograms were performed successfully via subclavian arterial puncture.

In 24 patients who underwent intraoperative angiography we also obtained postoperative angiograms within 3 months of surgery, after their discharge from the intensive care unit.

Angiographic Findings

Clip repositioning was performed because of unexpected findings after intraoperative angiography in a total of 37 (11%) of 337 aneurysms. Of these, 22 (6.5%) were residual aneurysms, 10 (3%) were parent vessel occlusion, and five (1.5%) combined residual aneurysms and branch vessel occlusion. Residual aneurysm was documented on intraoperative angiography in a total of 58 (17.2%) of 337 lesions; however, this finding was unexpected in only 27 (8%) of these cases. Thus, overall, 73% of the instances of clip repositioning were required for residual aneurysm. Furthermore, our series of residual aneurysms included two cases of unclipped MCA lesions. Subarachnoid blood was present in each case, and, after successfully clipping an MCA aneurysm, we observed on intraoperative angiography that the originally depicted aneurysm remained unclipped, necessitating reexploration and clipping of the second lesion.

Aneurysm Location. Of the 37 aneurysms that required clip repositioning, 12 were ACoA, six were PCoA, seven were MCA, four were ICA terminus, three were OphA, and five were posterior circulation lesions (Table 1). Clip repositioning was performed in 12 (13.6%) of the 88 ACoA aneurysms, five (13.5%) of the 37 posterior circulation aneurysms, and only six (6.6%) of the 91 PCoA aneurysms. No single location in the anterior or posterior circulation was found to be significantly predictive of the need for clip repositioning.

Aneurysm Size. Overall, 15 (40.5%) of the 37 clip changes were performed on large (diameter > 10 mm) or giant (diameter > 25 mm) aneurysms. Large and giant aneurysms comprised five (33%) of 15 occlusion cases and 12 (44%) of 27 residual cases. Further subdivision of these cases shows that aneurysms larger than 10 mm in diameter comprised less than 50% of ACoA, PCoA, and posterior circulation aneurysm clip changes, but more than 50% of the clip changes that were performed in lesions in MCA, ICA terminus, and OphA locations (Table 2). With logistic regression, large and giant aneurysms were found to have a significantly increased risk of unexpected findings on intraoperative angiography that required clip repositioning (OR 4.2, 95% confidence interval 2.7–5.3). Among aneurysms with diameters smaller than 10 mm, the ACoA location was

TABLE 1

*Distribution of 337 clipped aneurysms**

Aneurysm Location	No. of Lesions Clipped	No. of Clips Repositioned (%)
anterior circulation		
OphA	16	3 (18.8)
SHA	1	0
PCoA	91	6 (6.6)
AChA	3	0
ICA terminus	24	4 (16.7)
MCA	62	7 (11.3)
ACoA	88	12 (13.6)
ACA (A_1+A_2)	11	0
total	300	32 (10.7)
posterior circulation		
BA tip	18	2 (11.1)
VBJ	1	1
SCA	7	1
AICA	3	1 (33)
PICA	8	0
total	37	5 (13.5)

* ACA = anterior cerebral artery; AChA = anterior choroidal artery; AICA = anterior inferior cerebellar artery; BA = basilar artery; PICA = posterior inferior cerebellar artery; SCA = superior cerebellar artery; SHA = superior hypophyseal artery; VBJ = vertebrobasilar junction.

TABLE 2

*Distribution of aneurysm clip changes by size of lesion and unexpected angiographic findings**

Lesion Location/Size	No. of Aneurysms	No. W/ Clip Change (%)	No. W/ Occlusion			No. W/ Residual Lesion		
			Total	Small	Lg & Giant	Total	Small	Lg & Giant
location								
ACoA	88	12 (13.6)	6	6†	0	7	6†	1
PCoA	91	6 (6.6)	3	2	1	4	3	1
MCA	62	7 (11.3)	1	0	1	6	2	4
other ant circ	52	7 (13.5)	3	1	2	6	2	4
pos circ	37	5 (13.5)	2	1	1	4	2	2
total	337	37 (11.0)	15	10	5	27	15	12
size								
small (<10 mm)	280	22 (7.9)	10			15		
lg/giant (>10 mm)	57	15 (26.3)†	5			12		

* Ant circ = anterior circulation; lg = large; pos circ = posterior circulation.
† Significantly higher rates of unexpected findings.

also associated with a significantly increased risk for unexpected findings (OR 3.2, 95% confidence interval 0.9–4.6).

Vessel Occlusion. The number of cases involving parent or branch vessel occlusion was small. Of the 15 patients in whom unexpected vessel occlusions were demonstrated, only five suffered immediate postoperative strokes. On multivariate analysis, only the addition of the presence of SAH increased the risk of unexpected intraoperative angiography findings (OR 2.4, $p < 0.05$).

Accuracy of Intraoperative Angiography. Of the 24 patients who also underwent postoperative angiography, in two (8.3%) false-negative results were found on intraoperative angiography, and in one a false-positive result was found. Both incompletely clipped aneurysms were located in the ACoA area and subsequently rebled at 2 months and 5 months after the initial surgery. The false-positive angiogram was initially thought to reveal a residual PCoA aneurysm, which was not confirmed on direct visualization at reexploration and was ultimately found to be a loop of the PCoA.

Angiographically Confirmed Complications

In eight (2.6%) of the 303 operations, patients experienced complications related to angiography (Table 3). Of these complications only one (0.3%) resulted in permanent neurological injury. Significant difficulty was encountered during catheterization of the tortuous atherosclerotic right common carotid artery in this patient. Angiographic studies then demonstrated MCA branch occlusions, with a simultaneous decrease in the somatosensory evoked potential signal from the same hemisphere; intraoperative angiography was aborted at this time. The patient awoke with severe neurological deficits and subsequently died. No correlation was found between the development of angiographic complications and age, presentation with SAH, or presence of severe atherosclerosis.

Discussion

Technology for the performance of intraoperative angiography has been available since the mid-1960s.[16] When it was introduced, however, the machinery was cumbersome and the sensitivity of the procedure was limited. Intraoperative angiography has become increasingly popular in some treatment centers, although many surgeons still claim that its disadvantages outweigh the benefits of its use. Its major drawbacks include the need for additional anesthesia and operating room time, the added risk from angiography[23] and its associated heparin use, the additional radiation exposure received by patients and operating room staff,[6] the risk of false-negative results, and the lack of obvious clinical benefit after clip readjustment in cases of vessel occlusion. Hillman and Johansson[11] and Vajda[22] published data showing that meticulous microsurgical dissection and collapse of the aneurysm allowed good visualization and that intraoperative angiography was mostly allowing detection only of technical abnormalities that did not require surgical correction, thus negating the need for this test.

The literature in favor of routine intraoperative angiography after aneurysm clipping, however, is increasing. It supports the notion that surgical opinion alone is insufficient in a minority of cases to predict inadequate clip placement. In the routine postoperative angiography study conducted by Macdonald, et al.,[17] it was demonstrated that in 66 patients undergoing surgery, completely unclipped aneurysms were seen in three cases (4.5%), unexpected residual aneurysms in three (4.5%), and unexpected vessel occlusions in nine more cases (13.6%), for a total of 22.6% of unexpected findings. In procedures performed by expert surgeons, the rate of residual aneurysms ranges from 3 to 18%.[19] A clear distinction needs to be made, however, between the unexpected finding of residual lesions that were undetected after clipping and the situation in which the aneurysm configuration does not allow complete clipping and the detected residual lesion is therefore known to the surgeon. It is in the

cases of unsuspected residual aneurysm that intraoperative angiography is expected to make an impact.

Analyses of postoperative angiography have shown that the overall need for clip adjustment ranges from 4 to 21%, unexpected residual aneurysms can be found in 4 to 19% of cases, and vessel occlusion in 0.3 to 12%.[1,2,8,14,15,17,18,21] In our study, clip adjustment was required in 11% of cases, which is consistent with the rate reported in postoperative angiography literature. On intraoperative angiography unexpected residual aneurysm was demonstrated in 8% of clipped aneurysms and expected residual lesions that were not explored were observed in 8.3% (28 aneurysms). Included among these patients were two in whom new unclipped MCA aneurysms were detected. Our 8% rate of unexpected residual lesions is consistent with the 10% reported by Alexander, et al.,[1] in their series of consecutive use of intraoperative angiography. The previously reported rates of 19% in a series by Derdeyn, et al.,[5] and 27% by Origitano, et al.,[19] may in fact include all residual lesions. It is possible that reliance on intraoperative angiography routinely results in less diligence on the part of the surgeon and therefore an abnormally elevated rate of unexpected findings. Nevertheless, the rates for both unexpected and total residual aneurysms and for vessel occlusions found in this study are within the range of those quoted in postoperative angiography series, making overreliance on technology an unlikely confounding factor.

Aneurysm size and location have been reported to influence substantially the adequacy of aneurysm clipping. In the study by Origitano, et al., the unusually high rate of residual lesions may also be more likely to be biased because of the high percentage of large and giant aneurysms present in their series. As originally demonstrated by Alexander, et al.,[1] and confirmed by our data, an aneurysm larger than 10 mm is four times as likely to be unsatisfactorily clipped when compared with those smaller than 10 mm in diameter. Less agreement has been found among reportedly problematic aneurysm locations. Regarding aneurysm location, in contrast with the superior hypophyseal, ICA bifurcation, and superior cerebellar locations cited by Derdeyn, et al.,[5] and the PCoA location found by Alexander, et al.,[1] we found a significant increase in unexpected intraoperative angiography findings in the ACoA location. This was one of the locations reported by Rauzzino, et al.,[21] to be more prone to inadequate clipping due to the depth and anatomical complexity of the area. Although the percentage rates for unexpected findings in the posterior circulation, ICA bifurcation, and OphA locations were also high in our study, it is likely that the number of aneurysms clipped in each group was too small to reach statistical significance.

The rate of regrowth and subsequent rupture of residual aneurysms cannot always be predicted.[13] Rebleeding has been shown to occur in 20 to 80% of identified residual aneurysms followed over 10 to 20 years in multiple series,[7–9,15] and mass effect from regrown aneurysms affects 10 to 30% of patients. In addition, it has been shown that residual lesions of even 1 to 2 mm can result in regrowth of the aneurysm, and the morbidity associated with reoperation and the morbidity and mortality following aneurysm rupture can be very high.[7,8,15] Therefore, the advantage we see in intraoperative angiography is the ability it provides to assess and optimize clip positioning, which minimizes postoperative complications and the need for repeated operation at a later date if the anatomy of the aneurysm allows complete obliteration with a clip.

TABLE 3

All complications encountered in 303 aneurysm operations

Complication	No. (%)	Management & Outcome
major (1.3%)		
stroke &/or death (MCA embolic occlusion)	1 (0.3)	conservative, died
FA thrombosis	2	embolectomy in both, resolved
groin hematoma requiring repair	1	op repair of FA, resolved
minor (1.3%)		
FA pseudoaneurysm	2	conservative in both, resolved
aortic dissection	1	conservative, resolved
broken guidewire (lost in soft tissues of groin)	1	conservative, stable
total	8 (2.6)	

The unsuspected occlusion of a major vessel due to clip placement can also lead to significant mortality rates, and to morbidity for which a second procedure is of no benefit. Although it is unclear whether reopening of unwittingly clipped perforating vessels is of any benefit, the removal of a clip on a large branch or parent vessel can be of major significance in terms of infarction territory and eventual neurological function. Up to 12% of surgical procedures for aneurysm clipping are complicated by major vessel occlusions.[1] More than 50% of these patients developed stroke-related disabilities or died.[8,15,17] In our study, the rate of unsuspected occlusions was 4.5%, with a 33% stroke rate among those in whom the clips were repositioned. A slightly higher rate of vessel occlusion was found in patients who presented with SAH, which may explain the discrepancy between our results and the 19% vessel occlusion rate in the study by Origitano, et al.[19] Aneurysm size, however, was not found to be associated with higher vessel occlusion rates.

The benefit of intraoperative angiography, however, only exists if its complication rate is low. The complications listed in the literature mostly include arterial dissection, occlusion, and related embolic events in the ICA, as well as in the FA distribution. The rate of complications in the performance of postoperative angiograms has been 1 to 2%. In the performance of intraoperative angiography only, however, the reported rates have been as high as 5% overall and 2.4% for neurological complications.[19] In a cost/benefit analysis of intraoperative angiography published by Kallmes, et al.,[12] one of the factors that significantly tipped the balance was the morbidity rate. With the routine use of intraoperative angiography our rate of complications was 2.6% overall, with a neurological complication rate of 0.35% and a rate of serious complications of only 1.3% (four of 303). Although the overall rate of 2.6% seems rather high in comparison with other studies, the rate of major complications is comparatively small. Minor complications, which would not usually be included, were reported in our study. The ability to perform intraoperative angiography on a routine basis with an experienced team can turn this procedure into a cost-effective, low-risk, and minimally time-consuming one. In this study we show that routine single-vessel selective angiography entails minimal risk, does not prolong hospitalization, and spared 37 patients from a second oper-

ation with its risks of hemorrhagic and ischemic complications.

Although we advocate the routine use of intraoperative angiography, it is important to emphasize that the surgeon still needs to perform careful post-clipping inspection of the aneurysm, its neck, and the adjacent parent vessels, as well as the usual precautionary aneurysm dome puncture decompression and microdoppler auscultation. This is especially important in view of the two fatal cases that were false negative on intraoperative angiography and the one case that was false positive on intraoperative angiography in this study. Derdeyn, et al.,[4] reported a similar false-negative intraoperative angiography rate of 7%, and Alexander, et al.,[1] also reported a 5% rate. Our findings indicate that even with the expert reading of a neuroradiologist, the capability of angiographic visualization intraoperatively remains limited. In view of this, meticulous surgical methods continue to be essential.

Conclusions

Intraoperative angiography is a safe and effective adjunctive tool for aneurysm clipping. With routine use, the complications associated with intraoperative angiography itself are far outweighed by the potential benefits of the ability it provides to detect unexpected residual aneurysms or vessel occlusions in a little more than one in every 10 cases. If routine intraoperative angiography is not available, the results of our study indicate that cases involving ACoA, large, or giant aneurysms should be evaluated using intraoperative angiography.

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Manuscript received July 25, 2001.
Accepted in final form January 15, 2002.

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