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BACKGROUND AND PURPOSE: **The role of intraoperative angiography in the treatment of neurovascular lesions has remained extremely controversial. We retrospectively reviewed the utility, safety, and accuracy of intraoperative angiography to ascertain its effect on the treatment of patients with neurovascular lesions.**

METHODS: **We reviewed the results of intraoperative angiography in 91 patients treated surgically for intracranial aneurysms and in 98 patients treated surgically for arteriovenous malformations (AVMs). All treatments were completed at two major teaching hospitals between October 1987 and March 1995.**

RESULTS: **The initial angiographic findings caused the surgical procedure to be modified in 24 (26%) of the patients with aneurysms and in 28 (29%) of the patients with AVMs. Analysis of the final angiographic sequence showed residual lesions in nine (10%) of the aneurysm cases and in eight (8%) of the AVM cases. The imperfect angiographic results were deemed acceptable because there was either evidence of collateral flow when the parent vessel was occluded or the risk of further surgical modification was considered more dangerous than the abnormality itself. Seven patients suffered complications, of which only one had permanent neurologic sequelae: a CNS complication rate of 0.5%. Comparison of the intraoperative angiographic findings with those of postoperative studies revealed four false-negative results (5.2%).**

CONCLUSION: **Intraoperative angiography is an important component in the treatment of patients with intracranial vascular lesions. It is effective and can be carried out with low risk in this patient population.**

The advancement of surgical technique and perioperative support has enabled neurovascular surgeons to operate on increasingly complex vascular lesions. The refinement of intraoperative angiography allows the surgeon to inspect the anatomic results of the surgical procedure and to localize obscure and complex lesions.

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The goal of neurovascular surgery is the complete obliteration of the vascular lesion, yet the surgeon may be unable to confirm these results with visual inspection alone. Postoperative angiography can be used to ensure that the desired surgical results have been obtained; however, the patient may require repeat surgery (and face its associated risks) if a residual lesion exists. Intraoperative angiography should allow us to reduce the need for postoperative angiography and repeat surgery in most circumstances. Moreover, intraoperative angiography should reduce the risk of operative morbidity by preventing complications, such as occlusion of normal vascular structures. By seeing the anatomy during the operation, the surgeon can ascertain normal vascular flow before closing the wound (1).

The goal of this project was to evaluate the safety and effectiveness of intraoperative angiography in the treatment of aneurysms and arteriovenous malformations (AVMs). To this end, we retrospectively reviewed 189 cases to evaluate the effect of intraoperative angiography on the surgical plan, the rate of complications, and the rate of residual lesions despite a normal intraoperative angiogram.

Methods

Patient Selection

A list of all intraoperative angiographic procedures performed at two major hospitals from October 1987 to March 1995 was reviewed. During this period, were more than 1000 operations were performed to treat intracranial aneurysms and AVMs at the two hospitals. All patients who underwent surgical treatment for an aneurysm or AVM with the use of intraoperative angiography were included unless the angiogram was performed for reasons other than diagnostic evaluation (ie, temporary balloon occlusion without diagnostic films). Nine patients were excluded because the intraoperative angiographic reports were incomplete.

The decision as to whether to use intraoperative angiography was at the discretion of the neurosurgeon. Such factors as size and grade of the lesion, complexity of the regional anatomy, and proximity of the lesion to eloquent areas of the brain were considered reasons to use intraoperative angiography. Moreover, some of the neurosurgeons at our institutions routinely use intraoperative angiography for all intracranial neurovascular procedures.

Technical Factors

All intraoperative studies were performed with the use of a digital mobile C-arm unit (OEC Medical Systems, Warsaw, IN) in the operating room. In the majority of patients, the angiographic evaluation was performed through cannulation of the femoral artery; however, a few patients were studied through a carotid artery approach. Carotid artery cannulation was performed under direct visual observation by the surgical team. Depending on the patient's position during the surgical procedure, femoral artery cannulation was performed either immediately before intraoperative angiography or through an indwelling arterial sheath placed preoperatively after the induction of anesthesia. In cases requiring preoperative cannulation, the sheath was left in the femoral artery with a constant heparinized saline infusion (1000 U heparin and 500 mL normal saline at 10 to 15 drips per minute) to maintain patency of the lumen. Studies were performed by a staff neuroradiologist or neuroradiology fellow, and the results were reviewed immediately with the staff neurosurgeon.

Results

Patient Population

The intraoperative angiographic reports were reviewed for 184 patients. Angiography was unsuccessful in three patients: one patient was too unstable to complete the procedure, and in two patients the neuroradiologist was unable to introduce the catheter.

Intraoperative angiography was successfully performed in 181 patients who had a total of 189 procedures (for 91 aneurysms and 98 AVMs). During the entire study period, intraoperative angiography was performed in 91 (15%) of 607 patients with aneurysms and in 98 (21%) of 467 patients with AVMs. During 1994, intraoperative angiography was used in 34% of patients with aneurysms and in 25% of patients with AVMs. The increased use of intraoperative angiography for aneurysms in 1994 over previous years may relate to referral bias, as our neurosurgeons treat difficult lesions of the skull base and posterior circulation. In addition, the rise in use reflects the increasing experience our neurosurgeons and neuroradiologists have acquired in performing this procedure and in integrating it into both complex and routine neurovascular operations.

TABLE 1: Results of intraoperative angiography

	No. (%)
Aneurysms	91
Modification	24 (26)
Complete obliteration	75 (82)
Residual lesion	9 (10)
Arteriovenous malformations	98
Modification	28 (29)
Complete obliteration	82 (84)
Residual lesion	8 (8)

TABLE 2: Reason for residual lesion

	No.
Aneurysms	9
Vessel occlussion with collateral flow	2
Vessel occlussion requiring ECIC bypass	2
Residual neck secondary to technical factors	
Basilar tip aneurysm	2
Giant aneurysm	3
Arteriovenous malformations	8
Staged procedures	2
Residual within brain stem or other vital structure	5
Distant feeder, embolized postoperatively	1

Note.—ECIC indicates external carotid to internal carotid.

Intraoperative Angiography for Aneurysms

Intraoperative angiography was used in 88 patients undergoing 91 operations for the treatment of intracranial aneurysms. Three patients had a second procedure in which intraoperative angiography was also used: one patient underwent surgery for the same lesion, one for treatment of a second lesion, and the third for treatment of delayed occlusion of the internal carotid artery, necessitating external carotid to internal carotid (ECIC) bypass.

Evaluation of the initial angiographic results showed that the lesion was eliminated in 64 (70%) of the cases. On the basis of the intraoperative angiographic findings, the surgical procedure was modified by clip repositioning or placement of additional clips in 24 cases (26%) (Table 1).

A second intraoperative angiographic procedure was conducted in 19 cases (21%), and the surgical procedure was once again modified in eight cases (42%). Three or more intraoperative angiograms were obtained in six cases (7%).

Evaluation of the final intraoperative angiographic sequence verified complete obliteration of the aneurysm with normal flow in the surrounding vessels in 75 cases (82%), whereas a persistent abnormality was documented in nine cases (19%)

(Table 2). Intraoperative angiography in four of these patients revealed occlusion of a normal surrounding vessel. Good collateral flow was documented in two of these patients, and, in the other two, emergency ECIC bypass was performed. The remaining five patients had evidence of a residual aneurysmal neck. Three of these five had undergone treatment of giant aneurysms (one anterior communicating, one ophthalmic, one basilar), whereas the other two had basilar artery aneurysms.

Intraoperative Angiography for AVMs

Intraoperative angiography was used in 93 patients undergoing 98 procedures for the treatment of an intracranial AVM. Five patients had a second operation for treatment of the same lesion. Of these five, two were electively staged consequent to the intraoperative angiographic results, two had false-negative intraoperative angiographic findings, and the third had a negative intraoperative angiogram but suffered postoperative breakthrough bleeding, which, at the time of reoperation, was found to result from a small unclipped artery within the surgical bed.

Evaluation of the initial angiographic results showed that the lesion was eliminated in 66 cases (67%). On the basis of intraoperative angiographic findings, the surgical procedure was modified with further surgical exploration and resection in 28 cases (29%) (Table 1).

A second intraoperative angiogram was obtained in 24 cases (25%), and the surgical procedure was once again modified with further surgical exploration and resection in 11 (46%) of these. Three or more intraoperative angiograms were obtained in 10 cases (10%).

Evaluation of the final intraoperative angiographic sequence verified complete obliteration of the AVM without any evidence of residual nidus within the cerebral cortex or brain stem in 82 cases (84%). A persistent abnormality, including residual nidus, arteriovenous shunting, or early draining vein, was documented in eight cases (8%) (Table 2). Two of these patients underwent staged procedures motivated by the intraoperative angiographic results. Five patients had residual lesions within eloquent areas of the cortex or brain stem, and the final patient had a residual feeding vessel that was distant to the surgical site (treated endovascularly at a later date).

Complications

In 181 patients undergoing 189 studies, seven patients had known complications: an overall complication rate of 4% (Table 3). Four of these seven had femoral artery thrombosis related to catheter insertion; surgical intervention was required in three, and all four recovered without long-term sequelae. On the basis of the results of these four cases, the intraoperative angiographic technique was refined and modified in 1992 to increase the sheath flush rate; subsequently, there have been no known cases of thrombosis in the femoral artery.

TABLE 3: Complications of intraoperative angiography

	No. (%)
Overall	7 (3.7)
Systemic	
Femoral artery thrombosis	4 (2.0)
CNS	
Vertebral artery dissection	2 (1.0)
Basilar artery thrombosis	1 (0.5)

Two patients had asymptomatic vertebral artery dissection as a result of intravascular catheterization. The final complication involved thromboembolism of the basilar artery tip, which resulted in a left-sided cerebellar infarction; this was the only patient who suffered any long-term neurologic dysfunction as a direct consequence of intraoperative angiography. Therefore, the CNS complication rate was calculated to be 0.5%.

Comparison with Postoperative Angiography

Of the 189 intraoperative angiographic procedures, 76 (40%) were followed up with conventional angiography within 6 months of surgery. These studies revealed four cases (three AVMs, one aneurysm) in which abnormal findings that were not detected at intraoperative angiography were discovered postoperatively, resulting in a false-negative rate of 5.2%. Failure to identify the residual lesion was attributed to misinterpretation of the images in one patient with an AVM and to difficulty in obtaining adequate views in another patient with an aneurysm. In the two remaining cases (both AVMs), intraoperative angiography did not show a nidus, arteriovenous shunting, or early draining veins (either at the time of completion of the study or after retrospective review of the films), which were later evident on follow-up angiograms. Throughout our experience, however, no patient has returned with a delayed hemorrhage or other symptoms due to a retained AVM or aneurysmal rest after a negative intraoperative angiogram.

Discussion

To date we have performed intraoperative angiography in more than 200 patients at the University of Cincinnati and Good Samaritan hospitals. In reviewing the effectiveness of this procedure for patients undergoing surgery for an aneurysm or AVM, we noted that the intraoperative angiographic findings resulted in modification of the surgical procedure 27% of the time. The modification occurred because of either a residual lesion or obliteration of the normal vasculature. This percentage

TABLE 4: Comparison with previous studies

Author	Complication Rate (%)	Percent Modified (%)	False-Negative Rate (%)
Vitaz et al (present study)	3.7	27.5	5.2
Barrow et al (2)	1.7	12.9	2.0
Bauer (3)	. . .	8.3	. . .
Derdeyn et al (4)	1.8	11.9	1.8
Martin et al (5)	1.9	9.5	2.9

is slightly higher than those found by earlier investigators, who reported rates ranging from 10% to 17% (2–5) (Table 4). The difference may relate to the number of patients studied, the complexity of the lesions, or the stage in the operation when intraoperative angiography was incorporated.

Intraoperative angiography was also found to be useful in the reassessment of residual lesions after the surgical approach had been modified. Our study revealed 43 cases in which repeat imaging was conducted. The results of these repeat studies confirmed complete eradication of the lesion in 19 (44%) and persistent lesion requiring additional surgical manipulation in 24 (56%) of the cases. Therefore, it is necessary to repeat the imaging technique at various stages during the operation to identify the anatomic changes as the operation progresses and to ensure total eradication of the lesion.

Analysis of the combined data showed that intraoperative angiography verified complete eradication in 158 procedures (84%). In a second group of 15 patients (8%) the lesion was thought to be completely treated on the basis of previous intraoperative angiograms and surgical inspection; however, repeat intraoperative angiograms were not obtained after minor surgical manipulations. This lack of consistency was due to the absence of a standard protocol for the use of intraoperative angiography in the treatment of neurovascular lesions. Therefore, a final confirmatory intraoperative angiographic sequence to verify complete eradication of the lesion was not always performed. It is our opinion, however, that this should be done for all cases in which intraoperative angiography is used.

A third group contained 17 patients (9%) in whom the surgical procedure was terminated despite abnormal intraoperative angiographic findings. Nine of these patients were operated on for intracranial aneurysms. The surgical procedure was terminated by the staff neurosurgeon in five cases (three giant, three basilar tip aneurysms) because it was his belief that the best possible results had been obtained and that further manipulation would cause parent vessel injury, extensive parenchymal damage, or occlusion of surrounding vessels. In the other four cases, there was either intraoperative angiographic evidence of collateral filling of normal vessels that had been occluded during the operation (two patients) or a persistent occlusion required emergency ECIC bypass (two patients).

The remaining eight patients with persistent abnormalities underwent treatment for AVMs. Two of these patients had elective staging of the surgical resection after intraoperative angiography failed to show complete eradication of the lesion. Five patients had intraoperative angiographic evidence of a residual lesion in or near vital neural structures, and it was determined by the staff neurosurgeon that the risks associated with potential neurologic compromise from additional resection and exploration far outweighed the benefits of complete resection. In the final patient, intraoperative angiography showed a single persistent feeding vessel distant to the surgical bed. In this case, it was thought that postoperative intra-arterial embolization could be used to obliterate the vessel with less risk than extending the surgical resection.

We also examined the safety and accuracy of intraoperative angiography in our practice by calculating the rates of complications and of false-negative findings. The overall complication rate of 3.7% was comparable to that reported by previous authors (Table 4) (2, 5, 6). In addition, the CNS complication rate of 0.5% confirms the relative safety of the procedure. By comparing the results of postoperative angiography with those from intraoperative angiographic studies, we determined our false-negative rate to be 5.2%: an overall sensitivity of 94%. Of these four cases, two (one aneurysm and one AVM) were determined to be secondary to technical or interpretational error. Therefore, it can be assumed that if intraoperative angiography is conducted under ideal technical conditions and interpreted by an experienced staff neuroradiologist and neurosurgeon, the sensitivity could be expected to be greater than 97%. Thus, it is possible to use intraoperative angiography in place of conventional postoperative angiography in selected aneurysmal cases in which adequate technical factors are established. Nonetheless, the use of intraoperative angiography in place of conventional postoperative angiography for AVMs remains to be determined because, even with ideal intraoperative factors, there is still a small risk of obtaining false-negative results (two patients in our study).

We believe that intraoperative angiography is a safe, effective, and reliable method that allows the surgeon to assess the adequacy of results before the wound is closed. The procedure enables the surgeon to further resect a residual lesion or modify aneurysmal clip placement without requiring the patient to undergo a second operation, thus decreasing the risks associated with incompletely treated lesions (6–12). As well, intraoperative angiography can be helpful in the strategic planning of possible further resection versus staging the procedure after failure to obtain the desired results with the initial surgical approach. Intraoperative angiography can also be used to develop a roadmap to localize ob-

scure or distant residuals in AVM cases. Finally, intraoperative angiography can be used in the treatment of complex aneurysms in which complete obliteration of the lesion may not be possible. In this scenario, it gives the surgeon a picture of the residual lesion and allows an informed decision to be made about the acceptability of such aneurysmal rests. In this study, the use of intraoperative angiography may not have decreased the frequency of residual aneurysmal rests owing to the complexity of the lesions being treated; however, it was of benefit in illustrating the occlusion of normal vascular structures and thereby in decreasing the surgical morbidity associated with such complications by allowing clip repositioning or emergency ECIC bypass (two patients).

Conclusion

Our study shows that intraoperative angiography can provide a significant benefit by ensuring that the desired anatomic results have been obtained before the surgical procedure has been completed. In addition, this imaging technique may be used to help localize deep-seated lesions and to stage the removal of more complex AVMs, minimizing injury to normal brain tissue. Intraoperative angiography has also been used in place of preoperative angiography in emergency situations (13). We therefore recommend its use for all neurovascular procedures regardless of location or complexity. Intraoperative angiography should be repeated if necessary throughout the surgical procedure until complete obliteration of the lesion is documented. We agree with the authors of numerous previous studies in which it was shown that the only affordable benefit to the patient is from complete eradication of the lesion. Intraoperative angiography can be used to verify such results before the completion of the operation, which may obviate a second operation or reduce the morbidity associated with occlusion of normal surrounding vasculature. Furthermore, in patients with an aneurysm in whom adequate technical results have been achieved, intraoperative angiography can be used in place of conventional postoperative angiography. Such use for AVMs, however, needs further investigation.

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