Intraoperative digital subtraction angiography and the surgical treatment of intracranial aneurysms and vascular malformations

NEIL A. MARTIN, M.D., JOHN BENTSON, M.D., FERNANDO VIÑUELA, M.D., GRANT HIESHIMA, M.D., MURRAY REICHER, M.D., KEITH BLACK, M.D., JACQUES DION, M.D., AND DONALD BECKER, M.D.

Divisions of Neurosurgery and Neuroradiology, University of California School of Medicine, Los Angeles, California

Intraoperative digital subtraction angiography using commercially available equipment was employed to confirm the precision of the surgical result in 105 procedures for intracranial aneurysms or arteriovenous malformations (AVM's). Transfemoral selective arterial catheterization was performed in most of these cases. A radiolucent operating table was used in all cases, and a radiolucent head-holder in most. In five of the 57 aneurysm procedures, clip repositioning was required after intraoperative angiography demonstrated an inadequate result. In five of the 48 AVM procedures, intraoperative angiography demonstrated residual AVM nidus which was then located and resected. In two cases intraoperative angiography failed to identify residual filling of an aneurysm which was seen later on postoperative angiography, and in one case the intraoperative study failed to demonstrate a tiny residual fragment of AVM which was seen on conventional postoperative angiography. Two complications resulted from intraoperative angiography: one patient developed aphasia from cerebral embolization and one patient developed leg ischemia from femoral artery thrombosis. This technique appears to be of particular value in the treatment of complex intracranial aneurysms and vascular malformations.

KEY WORDS • intraoperative angiography • digital subtraction angiography • aneurysm • arteriovenous malformation

CEREBROVASCULAR surgical procedures have as their goal a specific anatomical result. In the case of aneurysm surgery, that goal is complete circulatory exclusion of the aneurysm without compromise of normal vessels. In the case of vascular malformations, complete excision of the lesion is the desired result. Failure to achieve the optimal anatomical endpoint may result in perioperative or delayed ischemic or hemorrhagic complications. Because of this, it has generally been standard practice to perform postoperative angiography within 1 week after surgery in order to confirm the efficacy of the cerebrovascular procedure. In a small number of cases an incomplete surgical result is identified requiring reoperation, as in the case of residual arteriovenous malformation (AVM). In other cases an improper technical result is seen, such as inadvertent clipping of a normal arterial branch, which might have caused a perioperative complication not remediable by reoperation. It is more logical and desirable to confirm the effectiveness of the surgical endpoint immediately, in the operating room, so that incomplete or imperfect results can be corrected. In a certain number of cases this will avoid perioperative complications or the need for reoperation. Intraoperative angiography has been performed by a number of investigators, but previously available techniques have been limited by poor resolution, lengthy film development times, and obscuration of vascular detail by overlying bone and radiopaque surgical implements.

Foley, et al., have reported the use of a portable digital subtraction unit that provides dynamic subtraction angiograms of high quality. The neuroradiological aspects of this technique have been discussed in a previous report. The present paper focuses on the application of these techniques and their results in neurovascular surgery.

Several questions are of particular importance. What technical factors are critical for the smooth performance
of high-quality angiography? What resolution can be expected from intraoperative studies? What are the causes and incidence of false-positive and false-negative intraoperative studies? How much time is required for the performance of intraoperative angiography? What complications are encountered using these techniques? This report draws from experience with 105 intraoperative angiographic studies in patients treated surgically for intracranial aneurysms or AVM's.

Clinical Material and Methods

From March, 1985, to July, 1989, intraoperative digital subtraction angiography was performed after 105 procedures in 101 patients at the UCLA Medical Center. Angiography was performed to evaluate the result of standard neurovascular surgical procedures (Table 1). Not all patients undergoing neurovascular procedures underwent intraoperative digital angiography. Intraoperative angiography was generally reserved for patients with more complex cerebrovascular lesions including: 1) virtually all AVM's; 2) large and giant aneurysms; and 3) anterior communicating artery, middle cerebral artery, vertebobasilar, and multiple aneurysms.

Patient Preparation and Placement

The patient's chest and neck must be free of overlying radiopaque equipment. The scrub nurse's instrument table must not obscure the patient's chest. We prefer to drape the patient without a fixed overhead table, and then position two draped Mayo stands over the patient for the instruments. These can easily be withdrawn at the time of angiography to provide unimpaired access to the groin for catheterization and to the chest for fluoroscopy. The use of a radiolucent operating room table is essential so that the aortic arch can be imaged fluoroscopically to allow selective catheterization of the carotid or vertebral arteries. We use a Skytron radiolucent table.*

It is important that the vascular lesion not be obscured by the standard radiopaque head-holder. During our early experience we used the Mayfield-Kees adjustable head-holder† and positioned it carefully to avoid superimposing it over the area of interest in either the lateral or anteroposterior projection. During the last year we have used a carbon-composite head-holder,‡ which has simplified head fixation. Only the skull fixation points are radiopaque. The head arc and the table attachment unit are radiolucent and do not obscure the intracranial or the neck vessels.

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* Radiolucent table manufactured by Skytron, Grand Rapids, Michigan.
† Mayfield-Kees adjustable head-holder manufactured byCodman and Shurtleff, Randolph, Massachusetts.
‡ Carbon-composite head-holder manufactured by Malcolm Rand Cranio-X-Ray Frame, Storz, St. Louis, Missouri.
§ DXR-Angiolus portable unit manufactured by OEC-Diagnostics, Salt Lake City, Utah.
frame by frame. A photography unit enables the production of permanent hard copies for the x-ray file jacket.

Results

Technical Factors

All attempts at femoral artery catheterization in the operating room were successful. Selective transfemoral catheterization of the carotid or vertebral artery was successful in all cases except one involving a left vertebral artery. In this case a subclavian injection was performed and opacification of the vertebrobasilar circulation was poor. Planned angiography was not carried out in one case because the patient had inadvertently been positioned on a radiopaque table, and the aortic arch could not be visualized. Variations in patient positioning often required that the angiographer perform selective aortic arch branch catheterizations while working from unconventional oblique fluoroscopic views of the arch. In spite of this, we have had success in catheterizing the carotid or vertebral artery in several patients in the park-bench position and one patient in the prone position. In these cases placement of a femoral artery sheath at the beginning of the operation, before positioning, was essential. In patients with direct puncture of a surgically exposed vessel, selective angiography through the route was successful. None of the punctured vessels became thrombosed.

Resolution of Angiogram

The contrast resolution of the device was excellent. All angiograms were performed by hand injection of a small amount of contrast material. The spatial resolution was good. Normal lenticulostriate vessels are at or just below the resolution of the unit, while larger vessels were readily seen (Fig. 1).

Time Requirement

The performance of intraoperative digital angiography for the confirmation of surgical results added 25 to 120 minutes to the procedure. The average time required was 45 to 60 minutes.

Alterations in Surgical Treatment Prompted by Intraoperative Angiography

Fifty-seven aneurysms were studied in 51 patients (several had multiple aneurysms, and two had more than one procedure for aneurysm recurrence). In five of these cases aneurysm clip repositioning was required after intraoperative angiography had demonstrated an inadequate result.

Fig. 1. Angiograms, lateral view, of the left internal carotid artery. Left: Preoperative conventional angiogram showing a large carotid-ophthalmic artery aneurysm. Right: Intraoperative digital subtraction angiogram. Aneurysm clips on the aneurysm are indicated by the arrow. Aneurysm occlusion and patency of the internal carotid artery are apparent. This image shows typical resolution for intraoperative digital angiography.

Fig. 2. Angiograms, lateral view, of the internal carotid artery. Left: Preoperative digital subtraction angiogram. Arrow indicates an intracavernous aneurysm extending medially into the sphenoid sinus, causing severe epistaxis. Center: Intraoperative digital subtraction angiogram, late phase, after initial aneurysm clip placement. The internal carotid artery is severely stenotic (arrow), causing relative stasis in the carotid siphon. Right: Intraoperative digital subtraction angiogram, second injection. After clip repositioning, the luminal diameter of the carotid artery is restored (arrow), and the aneurysm remains occluded. Dynamic viewing of the dye injection demonstrated rapid flow through the previously stenosed area.
Intraoperative digital angiography in vascular lesions

TABLE 2
Correlation of intraoperative with postoperative angiography*

<table>
<thead>
<tr>
<th>Etiology</th>
<th>Cases With False-Negative Intraop Angiogram</th>
<th>No.</th>
<th>Postop Finding</th>
</tr>
</thead>
<tbody>
<tr>
<td>aneurysm</td>
<td>22</td>
<td>2</td>
<td>residual neck</td>
</tr>
<tr>
<td>AVM</td>
<td>40</td>
<td>1</td>
<td>residual AVM</td>
</tr>
</tbody>
</table>

* AVM = arteriovenous malformation.

The first case was a patient with a large medial frontoparietal AVM accompanied by what, on preoperative angiography, appeared to be three closely clustered aneurysms of the ipsilateral suprachoidal internal carotid artery. At surgery three aneurysms, arising from the posterior communicating artery, the anterior cho-roidal artery, and the internal carotid artery bifurcation, were identified and clipped. However, intraoperative angiography demonstrated residual filling of one aneurysm. Further surgical exploration revealed a fourth aneurysm arising from the A1 segment of the anterior cerebral artery just beyond the carotid artery bifurcation. This aneurysm was also clipped, and repeat angiography showed no residual aneurysm. The AVM was resected at a second operation.

The second patient had an intracavernous internal carotid artery aneurysm that had eroded into the spheno-sinoid sinus causing massive epistaxis. After removing the anterior clinoid process and opening the anterior cavernous sinus, the medially projecting aneurysm was clipped. Intraoperative angiography demonstrated significant stenosis of the carotid artery. Replacement of the clip was successful in occluding the aneurysm without narrowing the carotid artery (Fig. 2).

The third case was that of a patient with a giant posterior inferior cerebellar artery aneurysm. Angiography after placement of a single aneurysm clip demonstrated incomplete closure of the aneurysm neck. A second clip was placed in tandem with the first, effectively closing the aneurysm.

The fourth patient had a subarachnoid hemorrhage from an aneurysm of the anterior inferior cerebellar artery, which supplied a brain-stem AVM. The aneurysm was approached through a retrolabyrinthine presigmoid exposure. The aneurysm ruptured during dissection, and the bleeding was controlled with three aneurysm clips. Intraoperative angiography demonstrated occlusion of the basilar artery as well as the aneurysm. Clip adjustment restored patency of the basilar artery and obliterated the aneurysm (Fig. 3).

The fifth patient had a basilar bifurcation aneurysm. After initial clip placement, angiography demonstrated occlusion of the contralateral posterior cerebral artery. Patency of this vessel was restored by clip adjustment. None of the five aneurysm patients had a hemorrhage or new ischemic deficit after surgery.

Forty-eight cerebral AVM's were studied in 48 patients. In five cases, a residual AVM nidus and arteriovenous shunting were seen on the intraoperative angiogram. In all five cases further exploration revealed the residual AVM, which was then resected. Repeat intraoperative angiography confirmed the completeness of resection in each case (Fig. 4). None of these patients had postoperative hemorrhage.

False-Negative and False-Positive Intraoperative Angiographic Results

Postoperative conventional angiography was performed in 62 cases and evidence of false-negative intraoperative studies was seen in three cases (Table 2). In two cases postoperative angiography revealed residual filling of a portion of an aneurysm that had appeared.
FIG. 4. Left: Preoperative conventional angiography, Towne view, vertebral artery injection. A large arteriovenous malformation (AVM) of the cerebellar hemisphere is seen. Center: Intraoperative digital subtraction angiography, anteroposterior view, vertebral artery injection. Residual AVM can be seen, fed by the superior cerebellar artery (arrows). Right: Intraoperative digital subtraction angiogram, anteroposterior view, vertebral artery injection (second injection). This final intraoperative angiogram demonstrates complete excision of the residual AVM fragment.

to be completely occluded on the intraoperative angiogram. In one of these cases the position of the aneurysm clip appeared to have changed. This suggests that persistent filling of the aneurysm was due to postoperative slipping of the clip rather than a failure of the intraoperative angiogram to demonstrate residual aneurysm. This aneurysm was occluded at a subsequent operation. In the second case residual filling of a portion of the neck of a basilar apex aneurysm was seen on the postoperative angiogram. Review of the intraoperative angiogram showed that the area of the aneurysm neck had been obscured by the superimposed curving P1 segments of the posterior cerebral arteries. Because of the relatively small size of the residual aneurysm sac in this case, it was elected to follow the patient expectantly. One year later, however, the patient had a second subarachnoid hemorrhage from the residual sac which had expanded. The recurrent aneurysm was clipped, and the patient recovered.

Postoperative conventional angiography was performed in patients with all but the smallest, most superficial AVM's. A residual AVM nidus that had been missed by the intraoperative digital angiogram was identified postoperatively in only one case (Table 2). In this case a tiny residual fragment of a thalamic AVM, fed by a thalamoperforating branch of the basilar artery, was identified (Fig. 5). The residual AVM was obliterated at a second operation.

False-positive intraoperative angiograms were obtained in three AVM cases. In each of these cases, a blush was seen that was considered suspicious for residual AVM; however, when the area of resection was again exposed and inspected with the microscope, no residual malformation was found. In these cases, conventional postoperative angiography confirmed complete resection. Presumably, the blush seen intraopera-

tively was caused by hyperperfusion in adjacent normal vessels.

**Complications**

The complications encountered in this series of patients are summarized in Table 3. One patient, a 62-year-old man, suffered a symptomatic cerebral embolus during intraoperative angiography. Apparently embolization occurred during transfemoral catheterization of the left common carotid artery performed for the evaluation of the result of excision of a left parietal AVM. The patient awoke from surgery with an expressive aphasia, and was found on postoperative angiography

<table>
<thead>
<tr>
<th>Complication*</th>
<th>No. of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>related to intraop angiogram</td>
<td></td>
</tr>
<tr>
<td>cerebral embolus</td>
<td>1</td>
</tr>
<tr>
<td>foot embolus</td>
<td>1</td>
</tr>
<tr>
<td>femoral artery occlusion</td>
<td>1</td>
</tr>
<tr>
<td>postoperative hemorrhage</td>
<td></td>
</tr>
<tr>
<td>aneurysm</td>
<td></td>
</tr>
<tr>
<td>epidural</td>
<td>1</td>
</tr>
<tr>
<td>SAH (aneurysm regrowth from residual neck)</td>
<td>1</td>
</tr>
<tr>
<td>intracerebral (late, cause unknown)</td>
<td>1 (fatal)</td>
</tr>
<tr>
<td>AVM</td>
<td></td>
</tr>
<tr>
<td>intracerebellar (residual AVM)</td>
<td>1</td>
</tr>
<tr>
<td>intraventricular (postoperative hypertension)</td>
<td>1 (fatal)</td>
</tr>
<tr>
<td>cerebral infarction from unrecognized arterial occlusion</td>
<td>0</td>
</tr>
<tr>
<td>craniotomy infection</td>
<td>1</td>
</tr>
<tr>
<td>other deaths (pulmonary embolus, myocardial infarction)</td>
<td>2</td>
</tr>
</tbody>
</table>

*SAH = subarachnoid hemorrhage; AVM = arteriovenous malformation.
Intraoperative digital angiography in vascular lesions

Fig. 5. Angiograms, lateral view, vertebral artery injection. Left: Preoperative digital subtraction angiography demonstrating a thalamic arteriovenous malformation (AVM) supplied by a thalamoperforating artery and by the medial posterior choroidal artery. Center: Intraoperative digital subtraction angiogram after clipping of the medial posterior choroidal artery and resection of the AVM by the posterior transcallosal approach. No residual AVM or early venous drainage is seen. Right: Postoperative conventional angiogram showing an early draining vein (arrows) coming from a tiny fragment of residual AVM fed by the thalamoperforating arteries. The residual AVM was obliterated at a second operation.

to have occlusion of a frontal branch of the left middle cerebral artery. At his 3-month follow-up examination he has a persistent mild aphasia.

One patient developed a femoral artery thrombus during treatment of an aneurysm associated with an AVM. In this case the femoral artery sheath was used for pressure monitoring and was inadequately flushed with heparinized saline. The thrombus lysed spontaneously without causing permanent ischemic damage to the leg or foot. This patient later developed femoral artery occlusion at the site of sheath insertion after a second procedure for AVM excision. At that time the femoral artery appeared to have been damaged during sheath insertion by an inexperienced operator. Severe leg ischemia developed which may have required amputation had the patient not died from a massive postoperative intraventricular hemorrhage. This patient had had three thalamic hemorrhages from a large (Spetzler and Martin Grade V) AVM in the parieto-occipital region that extended to the dorsal thalamus. After excision of the AVM, intraoperative angiography demonstrated no residual malformation. At the end of the procedure the systolic blood pressure rose precipitously to 200 mm Hg when mild hypotension was overcorrected. In the recovery room the patient developed fixed, dilated pupils and an emergency CT scan showed a massive intraventricular hemorrhage which, despite evacuation of the hemorrhage, proved fatal.

Two patients had postoperative intracerebral hemorrhage. One was a cerebellar hemorrhage from a residual AVM. In this case the intraoperative angiogram had suggested the presence of residual AVM. Immediate re-exploration of the area of AVM resection was deferred because the procedure had been characterized by significant difficulty in obtaining hemostasis. The patient was urgently returned to the operating room on postoperative Day 4 because of neurological deterioration due to hemorrhage at the operative site. The hematoma and the residual AVM were removed and the patient recovered, albeit with appendicular ataxia. The other patient died 4 months after clipping of an anterior communicating artery aneurysm. The cause of death was an intracerebral hemorrhage apparently originating from the region of the anterior communicating artery. In this case both the intraoperative digital angiogram and a postoperative conventional angiogram failed to show evidence of residual aneurysm. The precise cause of the late hemorrhage was not identified.

No patient developed postoperative cerebral infarction from inadvertently clipped vessels. One patient developed a craniotomy infection after a prolonged operation for removal of an AVM and required removal of the bone flap. There were no other instances of wound infections, meningitis, or septicemia.

Discussion

The efficacy of surgical treatment of intracranial aneurysms and AVM's is dependent on complete obliteration of the lesion, without compromise of normal cerebral vessels. Forster and his colleagues1 and Drake3 have reported follow-up results in patients with incomplete surgical resection of cerebral AVM's. These patients were not protected from subsequent intracranial hemorrhage; in fact, the natural propensity of these lesions to bleed did not seem to be at all reduced by subtotal removal. These facts have resulted in the recommendation that postoperative angiography be performed to confirm the completeness of surgical excision, and that reoperation is indicated when residual AVM is identified.

Drake and Vanderlinden4 also made a strong case for routine postoperative angiography after surgical treatment for aneurysms. In their studies of the long-term
results of aneurysm surgery, they confirmed that there were no episodes of recurrent hemorrhage from aneurysms shown by postoperative angiography to be completely obliterated. Of the 12 patients with only a small portion of the aneurysm remaining, two died from rebleeding shortly after hospital discharge and one died 11 years later from dilatation and rupture of the residual aneurysm neck. Of the 13 patients with a large portion of the aneurysm remaining, three died from early rebleeding and three died from late rebleeding. In a more recent report, Peeters and Walder described their techniques of intraoperative angiography in neurosurgery, primarily confirm the result of cerebrovascular procedures. Lueschop and Spence, advocated the use of intraoperative angiography to correct the defect. In three of 11 AVM cases angiography disclosed residual feeding vessels that were subsequently corrected. No angiographic complications were noted.

Foley, et al., reported the use of a commercially available unit for intraoperative digital subtraction angiography, and we have continued to use this unit. This device allows the performance of real-time serial subtraction angiography. There is no delay while films are being developed or manually subtracted. The image is recorded and can be reviewed immediately in forward and reverse directions at several speeds. This is quite useful in detecting small residual shunts and early draining veins. The high-contrast resolution of the device allows hand injection of small amounts of contrast material; no automatic injector is required. The spatial resolution is quite good, although not quite as good as with conventional film angiography. The limited resolution of the intraoperative study led to our missing a tiny residual fragment of a thalamic AVM, which was later seen on a conventional postoperative angiogram. In the vast majority of cases, however, postoperative conventional angiography confirmed the results of intraoperative digital angiography.

Our goal has been to duplicate, as much as possible, the procedures of the angiography suite in the operating room. Selective transfemoral catheterization of carotid and vertebral arteries permits careful, nonoverlapping imaging of each vascular territory. This can be very important in evaluating AVM's with multiple sources of arterial supply. Femoral puncture has almost become the rule in our practice because it avoids the necessity of exposure and puncture of cervical or intracranial arteries. Transfemoral catheterization of the cervical vessels at the time of angiography obviates prolonged catheterization of arteries supplying the brain, thus minimizing the risk of embolization. Although in several cases we have left a sheath in the femoral artery for prolonged periods, there have been only two local complications, both in the same patient.

Our experience indicates that intraoperative angiographic system incorporating video camera, monitor, and cassette recorder that enabled immediate playback of a high-resolution image obtained from a standard C-arm fluoroscope. He employed this system for intraoperative angiography in 48 cases. In seven of 33 aneurysm cases the intraoperative study demonstrated residual aneurysm or branch occlusion, and the clip was repositioned to correct the defect. In three of 11 AVM cases angiography disclosed residual feeding vessels that were subsequently corrected. No angiographic complications were noted.

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Our experience indicates that intraoperative angiography
Intraoperative digital angiography in vascular lesions

graphy has fulfilled our goals. Technical errors in the clipping of five aneurysms (among a total of 57 in this series) were detected and corrected, avoiding postoperative complications or the need for a second operation for clip repositioning. Residual AVM was detected and located in five of the 48 cases studied, and complete excision was accomplished when further dissection was directed to the appropriate area. It seems that in these 10 cases the use of intraoperative angiography resulted in a superior surgical result. The patients avoided reoperation to correct the technical deficiency and possibly avoided serious postoperative complications. The cost in time, effort, and complications of intraoperative angiography appear to be less than the cost, in financial and human terms, of reoperations and devastating postoperative complications.

Intraoperative digital subtraction angiography does not necessarily supplant postoperative angiography. In cases in which the resolution obtained by the intraoperative study is suboptimal, or in cases in which the microsurgical result is in question, postoperative angiography should also be obtained. Because of the optimal conditions and instrumentation in the angiography suite, the resolution of routine postoperative angiography still exceeds that of intraoperative examinations. However, improvements in the image quality obtainable with portable equipment are occurring rapidly and will soon obviate the need for a second confirmatory postoperative angiography in almost all cases.

Intraoperative angiography may not be necessary in all cerebrovascular procedures. Angiography may be superfluous after clipping small internal carotid artery aneurysms when the artery and adjacent branch vessels can be seen clearly and aspiration of the aneurysm causes the sac to collapse.

Based on the available experience, intraoperative digital angiography is recommended for surgical procedures for excision of intracranial AVM's, for treatment of large or giant intracranial aneurysms, and for treatment of aneurysms in locations where not all adjacent arterial branches may be optimally visualized (such as at the basilar apex, anterior communicating artery, or middle cerebral artery trifurcation). Intraoperative angiography should be considered in any other cerebrovascular procedures when there is doubt about the technical adequacy of the result.

References


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Address for Dr. Hieshima: Division of Neuroradiology, University of California School of Medicine, San Francisco, California.

Address for Dr. Reicher: Department of Radiology, Mercy Hospital, San Diego, California.

Address reprint requests to: Neil A. Martin, M.D., 74-140 CHS Division of Neurosurgery, UCLA Medical Center, Los Angeles, California 90024.