Intraoperative Digital Subtraction Angiography: A Review of 112 Consecutive Examinations

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PURPOSE: To examine the effect of intraoperative angiography on neurosurgery and angiographic technical success, safety, and accuracy. **METHODS:** Angiographic studies, surgical reports, and hospital records were reviewed retrospectively for 112 consecutive procedures in which intraoperative angiography was performed during neurosurgery. The results of conventional postoperative angiograms in 28 of the 112 procedures were also reviewed. A portable digital subtraction angiography unit was used for all patients. Decisions in the operating room were based on review of stored videotaped images. **RESULTS:** Eighteen studies were obtained in 14 patients after arteriovenous malformation resection. Unsuspected residual nidus was identified and resected in 3 patients. The intraoperative angiogram also altered therapy for 2 patients undergoing staged resections of arteriovenous malformations. Sixty-six studies were performed after aneurysm clipping, with clinically significant changes in surgical therapy made in 5 patients. Of 28 examinations after carotid endarterectomy, 3 led to revision. Two complications of angiography occurred. One led to a permanent neurologic deficit, yielding a complication rate of 1.5% for stroke. Two examinations could not be completed because of technical factors. Two false-negative examinations were identified on postoperative studies. One patient with a normal intraoperative study after carotid endarterectomy thrombosed the repaired internal carotid artery after surgery. **CONCLUSIONS:** Intraoperative angiography altered surgery in 13 of 112 procedures on 104 patients. This study supports the use of intraoperative angiography in arteriovenous malformation resection and in complex aneurysm surgery, but not for routine carotid endarterectomy.

Index terms: Angiography, intraoperative; Interventional neuroradiology

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The potential advantages of intraoperative angiography over conventional postoperative studies all relate to timing. Despite limitations inherent in the technique, information gained through an intraoperative study can lead to modifications at the time of initial operation that prevent complications or obviate the need for a second operation. This may involve the resection of an occult residual nidus of an arteriovenous malformation, the adjustment of an aneurysm clip, or the restoration of patency at carotid endarterectomy.

The usefulness of intraoperative angiography in identifying occult residual nidus during arteriovenous malformation resection has been recognized for many years: by Luessenhop and Spence in 1960 (1) and subsequently by others (2–9). Applications in aneurysm surgery also have been identified, such as the ability to confirm adequate obliteration of aneurysms and patency of parent or branch vessels (6–10). Similarly, the results of carotid endarterectomy may be assessed before skin closure (11–13) with evidence of reduced perioperative complications (14, 15).

Recent technologic advances in portable angiographic equipment and other factors have made intraoperative angiography capable of high-quality examinations (7, 16, 17), building on earlier efforts by other investigators (18). It can be performed in less than an hour with

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reasonable radiation exposure to patient and staff (Derdeyn CP, "Radiation Exposure to Patients and Personnel during Intraoperative Neuroangiography," presented at the American Roentgen Ray Society meeting, April 1994). However, there have been few reports on the technical success, accuracy, and safety of intraoperative angiography in neurovascular disease (7–9). In addition, the role of intraoperative angiography has yet to be defined—some advocate it as a replacement for conventional angiography, and others see it as a tool primarily for guiding therapy and assessing surgical results for complex intracranial vascular lesions. We present our experience with these issues in our series of 112 consecutive intraoperative angiograms.

Methods

One hundred twelve consecutive intraoperative angiograms were performed on 104 patients from August 1991 through January 1994. Studies were not obtained on all patients undergoing neurovascular procedures during this time (Table 1). Angiography was performed at the request of the referring physician, generally for complex or giant aneurysms or for deep arteriovenous malformations. A limited series of carotid endarterectomies was also evaluated. A biplane digital subtraction angiography unit was used for the conventional neuroangiograms (NeuroStar, Siemens AG, Erlangen, Germany).

Nearly all examinations were anticipated before surgery was begun, allowing preoperative placement of an arterial sheath for the planned catheterization. A 5-F femoral sheath was introduced in all patients undergoing craniotomy (n = 76) and in 3 patients for endarterectomy (n = 3). These 79 patients accounted for 87 procedures. Sheaths either were placed while the patient was in the operating room, usually after the induction of anesthesia and before surgery, or had been placed during previous diagnostic angiography. One sheath was placed before surgery while the patient was in the intensive care unit. The right common femoral artery was used in nearly all procedures (78 of 87). The sheath was continuously flushed with arterially pressurized heparinized saline when not in use.

TABLE 1: Use of intraoperative angiography, August 1991 through January 1994

	AVM	Aneurysm	CEA	**Total**
First year (August 1991 to December 1992)				
Intraoperative angiograms	6	28	27	
Surgical procedures	17	72	58	
Second year (January 1993 to January 1994)				
Intraoperative angiograms	12	38	1	
Surgical procedures	52	82	41	
Totals				
Intraoperative angiograms	**18**	**66**	**28**	**112**
Surgical procedures	**69**	**154**	**99**	**332**

Note.—AVM indicates arteriovenous malformation; and CEA, carotid endarterectomy.

Once in the operating room, the patient was positioned on a radiolucent operating table (Skytron, Grand Rapids, Mich). If a craniotomy was to be performed, the patient's head was immobilized in a carbon fiber head holder (Mayfield radiolucent skull clamp, Ohio Medical, Cincinnati, Ohio). Three patients were placed in prone position, and the remainder were supine. The femoral sheath was covered and draped to allow access during the angiogram. Care was taken to avoid placing radiopaque materials over the patient's head, neck, and chest. The operating room table was positioned to allow room for the portable angiography unit.

In all patients undergoing craniotomy and in three patients undergoing carotid endarterectomy, selective catheterization of the desired vessel was performed immediately before the angiogram via the 5F arterial sheath in the standard fashion. In patients undergoing carotid endarterectomy, angiograms were performed via direct antegrade or retrograde puncture of the surgically exposed common carotid artery (25 of 28), using an 18- or 20-gauge arteriotomy needle. The syringe was connected to the needle by standard connector tubing, and the needle was stabilized by suturing its hub. At completion the arteriotomy was often oversewn with a single suture before wound closure. In all studies (both direct punctures and transfemoral catheterizations), injections were done by hand. At the discretion of the angiographer, either ionic or nonionic contrast medium was injected. Three views of each lesion were routinely obtained, including an anterior, lateral, and oblique projection, and attempts were made to duplicate useful preoperative views. More views were obtained for studies of arteriovenous malformations in which more than one vessel was often catheterized. In some patients, the neurosurgical head-holding device prevented precise duplication of standard views.

A portable digital subtraction unit (OEC Diasonics, Salt Lake City, Ut) consisting of a C-arm fluoroscope, a digital image processor and storage unit, and a video monitor was used in all cases. This unit allows routine flouroscopy and real-time digital subtraction angiography. The recorded images could be reviewed at different speeds and frame by frame. Permanent hard copy images were made for the x-ray jacket with a photography unit. The most recent preoperative angiograms, either conventional diagnostic studies or, in most arteriovenous malformations, studies at the completion of embolization, were in the operating room for comparison in all cases. All studies were interpreted by the attending neuroradiologist and discussed with the neurosurgeon before leaving the operating room.

The femoral sheath was removed either in the recovery room or in the intensive care unit. This allowed observation of the puncture site and lower extremity in a routine manner by the nursing staff.

The medical records, including surgical and radiographic reports, were reviewed in all patients. Information gathered from these charts included the type and location of the vascular lesion, the intraoperative or postoperative complications that might be attributable to angiography or surgery, the dictated findings of the intraoperative studies, and the intraoperative decisions made on the basis of the study, as documented by the surgeon's operative note. Information derived from the dictated report of the angiogram included the vessels selected, the amount of contrast and the catheters used, the site of catheterization or puncture, and the specific findings in the study. There was concordance between the dictated reports and the surgical reports in all cases. All of the intraoperative and conventional angiograms were reviewed.

Results

Effect on Surgical Treatment

Arteriovenous Malformation Resection. Eighteen studies were performed on 14 patients. Findings led to alterations in surgical treatment in 5 patients. Residual nidus was not identified by parenchymal blush alone, because this finding could not be separated from normal tissue with the portable equipment. Only when parenchymal blush was accompanied by early draining veins was residual nidus identified. Unexpected residual nidus was found in 3 of the 18 studies for arteriovenous malformations. The residual malformation was then completely resected in these three patients at that sitting. Intraoperative angiography was relied on to confirm the total resection of the arteriovenous malformation. Postoperative angiography was used in two cases in which the surgical suspicion of residual nidus was high, despite a normal intraoperative study. Both studies confirmed the findings of the intraoperative angiograms.

Two other studies involved staged procedures in which intraoperative angiography was used to assess the amount of expected residual nidus and to identify the remaining feeding arteries. The first patient had a large parasagittal parietal arteriovenous malformation fed primarily by an enlarged pericallosal artery. The initial intraoperative examination obtained after attempted clipping of this vessel demonstrated persistent patency. Later in the same procedure, adequate clip placement was confirmed by repeat intraoperative angiography (Fig 1). The remaining arteriovenous malformation was completely removed during the planned second operation. A second patient was studied near completion of a planned single-stage resection. Based on the amount of residual nidus shown on intraoperative angiography, the surgeon elected to stage the procedure. Complete removal was achieved at the second and final surgery.

Aneurysm Clipping. In studies of 66 intracranial aneurysms in 63 patients, significant findings were made in 12, leading to clinically significant alterations in surgical therapy in 5 patients. Five of the 12 studies involved giant aneurysms with small, expected residual lumens after clipping but preserved flow in vessel branches. In these 5 patients, the operating neurosurgeon was satisfied with the surgical result and the craniotomy was closed after a final inspection of the aneurysm clip. Our institution is a referral center for the treatment of these more difficult neurovascular lesions, and our experience may reflect a higher proportion of complicated and giant aneurysms.

In three patients, absence of filling of a parent or branch vessel was identified on the intraoperative study. In one patient with a proximal posterior cerebral artery aneurysm, the distal posterior cerebral artery did not fill on the intraoperative angiogram. The clip and vessel were carefully reinspected, and normal pulsatile flow in the distal branches was observed. This may have been secondary to collateral flow. The clip, therefore, was not adjusted. After surgery, no neurologic sequelae were observed and the patient remained neurologically intact. Similar findings led to clip adjustment or replacement in two other patients. During clipping of a complex middle cerebral artery aneurysm, nonfilling of the superior division of the middle cerebral artery was identified and the clip was adjusted, restoring vessel patency. This patient suffered no clinical or computed tomographic (CT) scan evidence of infarction after surgery. In the other patient, nonfilling of the A1 segment of the anterior cerebral artery was identified during anterior communicating artery aneurysm repair, and clip repositioning restored flow. Despite prompt clip repositioning anterior cerebral artery distribution infarction occurred. Therefore, intraoperative angiography may have changed the clinical outcome in one of these three patients.

In three patients, a second, unsuspected aneurysm was identified after successful clipping of the first. In each of these patients, the second aneurysm was exposed and clipped at that sit-

Fig 1. Fifty-year-old man with a parasagittal parietal arteriovenous malformation fed primarily by the pericallosal artery. One goal of the first stage procedure was to clip the pericallosal artery.

A, The initial intraoperative examination after attempted clipping of this vessel demonstrates persistent patency (*black arrowhead*). The linear vertical subtraction artifact superior to the arrowhead is from the first clip (*open arrow*).

B, The clip was replaced and proper placement was subsequently confirmed.

ting. In one, the intraoperative study demonstrated satisfactory clipping of a giant aneurysm of the ophthalmic artery and showed an unsuspected aneurysm of the ipsilateral supraclinoid carotid; the aneurysm was then exposed and clipped at that sitting. This aneurysm had been obscured by the giant ophthalmic-level aneurysm on the preoperative conventional angiogram. The second patient with an unsuspected aneurysm had a 5-mm middle cerebral artery bifurcation aneurysm identified after successful clipping of a large supraclinoid internal carotid artery aneurysm. This unsuspected aneurysm was exposed and clipped. The conventional an-

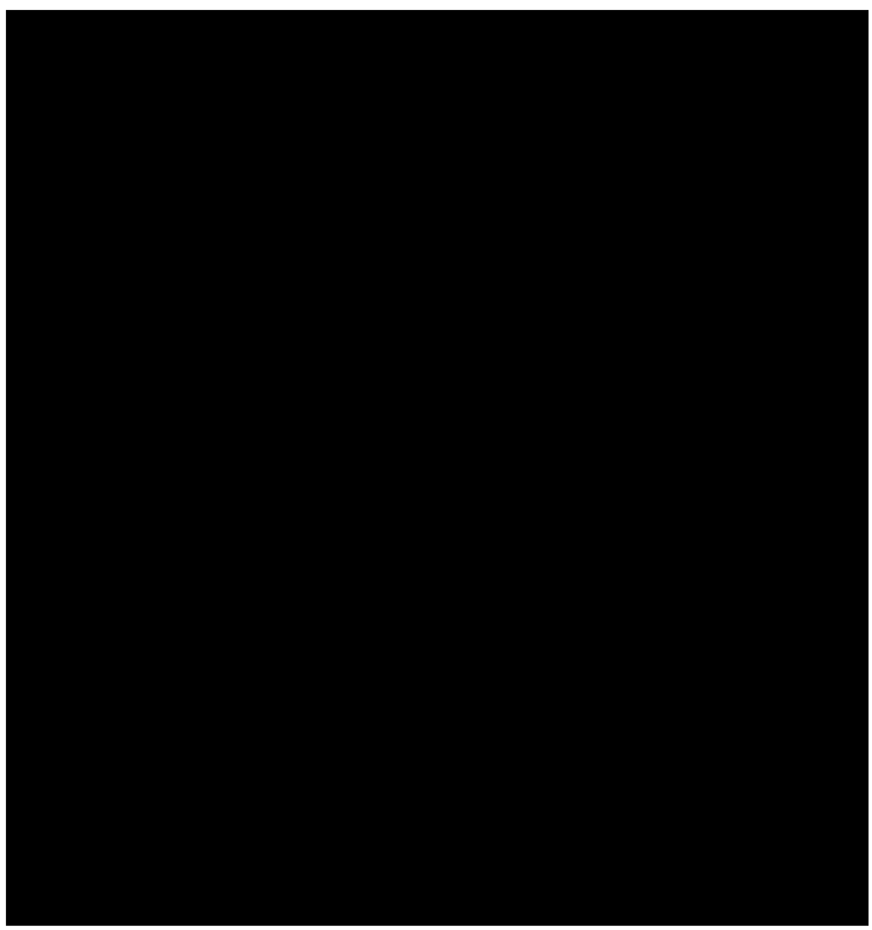

Fig 2. Forty-five-year-old woman with a complex anterior communicating artery aneurysm on preoperative studies (*A*, lateral and *B*, oblique). The intraoperative angiogram demonstrated an unclipped aneurysm (*black arrow*) arising posterior to the clip (*C*, lateral and *D*, oblique, respectively), as well as nonfilling of the contralateral distal anterior cerebral artery. The unclipped aneurysm was subsequently exposed and clipped. The patient recovered uneventfully and without neurologic sequelae.

giogram from an outside institution had not shown this aneurysm. The final patient had a complex aneurysm of the anterior communicating artery; it was interpreted as a bilobed lesion on the preoperative study despite multiple projections (Fig 2). The intraoperative angiogram after initial clip placement clearly showed the other "lobe" as a second aneurysm, which was subsequently clipped.

One emergency procedure was done on a rapidly deteriorating patient with subarachnoid and intraparenchymal hemorrhage on CT and clinical possibility of a mycotic aneurysm. Because of the patient's declining condition, intraoperative angiography was done instead of conventional angiography. A distal middle cerebral artery aneurysm (mycotic) was identified and located for surgical resection.

In summary, of 66 intraoperative studies for aneurysm, a clinically significant change in surgical treatment occurred in 5 patients. Three patients were spared a second craniotomy for a second aneurysm. One study may have prevented a middle cerebral artery distribution infarction by identifying branch vessel occlusion, and a mycotic aneurysm was successfully located in one patient.

Carotid Endarterectomy. Six of 28 intraoperative studies after carotid endarterectomy were judged to be angiographically abnormal. Several other patients had what were judged to be surgically insignificant irregularities of the repaired vessel wall. None of these latter patients had perioperative complications.

Of the six patients with abnormal intraoperative angiograms, three underwent surgical revision. In the first patient, a 50% stenosis was identified in the internal carotid artery. The vessel was again explored and residual plaque removed. In the second patient, the previously patent external carotid artery was found to be occluded. The external carotid artery was explored and further plaque was removed, restoring patency of the vessel. In the third, an internal carotid artery dissection was diagnosed. Because the preoperative study had shown an angiographic string sign with very slow flow through the internal carotid artery, the vessel was ligated.

Further surgery was not pursued in three patients with angiographically significant findings. A linear filling defect in the common carotid artery in one patient was attributed to an intimal flap. This was felt to be caused by the arterial puncture for the angiogram. Flow in the internal carotid was well preserved, and the artery was not reopened. In the second patient a 50% narrowing at the site of a vein patch graft was attributed to spasm by the surgeon, and the wound was closed. A dissection of the external carotid artery was observed in one patient. No further treatment was pursued because the flow was adequate. None of these patients had a postoperative or perioperative neurologic complication.

Technical Angiographic Success

The femoral artery was successfully catheterized in all patients. For transfemoral intraoperative angiography the patient was supine or in a slightly oblique supported position. In these patients, catheterization was performed in the standard fashion. Transfemoral angiography also was performed in three prone patients. In these patients, the sheath was placed after the induction of anesthesia while the patient was supine. The patients were then carefully turned prone and bolsters were placed above and below the sheath site to allow access during the angiogram. Because of the configuration of the operating room the left femoral artery, rather than the right, was catheterized in these patients for better access to the groin during angiography. In two patients studied supine, selective catheterization of the desired vessel was unsuccessful, and the procedure was terminated. No complications attributable to the sheath or its introduction were observed. No significant hematomas developed. Technically adequate angiograms were obtained in all procedures in which selective catheterization was successful.

Complications

Two complications were observed in 104 patients (112 procedures). In one patient an embolus in a branch of the left middle cerebral artery was identified on a postoperative study, 1 day after clipping of a superior cerebellar artery aneurysm. Only the left vertebral artery had been catheterized during the intraoperative angiogram. The cause of this infarction is unknown, but an embolic complication of angiography cannot be excluded. The other complication was an asymptomatic carotid dissection after direct carotid puncture, as mentioned

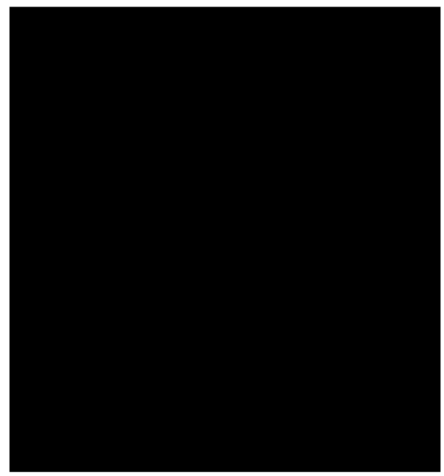

Fig 3. Forty-five-year-old woman with a giant ophthalmic level internal carotid artery aneurysm. *A*, preoperative oblique lateral view.

B, Anteroposterior and *C*, oblique views from the intraoperative angiogram do nots show residual aneurysm. A lateral projection could not be obtained because of patient position in the headholder. However, residual sac is shown on the lateral projection of the postoperative study (*black arrow*) obtained for the diagnosis of vasospasm (*D*). Spasm is present distal to the residual aneurysm.

above. No local complications of transfemoral catheterization were observed.

Angiographic Accuracy

Conventional postoperative angiography was done in 25 of the 66 aneurysm patients. All angiograms were obtained for the evaluation of vasospasm and consideration of interventional therapy. There was angiographic agreement in 22 of the 25 patients. Two patients had false-negative intraoperative examinations. One patient with a clipped giant ophthalmic level internal carotid artery aneurysm was shown to have a 5-mm residual lumen on postoperative conventional angiography. The projections obtained in the intraoperative examination appear normal (Fig 3). This residual aneurysm had been expected, however, and no further treatment was necessary. A second patient with a middle cerebral artery bifurcation aneurysm had an intraoperative study that identified what was initially interpreted as a tortuous proximal portion of a branch vessel, but on subsequent conventional angiography was demonstrated to be a small residual aneurysm. The third patient had residual aneurysm identified on a conventional postoperative study, which had not been seen on the intraoperative examination. Careful comparison of the two angiograms indicated that the clip had changed positions between the intraoperative and the postoperative study. This patient was operated on again and the clip replaced.

Two patients with resected arteriovenous malformations and one patient after carotid endarterectomy had normal intraoperative exams confirmed by postoperative examinations. The two postoperative arteriovenous malformation angiograms were to confirm total excision. The examination performed after carotid endarterectomy was part of a balloon occlusion test of the contralateral carotid in a patient with tumor encasement of that carotid. In total, 25 patients had postoperative angiography after

Fig 4. Fifty-seven-year-old woman examined after right carotid endarterectomy.

A and *B*, Two views of the repaired artery appear normal on the intraoperative angiogram. *Black arrows* point to the needle being used for the direct puncture. Neurologic examination in the recovery room after 1 hour revealed a new left hemiparesis and conventional angiography was pursued after a normal head CT.

C, The angiogram shows complete thrombosis of the repaired internal carotid artery. No abnormality of the vessel to account for the thrombosis was found on reexploration.

aneurysm clipping, 2 after arteriovenous malformation resection, and 1 after carotid endarterectomy. Two false-negative intraoperative examinations were identified on these 28 postoperative examinations.

Intraoperative angiography did not predict a postoperative internal carotid artery thrombosis in a patient undergoing carotid endarterectomy. Two intraoperative projections of the right carotid demonstrated minimal irregularities of the vessel wall, which were expected (Fig 4). In the recovery room, the patient initially was neurologically intact. One hour after surgery, a dense hemiparesis suddenly occurred. The occlusion was diagnosed by emergency postoperative conventional angiography. The patient returned to the operating room where the thrombus was removed and flow restored. No cause for the thrombosis could be identified at that surgery. A right middle cerebral artery distribution infarction developed.

Discussion

Effect on Surgical Treatment

Arteriovenous Malformation Resection. Complete resections of arteriovenous malformations are a cure; incomplete resections expose the patient to the risk of hemorrhage (19). For many arteriovenous malformations, particularly deep lesions, direct inspection after resection may miss a small residual nidus. Because of this, neurosurgeons have for many years incorporated intraoperative angiography in the treatment of arteriovenous malformations. Luessenhop reported the use of intraoperative angiography in the embolization therapy of arteriovenous malformations (1). Several investigators subsequently reported intraoperative techniques using direct carotid puncture, retrograde cannulation of the superficial temporal artery, or transfemoral catheterization (2–5). Exposure of a standard radiographic cassette was performed in each of these series, requiring good communication between surgeon and technician. Bauer (6) was the first to report the use of a video system for intraoperative angiography for arteriovenous malformations and aneurysms in 1984. The recent development of a commercially available portable digital subtraction unit have made these studies easier to perform.

Bauer studied 11 patients with arteriovenous malformations and in 3 discovered unclipped feeding vessels, which were subsequently controlled. Hieshema et al (7) performed 12 studies on 10 patients with arteriovenous malformations. Significant findings were made in 3, lead-

TABLE 2: Frequency of detection of unexpected residual nidus

Study	Number of Exams	Residual Nidus
Bauer, 1984	11	3
Hieshema, 1987	12	2
Martin, 1990	48	5
Barrow, 1992	39	6
Present study	18	3
Total	**128**	**19 (16%)**

ing to reexploration and complete resection in 1 patient. One patient with an identified occult residual arteriovenous malformation nidus could not be resected at that time because of edema, and a third patient was shown to have an unexpected thrombosis of a middle cerebral branch feeding vessel. Martin et al (8) reported identification of residual nidus in 5 of 48 arteriovenous malformations studied during surgery. All were located and resected at that operation. The most recent series by Barrow et al (9) reported identification of residual nidus in 6 of 39 intracranial arteriovenous malformations in which complete resection had been expected. The findings of this series were similar to those above, with significant findings made in 5 of 18 studies, leading to additional resection of residual nidus in 3 patients, and guiding surgery in two staged procedures. These series are summarized in Table 2. No false-negative examinations have been reported.

The finding of a vascular blush, without evidence of an early draining vein, has been previously noted by Martin et al, who had three patients with a blush suspicious for residual arteriovenous malformation. No residual arteriovenous malformation was found by further surgical exploration or follow-up conventional angiography in each instance. They attributed the blush to hyperperfusion in adjacent normal vessels. We did not note any cases of isolated vascular blush.

In summary, intraoperative angiography for complex or deep arteriovenous malformations is a well-established technique for excluding residual nidus and guiding any further resection. Unexpected residual nidus is frequently found, and intraoperative angiography offers the neurosurgeon the opportunity to resect an arteriovenous malformation completely, obviating a second operation. Intraoperative angiography has been used for this purpose for many years, and recent technologic advances have increased ease and reliability. In addition, in staged procedures intraoperative angiography assesses the amount of residual nidus and identifies the anatomy of the remaining feeding arteries and draining veins. Our experience and that of others cited above support the routine use of intraoperative angiography after arteriovenous malformation resection.

Aneurysm Clipping. The goal of aneurysm surgery is to obliterate the lumen of the aneurysm without occluding the parent or branch vessels. The incidence of incomplete obliteration is not known, but Feuerberg et al (20) found residual aneurysm in 4% of intracranial aneurysms. There may be a higher incidence in giant aneurysms. Residual aneurysms have been shown to enlarge and hemorrhage (20–22). Branch vessel occlusion by an aneurysm clip also may complicate aneurysm surgery. In a recent report of 66 consecutive postoperative angiograms obtained after aneurysm clipping, nine unexpected major vessel occlusions were identified (23). The use of intraoperative angiography may reduce the incidence of both of these complications.

Although there have not been large series to confirm this hypothesis of reduced complications, intraoperative angiography has shown residual aneurysms, branch vessel occlusion, and unsuspected aneurysms. Drake and Allcock reported the use of intraoperative angiography for the early assessment of aneurysm clip placement in 1973 (10). Bauer in 1984 reported changing clip placement because of the intraoperative examination in 7 of 33 patients (6). Barrow et al (9) found that intraoperative examinations altered surgery in 7 of 62 patients. Four of these required clip replacement: two for residual aneurysm, one for branch vessel occlusion, and one for parent vessel kinking. In 2 other patients, the intraoperative angiogram provided information that led to aneurysm resection and bypass rather than clipping. In the final patient, the intraoperative study demonstrated adequate collateral circulation after trapping of an aneurysm, obviating the need for a bypass procedure. In the study by Martin et al (8) intraoperative angiography led to clip repositioning in 5 of 57 aneurysms. In the current series, clip repositioning for branch vessel occlusion occurred in 2 of 66 studies. In addition, the intraoperative examination revealed an unsuspected aneurysm in 3 patients and showed a suspected mycotic aneurysm in 1 patient. Each of the unsuspected aneurysms was then exposed and clipped.

The development of modern microsurgical techniques and the multitude of available aneurysm clips have made the goals of aneurysm surgery more easily achievable in small uncomplicated aneurysms. However, in more complicated lesions such as large or giant aneurysms, or those with broad-based necks or atheromatous or calcified walls, or those involving the origins of several branch vessels, reaching these goals may be difficult or impossible. For this reason, many techniques have been developed to increase the changes of adequate treatment. These include temporary arterial occlusion with cerebral protection (24) and cardiopulmonary bypass with hypothermia (25). Several case reports describing novel approaches to complex aneurysms have incorporated intraoperative angiography as a useful tool in confirming achievement of surgical goals and guiding further surgical intervention (24, 26).

Intraoperative angiography is able to show reliably parent and branch vessel occlusion, residual aneurysm, and the presence of other aneurysms, allowing therapeutic modifications in the operating room. Significant intraoperative findings requiring surgical modifications are identified frequently (Table 3). Intraoperative angiography may reduce postoperative and perioperative complications, as well as the need for reoperation, although the incidence of clinically significant findings appears to be low.

Carotid Endarterectomy. Postoperative stroke after carotid endarterectomy is an uncommon but potentially catastrophic occurrence. It is often caused by abnormalities of the repaired vessel wall, which lead to thrombotic occlusion or embolization (27–29). The use of intraoperative angiography for identification of these abnormalities is controversial. The group of carotid endarterectomies studied represent a series of patients referred primarily by one neurosurgeon (R.L.G.).

The use of intraoperative angiography in carotid endarterectomy was reported by Blaisdell in 1967 (11). Subsequent studies documented a reduction in perioperative stroke and mortality when intraoperative angiography was used (14, 15). The intraoperative arteriograms in these studies were obtained by directly injecting the carotid via a 19-gauge needle and taking a single projection plain film using a portable C-arm. Bredenberg et al reported the use of a portable digital subtraction angiography unit and described their technique (30). They quoted a reopening rate of 5%, comparable to previous series. The rate of reopening in an ultrasonographic series was similar, with a 5% rate reported by Zierler et al (13).

However, intraoperative angiography adds time and potential complications to a short, low-morbidity surgical procedure, and postoperative occlusion despite normal intraoperative angiographic findings has been reported previously (30). The rate of reopening is low, and approximately half are for external carotid lesions. Because of these factors, some authors have abandoned the routine use of this procedure except in specific situations where the chance of making a significant finding is higher (31).

In our series of 28 procedures, we identified six abnormal studies, leading to reoperation in three. In each of the three patients, the angiographic findings were confirmed. However, it is not clear whether the abnormalities detected would have caused any postoperative complications if not repaired, and the one neurologic complication in this group of patients occurred despite a normal intraoperative study (Fig 4). We are no longer performing routine intraoperative angiography after carotid endarterectomy for these reasons. Therefore, we will devote the remaining discussion to the role of intraoperative angiography in the surgical treatment of arteriovenous malformations and aneurysms.

TABLE 3: Frequency of aneurysm clip replacement or other change in therapy

Study	Number of Exams	Change in Therapy
Bauer, 1984	33	7
Martin, 1990	57	5
Barrow, 1992	62	7
Present study	66	6
Total	**218**	**25 (11%)**

Complications

We observed one neurologic complication after transfemoral catheterization in 87 procedures. Embolic complications of transfemoral catheterization were reported in 2 of 97 procedures by Martin et al (8). They reported one cerebral infarction and one peripheral embolus to the foot. Barrow et al reported an asymptomatic embolus to the A1 segment of the anterior cerebral artery in their series of 115 intraoperative procedures. They also reported a fatal postoperative aortic dissection, which may have been secondary to angiography. Hieshema et al reported no angiographic complications in 32 intraoperative diagnostic studies (7). Based on these series and ours, the frequency of embolic complications (1.5%) in intraoperative angiography is comparable to that reported in conventional angiography, although many have reported a lower frequency of complications with conventional cerebral angiography. In our own practice, embolic complications of conventional diagnostic angiography over the past year included a 0.6% frequency of stroke and a 1% frequency of transient ischemic attacks. There is no obvious reason for a higher frequency of angiographic complications in the operating room, as standard angiographic techniques and precautions are followed. However, possible contributing factors may be the often suboptimal fluoroscopic visibility of the aortic arch and the nonstandard positioning of the patient. Both combine to make selective catheterization more difficult than with conventional angiography. Perhaps as more experience is gained in these procedures, the incidence of complications will fall.

Angiographic Accuracy

Because of technologic advances, the quality of current digital subtraction intraoperative angiography is very good. However, intraoperative technology as it exists today still is not a match for conventional angiography. Conventional angiography in a dedicated angiography suite offers biplane capability, which increases the diagnostic yield of each injection, higher resolution, and greater flexibility in terms of projections. It is not surprising, therefore, that an intraoperative study will miss some important findings. Martin et al identified three false-negative intraoperative examinations in their series with angiographic follow-up in 62 patients. Two residual aneurysm sacs were missed, and a small residual arteriovenous malformation nidus was missed in a third. In the series reported by Barrow et al one residual aneurysm sac was identified in 17 postoperative examinations after aneurysm clipping, and one small arteriovenous shunt was found in 30 postoperative angiograms for arteriovenous malformation. We observed two false-negative examinations in 25 studies for aneurysm with angiographic follow-up. Both had small residual aneurysms. We had no false-positive intraoperative angiograms. We were unable to identify any factors in the false negative studies that would enable us to predict which patients might be more likely to need postoperative angiography in addition to an intraoperative angiogram.

With only two conventional postoperative studies for residual arteriovenous malformation, it is not possible to assess the accuracy of intraoperative angiography in this series. We are currently using intraoperative angiography to confirm total resection of the arteriovenous malformation nidus although its accuracy has not been validated.

Cost Benefit Analysis

Any analysis of the cost benefit of this procedure is flawed because of the retrospective nature of this report. The selection of patients for intraoperative angiography was at the discretion of the surgeon. A randomized trial would be necessary to identify any cost benefit. However, it may be useful to explore these issues. In arteriovenous malformation surgery, intraoperative angiography spared three patients an additional craniotomy. It also was very helpful in guiding two staged procedures, but that assistance cannot be quantified. In general, conventional postoperative angiography was not pursued after a negative intraoperative examination except in two patients in whom the neurosurgeon had a strong suspicion of residual nidus. As mentioned above, both studies were negative for residual arteriovenous malformation. The accuracy of intraoperative angiography has not yet been confirmed, however. The cost of 18 intraoperative studies was approximately $36 000 ($2000 each, including cost of operating room time and angiography supplies)—less than the cost of the three avoided craniotomies.

In aneurysm procedures, intraoperative angiography showed residual or additional aneurysm in three patients, sparing them a second craniotomy. In two patients it showed branch vessel occlusion that required clip replacement, although one patient had an infarct in the distribution of the branch vessel. One significant angiographic complication occurred. Therefore, one stroke was likely prevented by clip replacement, and one may have been caused by the intraoperative procedure. The 66 examinations for aneurysm were performed at an approximate total cost of $132 000, which exceeds that of the three repeat craniotomies avoided by the intraoperative examinations. If it were clear that intraoperative angiography obviated the need for conventional postoperative studies, the case for routine intraoperative studies would be very strong. However, the 8% false-negative rate in aneurysm studies is too high to claim that postoperative examinations are unnecessary.

Summary

What, then, is the role of intraoperative angiography? With the proper equipment, it can be performed easily and is capable of showing potentially important abnormalities. Because the complication rate is equal to or greater than that of conventional angiography, the benefit of intraoperative angiography must be balanced by the risk. It can show residual nidus and feeding arteries in arteriovenous malformation surgery, guide further intervention, and reduce the need for an additional craniotomy to resect an unsuspected residual nidus. The high incidence of clinically significant findings on intraoperative studies supports the routine use of this technique in arteriovenous malformation surgery. In aneurysm surgery, it can confirm branch vessel patency and show residual aneurysm, particularly in complex and giant aneurysm repair. The frequency of clinically significant findings is small (5 of 66), however. The key to improving the cost/benefit ratio and the benefit/risk ratio for intraoperative examinations in cerebral aneurysm surgery may be in identifying a subset of the patient population undergoing clipping in whom a clinically significant finding would be more likely. We have been unable with the present data to identify such a subset but plan future analysis. In addition, the false-negative rate in this series and others emphasizes the fact that conventional angiography remains the standard with which intraoperative angiography must be compared. Despite these problems, however, we believe intraoperative angiography has a clear, problem-solving role in the surgical management of arteriovenous malformations and complicated aneurysms. Intraoperative angiography does not appear to be useful in routine carotid endarterectomy.

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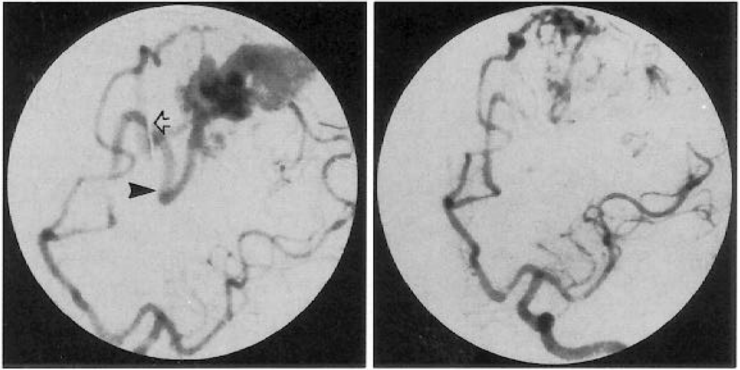

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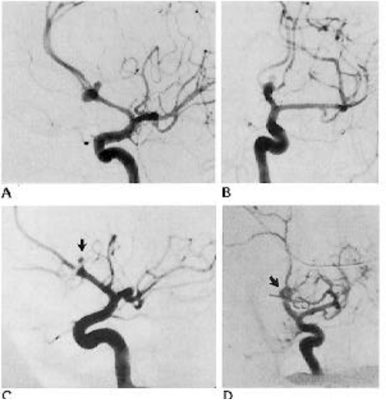
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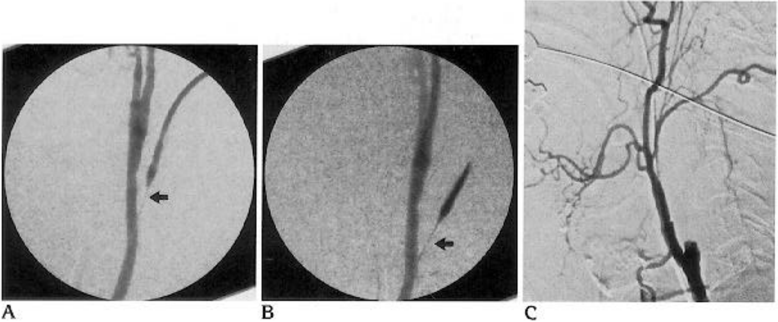
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