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Cerebral Angiography in Brainstem Revascularization

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Surgical management of patients with vertebrobasilar insufficiency has been developed within the past decade. Cerebral angiography plays a crucial role in identifying potential surgical candidates and in directing the surgical approach. Fifty-two patients underwent brainstem revascularization procedures at Henry Ford Hospital between November 1979 and August 1985. Twelve occipital artery to anterior inferior cerebellar artery bypasses, five occipital artery to posterior inferior cerebellar artery bypasses, four intracranial vertebral endarterectomies, 29 superficial temporal to superior cerebellar artery bypasses, and two superficial temporal to posterior cerebral artery bypasses were performed. The preoperative angiograms in these patients were analyzed to illustrate how angiographic localization of vascular disease directs the surgical approach. We report the results of postoperative angiograms. Technical features of the various surgical procedures, the role of the neuroradiologist, and several features of the angiographic technique used with these patients are described.

Within the past decade, surgical treatment has become available to patients with vertebrobasilar insufficiency. The first extracranial to intracranial bypass procedure for posterior fossa revascularization was performed by Ausman et al. [1] in 1975. Since then, other innovative surgical procedures directed at posterior fossa revascularization have been devised [2, 3]. Cerebral angiography plays a pivotal role in the management of these patients by first identifying that subgroup of patients with vertebrobasilar insufficiency who are surgical candidates, and second in directing the surgical approach. Despite this, the role of cerebral angiography in posterior fossa revascularization remains unreported in the radiologic literature.

Materials and Methods

Patient Population

All 52 patients in this series were clinically diagnosed as having vertebrobasilar insufficiency on the basis of having two or more of six signs and symptoms [4]: (1) motor and/or sensory symptoms in the same attack, (2) ataxia, (3) diplopia, (4) dysphagia, (5) homonomous hemianopsia, and (6) perioral numbness and dizziness. Most patients had four or five signs and/or symptoms consistent with the clinical diagnosis. The frequency of vertebrobasilar transient ischemic attacks (TIAs) in this group ranged from several per day to two per year for a period of 1 day to 6 years. All had tried antiplatelet agents, and 70% were on anticoagulants without relief of symptoms.

Between November 1979 and August 1985, these 52 patients underwent brainstem revascularization procedures at the Henry Ford Hospital neurosurgery department. An occipital artery to anterior inferior cerebellar artery (OA–AICA) bypass was performed in 12 patients, nine on the right and three on the left. An occipital artery to posterior inferior cerebellar artery (OA–PICA) bypass was performed in five patients, three on the left and two on the right. Four patients underwent an endarterectomy of the vertebral artery at the craniocervical junction, one on the right and three on the left. A superficial temporal artery to superior cerebellar artery bypass (STA–SCA) was performed in 29 patients, and an STA–posterior cerebral

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artery (PCA) bypass in two. The average age was 59 years (range 42–70). There were 42 men and 10 women.

Preoperative Angiographic Technique

A four-vessel cerebral angiogram was obtained in all patients before surgery. The complete vertebrobasilar circulation from vertebral origin to intracranial branches was imaged bilaterally in each case. The carotid circulation was evaluated bilaterally as was the interdependence of anterior and posterior circulation. Arch aortography was performed only if needed to confirm suspected occlusion of a vessel that could not be catheterized selectively. All arch studies after 1982 were performed with the intraarterial digital technique.

In the last 2 years, we have routinely used a biplane projection with the head turned 30° to the contralateral side to image the entire length of the vertebral artery with one injection. Vertebral origins were seen with selective subclavian injections. Magnification and subtraction techniques were used in all studies [5].

Postoperative Angiographic Technique

Postoperative angiograms were obtained in 51 patients, 48 by the femoral route and three axillary, at an average of 12 days after surgery (range 1–42 days). Postoperative studies were limited to injection of the ipsilateral external carotid circulation in bypass patients and of the operated vertebral circulation in endarterectomy cases [5].

Preoperative Angiographic Evaluation

For purposes of this study, each vertebral artery was divided into six segments (origin, anatomic first segment, anatomic second segment, C1 to PICA, PICA origin, and PICA to basilar) (Fig. 1) [6]. Each segment was evaluated for percentage stenosis of the vessel diameter. The diameters of the stenotic segment(s) and the nearest uninvolved portion of the same vessel were measured directly on the films. Percentage stenosis was calculated as % *stenosis* = 100 × *stenotic segment/uninvolved segment*. If a particular lesion involved two adjacent arterial segments, it was included in both. The percentage of the entire group with a lesion was calculated for each segment. Patients in whom the artery was occluded proximal to a given segment were not included in the statistics of that particular segment. Therefore, the number of patients included in the statistics for each segment varies, with the lower numbers in the more distal vertebral segments.

The average percentage stenosis in those patients with lesions in a given segment was calculated for each segment. Patients in whom the vertebral artery ended in PICA were averaged into the PICA to basilar segment as 100% stenosis. In only one patient was a vertebral artery occluded at the origin and reconstituted distally. This patient was included as 100% stenosis at the origin, not included in the first- or second-segment statistics and counted as 0% stenosis beyond C1.

For the purposes of this study, the basilar artery was divided into four segments: (1) proximal (to AICA), (2) AICA origin, (3) middle basilar (distal to AICA origin), and (4) basilar tip (including origin of SCAs and PCAs). The frequency and severity of lesions in each segment were calculated in a manner identical to those for the vertebral arteries.

Two of the 31 upper brainstem revascularization cases had preoperative angiograms done elsewhere and are not included in this evaluation.

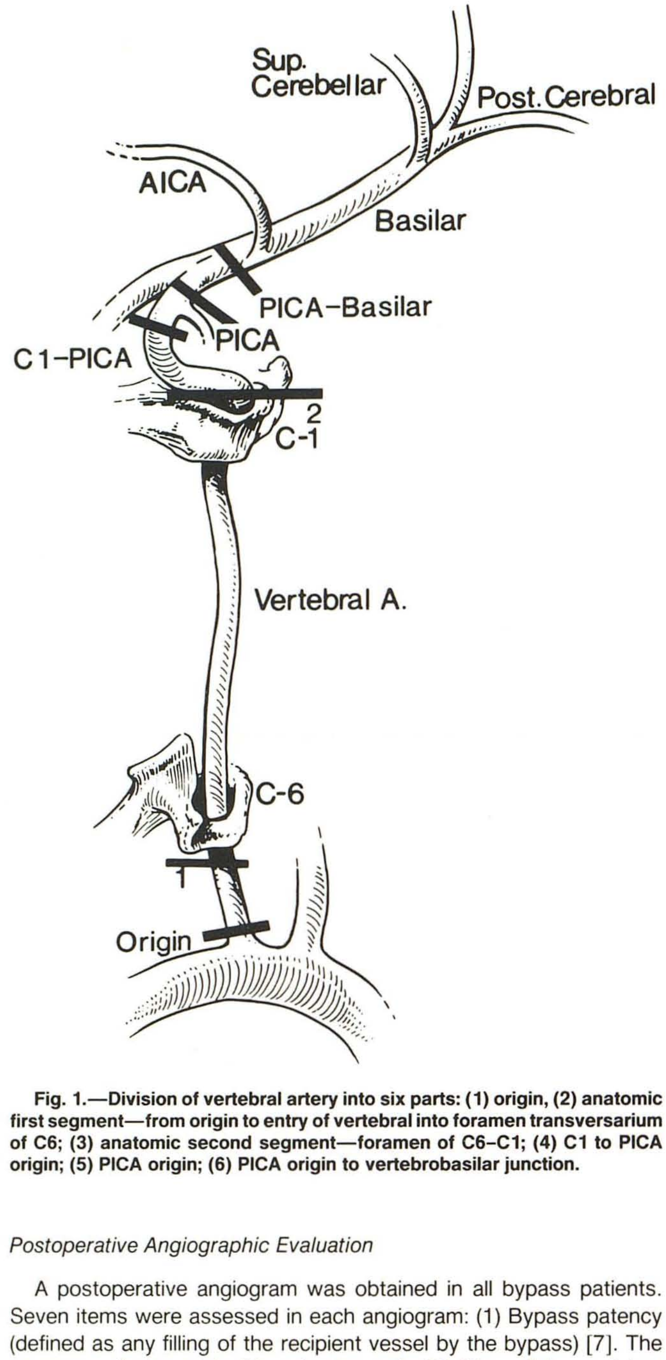


Fig. 1.—Division of vertebral artery into six parts: (1) origin, (2) anatomic first segment—from origin to entry of vertebral into foramen transversarium of C6; (3) anatomic second segment—foramen of C6–C1; (4) C1 to PICA origin; (5) PICA origin; (6) PICA origin to vertebrobasilar junction.

Postoperative Angiographic Evaluation

A postoperative angiogram was obtained in all bypass patients. Seven items were assessed in each angiogram: (1) Bypass patency (defined as any filling of the recipient vessel by the bypass) [7]. The presence of antegrade (2) and retrograde (3) filling of the recipient vessel. (4) Filling of the basilar artery via the bypass. (5) Hypertrophy of the donor vessel. (This was graded by visual inspection as none, moderate, or marked; moderate enlargement roughly corresponds to less than 50% and marked greater than 50% increase in diameter of the donor vessel after bypass. Changes in magnification between pre- and postoperative studies were considered when grading.) (6) Evidence of arterial narrowing at the anastomotic site. (7) The number of vertebrobasilar branches (including the recipient vessel) filled via bypass flow was recorded. Patients in whom the bypass was occluded are not included in the results of the arterial narrowing or donor hypertrophy categories.

Three of the four endarterectomy patients underwent postoperative angiography. These studies were evaluated for patency and morphology of the endarterectomized segment.

Clinical Evaluation

Each patient's postoperative clinical status (asymptomatic, improved, no change, worse, died) was recorded at the time of hospital discharge. Perioperative complications were recorded after surgery. These data were retrieved from a computerized file and correlated with angiographic results for purposes of this study.

Results

Preoperative angiographic results are in tabular form only for the 12 OA–AICA patients and for 29 of the upper brainstem revascularization patients (Table 1). Preoperative angiograms in the 12 OA–AICA patients demonstrated lesions occurring with the greatest frequency and severity in the PICA to basilar segment. Lesions were slightly less common at the vertebral origin, in the C1 to PICA segment, PICA origin, and proximal basilar. Lesions were uncommon elsewhere. Three right and three left vertebral arteries ended in PICA.

Preoperative angiograms in the five OA–PICA patients demonstrated stenotic lesions occurring with greatest frequency and severity in the C1 to PICA segment and at the vertebral origin. Lesions were rare elsewhere, particularly (and contrary to the OA–AICA patients) in the proximal basilar. The vertebral artery opposite the bypass ended in PICA in two patients. Each patient had multiple focal stenoses or a single fairly long segment of high-grade stenosis of the C1 to PICA segment on the side of the bypass.

TABLE 1: Preoperative Angiographic Findings in OA–AICA Bypass and in Upper Brainstem Revascularization

Arterial Segment	OA–AICA Bypass (*n* = 12)		Upper Brainstem Revascularization (*n* = 29)	
	% with Stenotic Lesion	Average % Stenosis	% with Stenotic Lesion	Average % Stenosis
Left vertebral:				
Origin	75 (*n* = 12)	57	41 (*n* = 28)	60
Cl to PICA	36 (*n* = 11)	72	28 (*n* = 27)	36
PICA origin	27 (*n* = 11)	70	28 (*n* = 25)	46
PICA to basilar	90 (*n* = 11)	94	64 (*n* = 25)	77
Right vertebral:				
Origin	58 (*n* = 12)	68	26 (*n* = 27)	62
Cl to PICA	56 (*n* = 10)	90	20 (*n* = 25)	54
PICA origin	29 (*n* = 7)	85	22 (*n* = 23)	30
PICA to basilar	71 (*n* = 7)	97	65 (*n* = 23)	89
Basilar:				
Proximal to AICA origin	40 (*n* = 10)	77	51 (*n* = 27)	84
AICA origin	11 (*n* = 9)	10	31 (*n* = 26)	67
Middle (distal to AICA origin)	22 (*n* = 9)	15	44 (*n* = 27)	69
Tip	11 (*n* = 9)	15	4 (*n* = 26)	30

Note.—OA = occipital artery; AICA = anterior inferior cerebellar artery; PICA = posterior inferior cerebellar artery.

All four endarterectomy patients had a short unifocal segment of high-grade stenosis of the C1 to PICA segment, with the opposite vertebral being occluded (two patients) or ending in PICA (two patients).

Preoperative angiograms analyzed in 29 upper brainstem revascularization patients demonstrated stenotic lesions in the vertebral arteries occurring with greatest frequency and severity at the vessel origin and in the PICA to basilar segment (Table 1). Stenotic lesions occur with significant frequency and severity in the proximal and middle basilar artery. Because of distal basilar filling via patent posterior communicating arteries in certain cases of proximal basilar occlusion, the number of patients in each basilar segment does not systematically decline distally in Table 1. Two left and 10 right vertebral arteries end in PICA.

Results of the postoperative studies in the 48 bypass patients are summarized in Table 2. In general (and particularly in the OA–AICA group) the bypass procedures were highly successful from a technical standpoint (high patency and low rate of angiographically identifiable complications, such as arterial narrowing). A high percentage of patients also had good bypass performance (basilar filling and donor hypertrophy). Selective external carotid injections produced no apparent compromise of bypass integrity in any patient.

Postoperative angiograms in two of the three endarterectomy patients studied demonstrated successful removal of the stenotic plaque and excellent basilar filling. The vertebral artery was occluded at the endarterectomy site in the third patient.

Overall, 69% (36/52) of patients were asymptomatic or improved after surgery. The percentage of improved or asymptomatic patients by procedure was PICA, 80%; AICA, 75%; SCA, 71%; and vertebral endarterectomy, 25%.

Excellent correlation was seen between clinical outcome and the presence of arterial narrowing at a bypass anastomosis. This complication was seen in only three (9%) of 33 adequately angiographed, improved patients vs five (36%) of 14 unimproved patients with a patent bypass/endarterectomy. Bypass or endarterectomy occlusion was present in

TABLE 2: Postoperative Angiographic Results in OA–AICA, OA–PICA, and Upper Brainstem Bypass

Finding	OA–AICA (*n* = 12)	OA–PICA (*n* = 5)	Upper Brainstem (*n* = 31)
Bypass patent (%)	100	80	94
Antegrade filling of recipient vessel (%)	100	80	94
Retrograde filling of recipient vessel (%)	100	80	68
Basilar artery filling (%)	82	60	52
Donor hypertrophy (%)	64	75	57
Arterial narrowing at anastomotic site (%)	9	50	17
No. of basilar branches filling	3.6	2.6	2.2

Note.—OA = occipital artery; AICA = anterior inferior cerebellar artery; PICA = posteior inferior cerebellar artery.

only two (6%) of 35 improved patients vs two (13%) of 16 unimproved patients.

Overall mortality was four (8%) of 52. All four of these patients were in the SCA group. The bypass was occluded in one and in spasm in two of these four.

A major perioperative complication (infarct) was encountered in seven patients. Four of these seven eventually died. Relatively minor perioperative complications that were all successfully treated without apparent long-term sequelae were present in 15 patients (meningitis/CSF leak, seven; seizure, four; subdural hematoma, two; and cerebral or cerebellar edema, two). Postoperative seizures were all well controlled medically. No perioperative morbidity was encountered in 30 of 52 patients.

All patients were on antiplatelet agents postoperatively. All asymptomatic and improved patients were taken off anticoagulants.

Discussion

In 1946, Kubic and Adams [8] published the first widely accepted description of the clinical syndrome of vertebrobasilar insufficiency. This clinical syndrome was further defined by Millikan et al. [9] in 1955 and by Cartlidge et al. [4] in 1977.

Proposed etiologies for the symptoms of vertebrobasilar insufficiency fall into three categories: (1) thromboembolic, (2) hemodynamic, and (3) local perforating vessel disease [10–12]. Medical therapy for vertebrobasilar insufficiency is based on the premise that symptoms are primarily thromboembolic in nature. The first specific form of therapy for treatment of symptoms was systemic anticoagulation recommended by Millikan et al. [9] in 1955. Both a decreased mortality and decreased incidence of stroke have been reported with this form of therapy [13]. However, these study groups lacked angiographic correlation of suspected vascular disease. Also, other possible causes of symptoms suggestive of vertebrobasilar insufficiency were not rigorously excluded in these patients. Anticoagulant and antiplatelet therapy have not proved to be of value in any clinical study that contains randomized patients or patients who have undergone angiography [10]. In fact, no therapeutic technique, medical or surgical, has been proved to be unequivocably beneficial in the treatment of vertebrobasilar insufficiency [10]. Recently published results from the extracranial-intracranial bypass study group find no reduction in stroke rate after STA–middle cerebral artery (MCA) bypass for patients with symptomatic atherosclerotic disease of the internal carotid or middle cerebral artery [14]. Patients with vertebrobasilar insufficiency were not included in this study, which does not purport to evaluate the efficacy of posterior fossa bypass. The clinical results in these 52 patients may justify undertaking a randomized trial comparing surgical with medical therapy for vertebrobasilar insufficiency. Sixty-nine percent of these patients were either less symptomatic or asymptomatic after surgery. Most important, these surgical results were achieved in a patient population that had already failed on medical therapy.

Several investigators have noted a qualitative difference between TIAs in the anterior and posterior circulation: TIAs are more likely to be of hemodynamic origin in the posterior circulation and of thromboembolic origin in the anterior circulation [11, 12, 15]. Surgical therapy for vertebrobasilar insufficiency is based on the premise that symptoms are usually of hemodynamic origin [15]. If the flow deficit distal to a stenotic lesion is corrected, then symptoms will be also. Hemodynamic changes are caused by a deficiency of blood flow distal to a stenotic lesion or lesions that may be located at any level(s) in the vertebrobasilar system. Ischemia induced by dysautoregulation distal to a stenotic lesion is also thought to play a key role in patients whose symptomatology is highly sensitive to postural changes [11]. Surgical correction of stenoses is also directed at prevention of permanent deficit resulting from stroke. Thirty-five percent of patients with vertebrobasilar TIAs will progress to stroke if untreated [4]. This percentage was derived from a nonangiographed population with vertebrobasilar insufficiency defined by clinical symptoms only, and may be higher if patients without angiographically proven lesions are excluded. Thompson et al. [16] found a 44% mortality within 3 months in 22 patients with angiographically proven basilar occlusion. TIAs preceded brainstem infarcts in 50% of these patients.

A variety of surgical approaches to stenotic lesions of the extracranial vertebral artery has been described. These include bypass with both arterial and vein graft donor vessels, vertebral transposition, endarterectomy, a variety of angioplastic procedures, and decompressive procedures [6].

The surgical options for correction of intracranial vertebral and basilar lesions are much more limited, however. Extracranial to intracranial bypass procedures or intracranial vertebral endarterectomy are the only surgical treatments available for lesions of the intracranial vertebrobasilar system [10, 17, 18]. Balloon angioplasty of basilar stenoses has been reported, but results have been unsatisfactory [19].

Until 1975, systemic anticoagulation was the only treatment available to patients with vertebrobasilar insufficiency caused by lesions of the posterior intracranial circulation. In 1975, Ausman et al. [1] reported the first case of posterior fossa revascularization. In this patient with bilateral distal vertebral artery occlusion an OA–PICA bypass was performed. The principle in posterior fossa revascularization is to bypass distal to a stenotic or occlusive lesion [20–22]. To this end, the STA–SCA bypass was introduced in 1979 for lesions proximal to the SCA origin [2].The OA–AICA was introduced in 1981 for lesions proximal to the AICA origin [3].

The best site for anastomosis is that segment of the recipient vessel that has the largest diameter and fewest brainstem branches. Anatomic studies show this site to be the perimesencephalic segment of the SCA, the segment of the AICA just beyond the seventh and eighth nerves in the cerebellopontine angle cistern, and the caudal loop of the PICA [22]. Recipient vessel diameters in these locations vary from 1.0 to 1.8 mm [22].

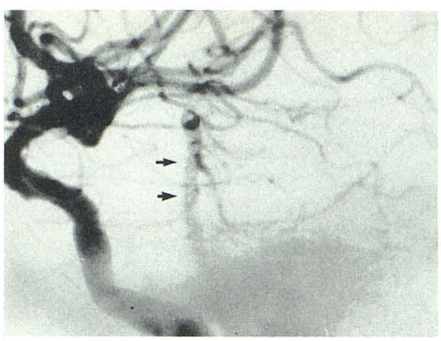
All 31 upper brainstem revascularization procedures were performed via a right temporal craniotomy to avoid the left temporal speech area. Use of the PCA as the recipient vessel is avoided whenever possible at this institution because of the potential danger of visual loss in the event of recipient vessel occlusion [12, 21]. Should the SCA become occluded distal to its brainstem branches, the potential for production of a serious deficit is minimized by a rich collateral network over the cerebellar hemisphere [12]. Two patients in this series underwent an STA–PCA rather than an STA–SCA bypass. In these cases the latter procedure was planned preoperatively. However, upon surgical exposure, the right SCA was found to be too small or the perimesencephalic loop too low-lying for a technically successful anastomosis. The PCA was then chosen as the alternative recipient vessel.

Before the late 1970s, detailed angiography of the posterior fossa was avoided because of fear of complications and the knowledge that the angiographic findings would probably not change treatment, as medical therapy was the only option available. However, with the relatively recent availability of these surgical procedures and with technical advances in cerebral angiography that can detail posterior fossa, angiography in patients with vertebrobasilar insufficiency is now justified [2, 10, 23].

Caplan and Rosenbaum [23] studied a group of patients with vertebrobasilar insufficiency who had angiographic and autopsy correlation and found that the clinical presentation did not allow accurate determination of the site or the nature of vascular disease. Lesions producing symptoms of vertebrobasilar insufficiency may be located at any level from the extracranial vertebral arteries to the median and paramedian basilar artery branches [23]. A patient with symptoms on a vascular basis may have gross large-vessel occlusive disease, or may have an entirely normal angiogram. In the latter case, symptoms are presumably caused by plaque formation at the origin of, or arteriolar hyalinization of, one or more small basilar perforating arteries [23]. Furthermore, cerebral angiography is the only reliable method by which the nature and location of the vascular disease causing symptoms can be accurately determined [10, 23].

Results of the preoperative studies in this group of patients demonstrate the important role angiography plays in identifying that subgroup of patients with vertebrobasilar insufficiency who are surgical candidates. Furthermore, the final decision as to which surgical procedure will be used is primarily dictated by the angiographic findings. It is incumbent on the neuroradiologist performing the preoperative angiogram to demonstrate all areas of stenosis in the vertebrobasilar system and the relationship of the lesions to potential recipient vessels. Lesions of the anterior circulation and the interdependence of anterior and posterior circulation must be demonstrated. Also, suitable donor vessels must be identified and characterized as to size, length, and mobility.

Preoperative angiograms in 40% of patients who underwent OA–AICA bypass demonstrated high-grade stenosis of the basilar artery proximal to the AICA origin. The other 60% had more proximal disease generally involving the PICA to basilar segments. These findings narrow the surgical options to one choice: the OA–AICA bypass (Fig. 2). This distribution of atherosclerotic lesions is fairly common, resulting in the greater frequency of OA–AICA procedures than OA–PICA bypass or vertebral endarterectomy, for lower brainstem vascular disease.



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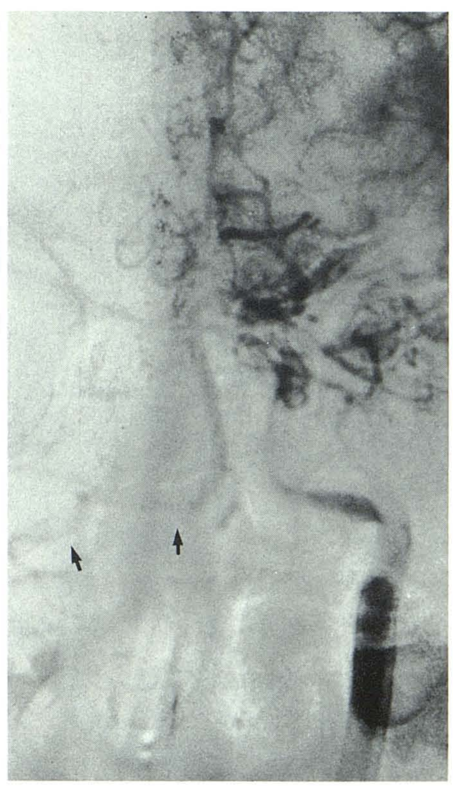

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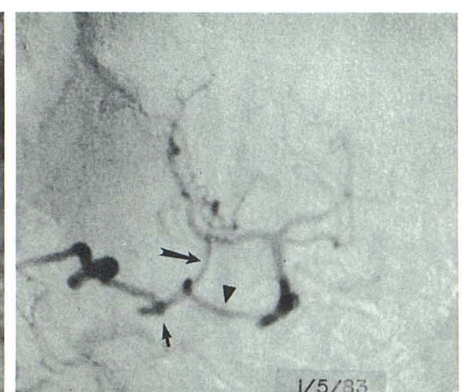

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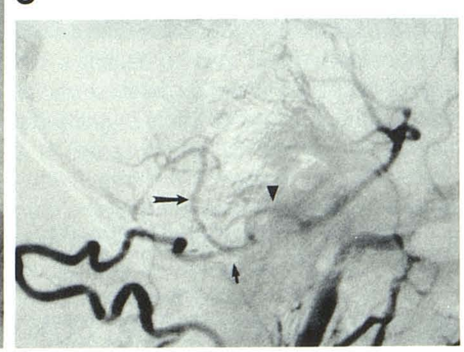


D

Fig. 2.—OA–AICA bypass for bilateral distal vertebral occlusion.

***A*, Lateral right carotid injection. Preoperative angiogram shows basilar filling (*arrows*) via patent right posterior communicating artery.**

***B*, Anteroposterior late arterial phase of same run shows large right AICA (*arrows*). En face projection "elongates" basilar artery.**

***C* and *D*, Anteroposterior (*C*) and lateral (*D*) right external carotid injection. Postoperative angiogram shows patent end-to-side anastomosis between OA and AICA (*small arrows*) just beyond porus acusticus. Antegrade (*large arrows*) and retrograde (*arrowheads*) recipient vessel and basilar filling are seen.**

Patients who were candidates for both vertebral endarterectomy and OA–PICA bypass had one vertebral artery occluded or ending in PICA and the other stenotic at the C1 to PICA segment. If the lesion is of short length and unifocal at angiography the patient is an endarterectomy candidate (Fig. 3). A long lesion or more than one lesion makes the patient an OA–PICA candidate (Fig. 4). Because of a larger-caliber conduit and greater potential flow, endarterectomy is theoretically preferable to OA–PICA bypass when technically possible.

Stenotic lesions of the mid basilar artery were present in almost one-half of the upper-brainstem revascularization patients (14 of 29) (Fig. 5). The SCA is the only viable recipient vessel available for purposes of bypassing lesions in this location. Most of these patients also had additional more proximal lesions.

Nearly one-half (15 of 29) of the upper-brainstem revascularization patients, however, did not have middle basilar stenosis. Instead, multiple, highly stenotic or occlusive lesions of the proximal basilar or vertebral artery (or a vertebral artery ending in PICA) were found. This prevented adequate preoperative visualization of the entire vertebral basilar system, particularly potential AICA or PICA recipient vessels. Because of proximal obstructing lesions in this group, only the basilar tip was imaged preoperatively (via posterior communicating collateral flow). Therefore, the only potential recipient vessel that could definitely be identified preoperatively was the SCA (Fig. 6).

This illustrates one of the major limitations of preoperative angiography in patients with vertebrobasilar insufficiency. In order to direct the surgical approach logically, the entire vertebrobasilar system and the relationship between all lesions and potential recipient vessels should be imaged. Patients who will benefit the most from surgery are generally those with the most severe stenotic/occlusive disease. However, it is precisely this group in whom visualization of the entire vertebrobasilar circulation is most difficult, and the status of the vessels beyond a lesion or lesions may remain unknown. In cases of extracranial vertebral occlusion, delayed filming can be invaluable in imaging reconstituted circulation distal to the site of occlusion. In cases of intracranial vertebrobasilar occlusion, the only information about the status of the basilar artery may come from collateral posterior communicating flow, hence the importance of thorough evaluation of the anterior circulation in these patients.

All arteriographic studies of posterior fossa circulation in this series of patients were performed with magnification and subtraction film technique. The role of intraarterial digital subtraction angiography (DSA) in the evaluation of patients with severe obstructive/occlusive disease of the vertebrobasilar circulation has not been investigated thoroughly as yet. It is possible that intraarterial DSA might give information regarding potential recipient vessels located distal to severe obstructive or occlusive lesions that is not available with conventional film technique. However, our preliminary experience with intraarterial DSA would indicate that this technique may not adequately resolve stenoses of the small potential recipient vessels in the posterior circulation. This possible

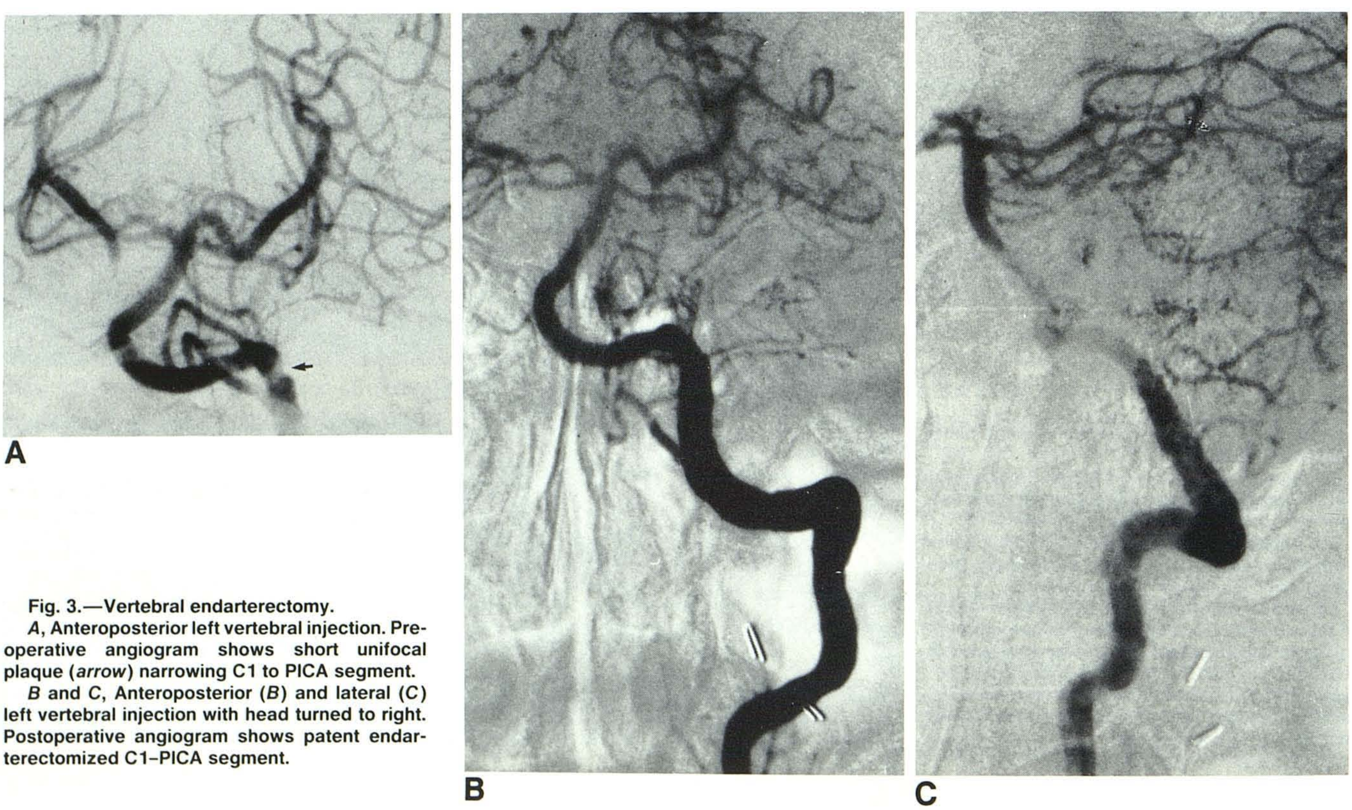
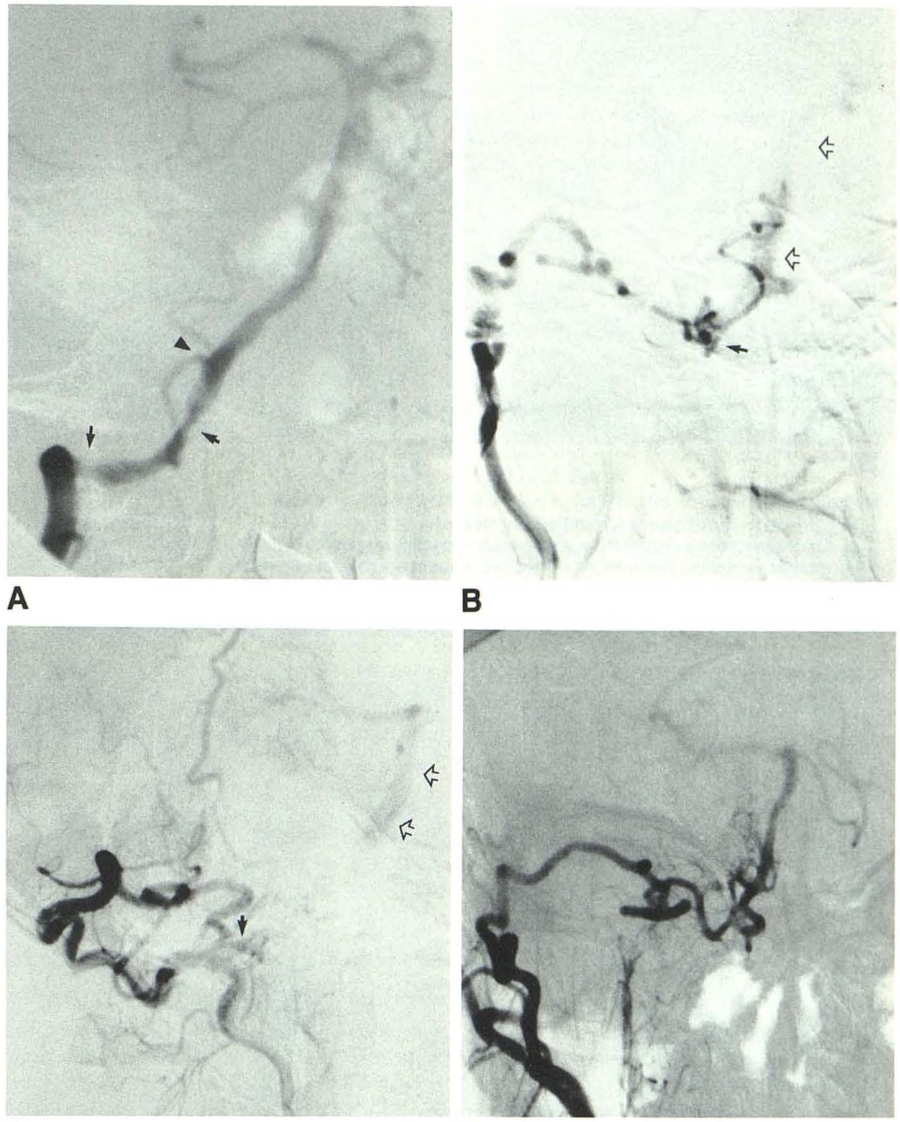


Fig. 3.—Vertebral endarterectomy.

_A_, Anteroposterior left vertebral injection. Preoperative angiogram shows short unifocal plaque (_arrow_) narrowing C1 to PICA segment.

_B_ and _C_, Anteroposterior (_B_) and lateral (_C_) left vertebral injection with head turned to right. Postoperative angiogram shows patent endarterectomized C1–PICA segment.



A B C D

Fig. 4.—OA-PICA bypass.

A, Anteroposterior right vertebral injection with head turned to left. Preoperative angiogram shows two areas of discrete narrowing (*arrows*) proximal to PICA origin (*arrowhead*).

B and *C*, Anteroposterior (*B*) and lateral (*C*) selective right occipital artery injection. Postoperative study shows patent OA-PICA anastomosis (*solid arrows*). Faint but definite filling of basilar artery (*open arrows*) is typical of early postoperative OA-PICA bypass angiogram.

D, Anteroposterior right external carotid injection in different patient. Postoperative OA-PICA study shows more intense basilar opacification (seen in only one OA-PICA patient).

limitation must be either disproved or overcome before intra-arterial DSA alone is considered an acceptable radiologic approach in posterior fossa revascularization.

Twenty-two of the total 52 patients had one vertebral artery ending in PICA. The high incidence of this "normal variant" in a group with symptoms of vertebrobasilar insufficiency suggests that this is not an entirely benign anomaly. Vertebral artery ending in PICA imposes a significant liability on patients who develop atherosclerotic disease in the vertebrobasilar system.

Good correlation is seen between an unsatisfactory surgical result at postoperative angiography and an unsatisfactory clinical outcome. The bypass/endarterectomy was occluded or in spasm in seven (44%) of 16 unimproved patients vs only five (14%) of 35 improved patients. The degree of arterial narrowing at the anastomotic site in the three improved patients with spasm presumably allowed sufficient bypass flow to improve symptoms. It is difficult to rationalize how two patients improved with an occluded bypass.

Bypass/endarterectomy patency was documented in 33 of 35 improved patients. However, basilar filling via the bypass was demonstrated in only 21 of this group. The discrepancy between filling of the target vasculature and clinical outcome was addressed by Anderson et al. [24], who found the entire sylvian group filled in only seven of 11 postoperatively asymptomatic STA-MCA bypass patients. They concluded that "these patients had a lesser or only intermittent need for additional flow. The new collateral channel may have supplied this need by establishing a continuous and unobstructed source of blood . . ." Seven of the 16 unimproved patients suffered a perioperative stroke. The bypass was in spasm in one of the other nine unimproved patients. In eight of these nine unimproved patients (without perioperative stroke) a well-functioning bypass did not produce clinical improvement. Bypass flow may have not met demand in these patients, or TIAs in this small percentage of patients may have resulted from embolic episodes. Alternatively, some or all of these patients may have been symptomatic from obstruction of one

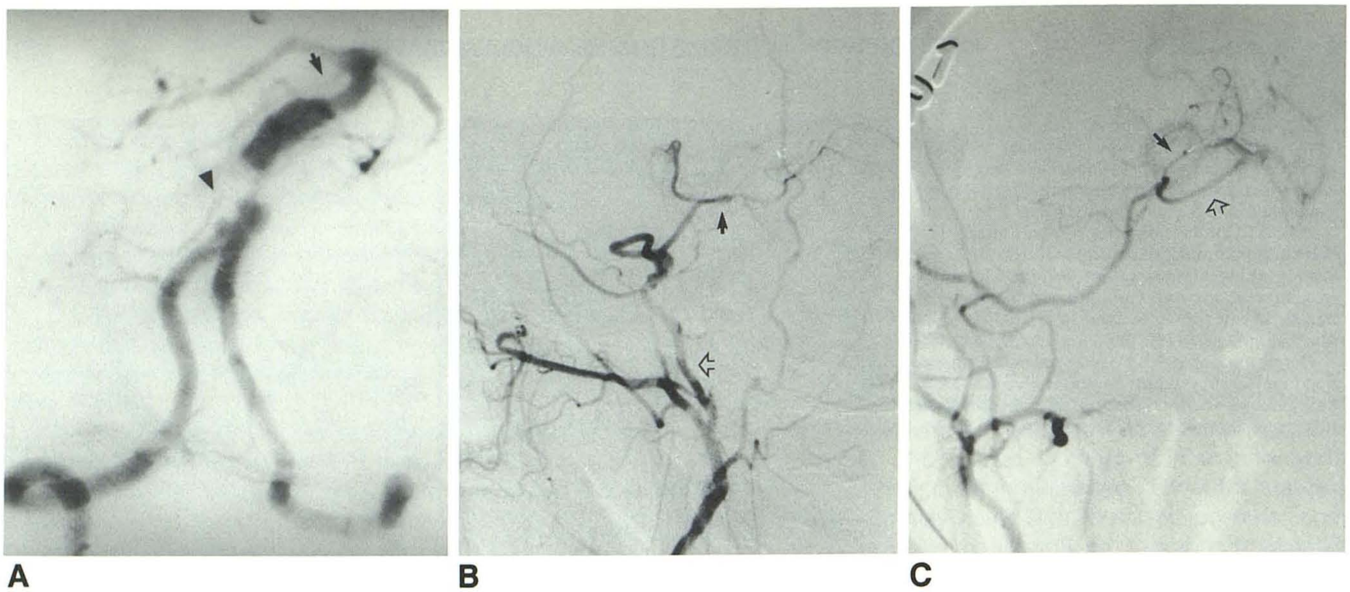


Fig. 5.—STA-SCA bypass for midbasilar stenosis.

A, Anteroposterior preoperative vertebral angiogram shows circumferential midbasilar lesion. Right AICA is filled but is unacceptable as potential recipient vessel as its origin is proximal to bulk of plaque (*arrowhead*). SCA is only acceptable recipient vessel seen (*arrow*).

B, Lateral right external carotid injection. Postoperative angiogram shows anastomosis of STA to SCA (*solid arrow*). STA is of large caliber (*open arrow*) after bypass.

C, Anteroposterior right external carotid injection. Postoperative angiogram shows antegrade (*solid arrow*) and retrograde (*open arrow*) filling of recipient vessel. Filling of four basilar branches (both PCAs and SCAs) via bypass is seen.

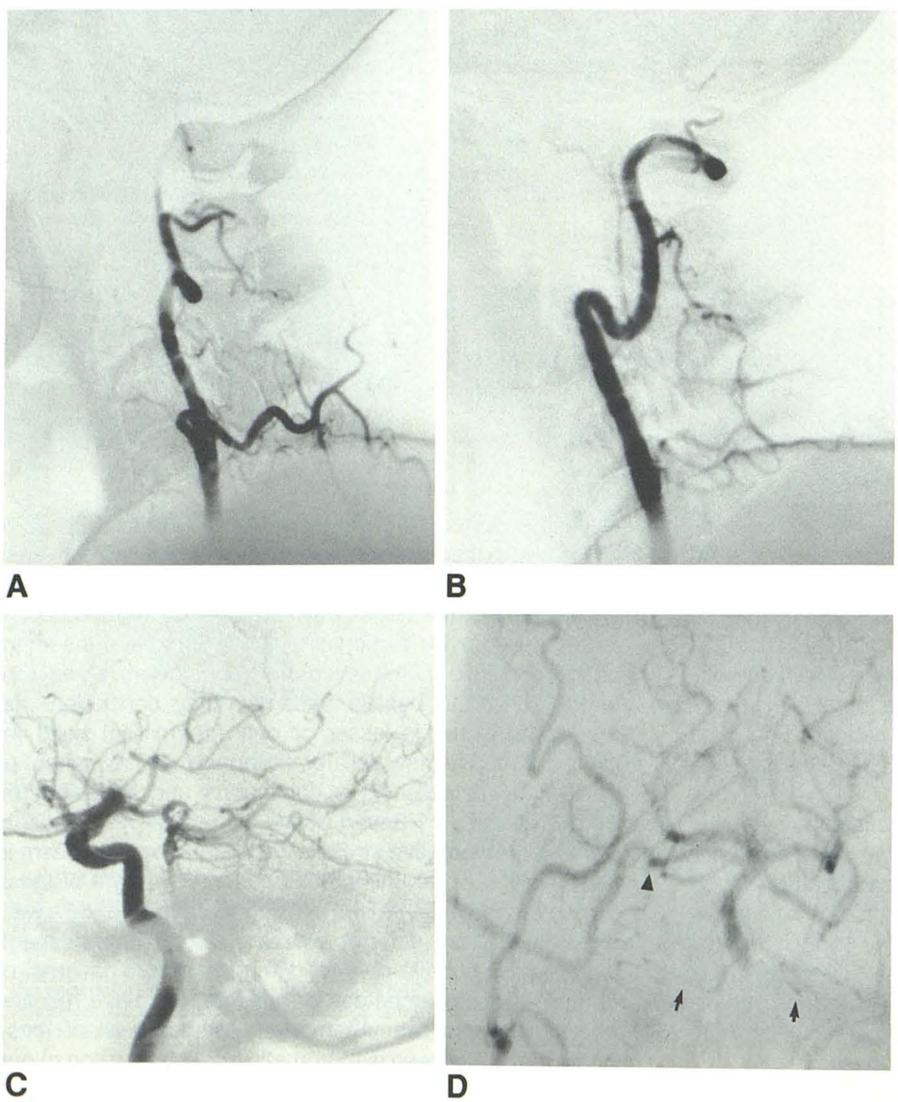


Fig. 6.—STA-SCA bypass for bilateral distal vertebral artery occlusion.

A and *B*, Right (*A*) and left (*B*) vertebral artery occlusion in C1 to basilar segment at preoperative angiography.

C, Lateral carotid injection. Preoperative angiogram shows filling of upper basilar artery via posterior communicating artery. SCA is only viable recipient vessel seen preoperatively.

D, Anteroposterior right external carotid injection. Postoperative angiogram shows filling of six basilar branches via STA-SCA anastomosis (*arrowhead*). AICA bypass (*arrows*) would have been possible had it been possible to see one of these vessels preoperatively.

or more small brainstem perforating branches. In such a patient an increase in gross basilar flow via a bypass would not eradicate symptoms caused by local disease. The findings at preoperative cerebral angiography, therefore, may not be an entirely accurate indicator of the demand for posterior fossa blood flow augmentation in patients with vertebrobasilar insufficiency. For this reason, a preoperative diagnostic method that accurately measures cerebral perfusion may be needed in addition to conventional angiography to aid in the appropriate selection of candidates for these procedures. Attempts to measure regional blood flow noninvasively have been reported using both ^{133}Xe inhalation with external collimation and stable xenon-enhanced CT scanning [25–27]. To date, the value of these techniques as preoperative screening tests in potential posterior fossa bypass candidates is unclear. Positron emission tomography (PET) has been shown to demonstrate regional changes in cerebral metabolism after STA–MCA bypass [28]. However, a group of metabolic findings on PET scanning that reliably predicts a patient's response to bypass surgery has not been identified [24].

It should be emphasized that this study represents only short-term angiographic follow-up of these patients. Preliminary results indicate that intracranial filling and donor hypertrophy may increase with time in posterior fossa revascularization, as is the case with supratentorial bypass procedures [7, 29].

In summary, no therapeutic method, medical or surgical, has yet been proved to be unequivocably beneficial in treatment of vertebrobasilar insufficiency. Newly developed surgical approaches to the vertebrobasilar circulation show promise as alternatives to medical treatment. In this series of patients a favorable postoperative angiographic result generally correlates well with a favorable postoperative clinical result and vice versa. To our knowledge this is the first report in the radiologic literature on the subject of angiography in posterior fossa revascularization. Radiologists play a vital role in the preoperative evaluation of patients with vertebrobasilar insufficiency. The type of surgical procedure for which the patient is best suited is determined by angiography. Postoperative angiography provides a safe and reliable method of evaluating anatomically the performance of the procedure.

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