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Digital Subtraction Angiography of the Intracranial Vascular System: Comparative Study in 55 Patients

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Intracranial vessels were examined in 55 patients with both conventional selective catheterization and intravenous digital subtraction angiography using a prototype digital subtraction unit. In 65% of the patients, the digital subtraction angiogram was diagnostic, but the overall quality was inferior to conventional selective angiography. In 22%, the digital subtraction angiogram provided diagnostic information, but there was a significant chance of misinterpreting the results of the study. In 13% of cases, the subtraction angiogram was not diagnostic. As now developed, digital subtraction angiography can replace conventional cerebral angiography for preoperative evaluation of the juxtaseptal carotid artery prior to transphenoidal surgery because the large intracerebral vessels are consistently well visualized with digital subtraction. The dural sinuses are better visualized with digital subtraction than with conventional angiography because with digital subtraction all the vessels of the brain are opacified, whereas with conventional angiography, there is a mixture of opacified and unopacified blood in the sinuses. Combined with computed tomography, digital subtraction angiography can replace conventional angiography for determining the preoperative extent and vascularity of tumors. It can be used for postoperative evaluation of aneurysms, arteriovenous malformations, extracranial to intracranial bypasses, and after the embolization of vascular lesions.

Intravenous angiography using a digital subtraction system is one of the more important radiologic diagnostic advances since computed tomography (CT). Its clinical usefulness, particularly for evaluating the extracranial carotid vascular system, has been reported [1-8]. We tried to ascertain the accuracy and usefulness of digital subtraction angiography in evaluating the intracranial vascular system using conventional angiography for comparison.

Subjects and Methods

In 55 patients with suspected intracranial disease who had abnormal selective carotid or vertebral angiograms, digital subtraction angiography (DSA) was used to visualize the intracranial circulation. The DSA results were tabulated as: (0) unsuccessful or uninterpretable; (1) nondiagnostic, vessels seen; (2) diagnostic, significant chance for error; or (3) diagnostic, information comparable to conventional angiography.

The DSA examinations were performed with a commercial prototype unit (Technicare Corp., Solon, Ohio) using a 1,300 mA x-ray generator and a water-cooled x-ray tube having a nominal focal spot selection of 0.6/1.2 mm and a heat capacity of 1.8 million heat units. X-rays were detected using a 22.9, 15.2, or 11.4 cm cesium iodide image intensifying tube. An 8:1 grid with 40 line pairs/cm was used. The output phosphor of the image tube was scanned with a 3 video camera with a lead oxide tube. The video signal from the camera was logarithmically amplified and digitized for storage in the image processor, which has 256 × 256 × 8 bit memories. A PDP 11/34 computer was used for image processing. The image was viewed on a television monitor, which was photographed as 8.5 × 8.5 cm images with a multifram camera.

DSA was performed within 1 week of conventional angiography. The radiographic

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technique for individual exposures was 1,000 mA/80 kV with the exposure time optimized for each patient. With the 11.4 cm image intensifier mode the exposure time was 30–50 msec.

A 16 gauge, 20.3-cm-long intracatheter was inserted in a peripheral arm vein and attached to a pressure injector. A small test injection (about 2 ml) was made with fluoroscopic observation to assess the adequacy of the vein and its course distal to the catheter tip. Veins the size of the 16 gauge catheter were injected without complications if they had a straight course into the subclavian vein. If the vein was small and had a tortuous course, then the catheter was repositioned under fluoroscopic control into a larger vein or another intracatheter was placed in a different arm vein. A 25 ml solution of 5% dextrose was layered over 45–54 ml of contrast material in the injector reservoir and injected at rates of 15–20 ml/sec depending on the vein size and course.

In most cases, anteroposterior and lateral views of the head were obtained. For posterior fossa lesions a Towne view was used. For juxtasellar or pituitary lesions, a base view was made if the patient's neck could be sufficiently extended. Oblique projections were used to study aneurysms and extracranial to intracranial anastomoses. A 25° off-lateral oblique view was used for evaluation of both carotid siphons. A 1,000 ml bag of saline solution was strapped to the head when needed to achieve a more uniform density of the part of the head being examined. An 11.4 cm image intensifying mode was used in most examinations to maximize the spatial resolution. When it was necessary to examine a large area of the brain, such as to visualize the dural sinuses, a 15.2 cm mode was used.

Exposures began at 10 sec after the beginning of the injection and 20 exposures were collected at a rate of one frame/sec. Additional exposures were obtained if the cerebral circulation was slowed or if late venous images were needed. The radiation dose to the skin of the head was 300 mR (77.4×10^{-6} C/kg) for each exposure. The real time digital images demonstrated the arrival of the contrast material in the area of interest. Any of the precontrast images could be used as a mask to optimize subsequent subtracted images. A usual study included three separate injections. The maximum number of injections in one patient was five.

Results

In 36 (65%) of the 55 patients, DSA was as accurate as conventional angiography for diagnosis of the abnormality. In 12 (22%) patients, DSA was diagnostic, but there was a significant chance of diagnostic error because of poor visualization of the abnormality. In six (11%) patients, DSA was not diagnostic although major vessels were visualized. In one patient, DSA could not be interpreted because motion during each injection caused misregistration subtraction artifacts between the mask image and the contrast-containing image. The results are summarized in table 1.

Tumors

Of the 55 patients, 10 had meningiomas, all of which were demonstrated with conventional angiography. In seven of the patients, DSA was as diagnostic as conventional angiography (fig. 1). In four of the seven patients, where the tumor involved the sphenoid wing and middle fossa, the size and extent of the tumor blush was visualized better with DSA than with conventional angiography.

In two patients with parasagittal meningiomas, a faint tumor blush could be identified with DSA. The enlarged

middle meningeal branches that were well seen with selective external carotid angiography were not visualized with DSA. In one of these two, partial obstruction of the dural sinus was seen better with DSA than with conventional angiography. One patient had parasagittal and convexity meningiomas faintly demonstrated with common carotid angiography, but no abnormalities were demonstrated with DSA.

Six other patients with tumors were studied. One had a large glomus jugulare tumor that was defined equally well with DSA and conventional angiography. The other five patients had tumors that were relatively avascular. In two of these, vessel displacement was demonstrated by DSA. One patient had an astrocytoma of the temporal lobe, and there was displacement of the middle cerebral artery branches on DSA, giving information comparable to conventional angiography. The other patient had a chordoma and DSA demonstrated basilar artery displacement by an avascular mass and unaffected carotids (fig. 2). In one patient with a parietal lobe glioblastoma, both DSA and conventional angiography demonstrated inferior displacement of the pericallosal artery and subfalcial herniation.

In one patient in whom a biopsy was not done of a brain stem mass lesion, DSA was diagnostic by demonstrating lateral displacement of the posterior cerebral artery, but there was a significant chance for diagnostic error. The conventional angiogram demonstrated stretching of the thalamoperforating arteries and a capillary tumor blush that could not be identified with DSA. DSA was normal in one patient with a metastatic parietal lobe lesion, while the conventional angiogram in this patient showed "draping" of cortical vessels around the lesion.

Arteriovenous Malformations

Ten patients with arteriovenous malformations were studied. In seven of these, DSA was as diagnostic as conventional angiography. The arterial supply and venous drainage of the malformation were seen clearly with DSA (fig. 3). The youngest patient was a 9-day-old girl with a vein of Galen aneurysm that was evaluated to assess the effect of surgery. The DSA clearly showed persistent filling of the aneurysm via the posterior cerebral arteries (fig. 4). In one case, there was a significant chance of diagnostic error in the interpretation of the DSA of a 1×1 cm occipital lobe arteriovenous malformation, which was well seen with conventional angiography and poorly seen with DSA. One patient had a small dural malformation that was not visualized with DSA. One patient had an uninterpretable DSA examination because of motion.

Aneurysms

Ten patients with aneurysms were studied. Four of these patients had large aneurysms of more than 3 cm in diameter. In three patients, DSA was as diagnostic as conventional angiography. One of the aneurysms was partly thrombosed. The neck of the aneurysm was well demonstrated with DSA. In the fourth patient the large intracavernous aneurysm was

TABLE 1: Diagnostic Usefulness of Digital Subtraction Angiography Compared with Conventional Angiography

Type of Abnormality	No. Cases (%)				Total
	Rating				
	0	1	2	3	
Tumor:					
Meningioma	0	1	2	7	10
Other	0	1	1	4	6
Arteriovenous malformation	1	1	1	7	10
Aneurysm	0	1	2	7	10
Anastomosis	0	2	0	6	8
Atherosclerosis:					
Occlusive	0	0	4	1	5
Dolichoectasia	0	0	1	0	1
Fistula	0	0	1	2	3
Sellar mass	0	0	0	2	2
Totals	1 (2)	6 (11)	12 (22)	36 (65)	55 (100)

Note.—Digital subtraction angiograms were rated as: (0) unsuccessful or uninterpretable; (1) nondiagnostic; (2) diagnostic, significant chance for error; or (3) diagnostic.

identified, but there was felt to be significant chance for error because of patient motion. Six of the patients had aneurysms smaller than 2 cm. Four of these aneurysms were as well visualized with DSA as with conventional angiography. The smallest visualized in this group was an 8 × 5 mm aneurysm of the anterior communicating artery. A posterior communicating artery aneurysm 5 mm in diameter was seen with DSA, but there was a chance of misinterpreting this aneurysm as a turning vessel. An 8 mm intracavernous aneurysm was missed in one patient because oblique views were not obtained.

Anastomoses

In the first two patients studied with superficial temporal to middle cerebral anastomoses, the anastomoses demonstrated with conventional angiography were not demonstrated with DSA on anteroposterior or lateral views. The external carotid to internal carotid anastomosis was identified in the next six patients with DSA by using oblique projections and a water-bag was placed beside the head to produce a uniform field density (fig. 5). The external carotid to internal carotid anastomosis has been identified when the superficial temporal artery is as small as 1.5 mm in diameter.

Atherosclerosis

Five patients with large vessel atherosclerotic disease were studied. In one of the five patients, a marked stenosis of the middle cerebral artery was demonstrated by DSA. The severity of the stenosis and the degree of collateral filling were well shown. In one patient, DSA overestimated, and in another, it underestimated the degree of stenosis of the horizontal part of the middle cerebral artery. In one patient, because of overlap, the cavernous part of the internal carotid artery could not be evaluated and the severity of stenosis was underestimated. In one patient with dolichoectasia, the lateral position of the basilar artery was visualized

with DSA on the anteroposterior view; however, there was significant overlap from the internal carotid artery.

Fistulas

Three patients with carotid cavernous sinus fistulas were examined. In one patient, both studies demonstrated continued patency of the internal carotid artery after balloon occlusion of the carotid cavernous fistula. In two other patients, DSA and conventional angiography were performed to evaluate proptosis. In both cases, DSA and conventional angiography showed the presence of a carotid cavernous fistula demonstrating an enlarged superior ophthalmic vein draining retrogradely from the cavernous sinus. DSA could not demonstrate the exact site of communication between the carotid artery and the cavernous sinus as well as conventional angiography.

Sellar Masses

Two of the 55 patients had enhancing mass lesions identified with CT in the region of the sella turcica. In both patients, DSA demonstrated elevation of the horizontal segment of the anterior cerebral arteries with no evidence of an intracranial aneurysm or extension of the parasellar internal carotid arteries into the sella turcica (fig. 6).

Discussion

DSA has several advantages over conventional film screen angiography. Being less invasive and safer, it can be performed on an outpatient basis, avoiding the cost of hospitalization. DSA real time subtraction images are faster and less costly than conventional film screen angiograms. The average cost of film and magnetic tape for a DSA examination at our institution is \$10. The total cost for the conventional angiogram film is \$76–\$114 excluding additional subtraction films.

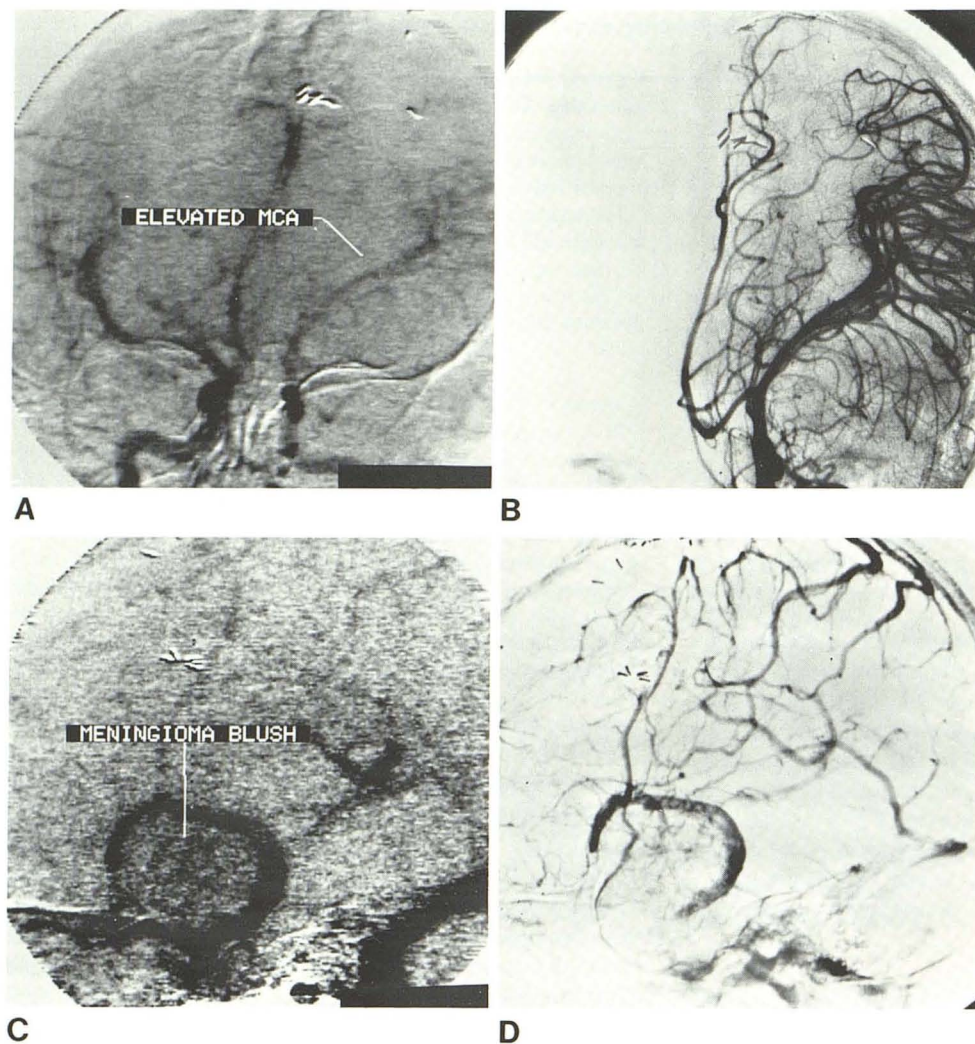


Fig. 1.—Sphenoid ridge and middle fossa meningioma in 12-year-old girl. Anteroposterior DSA (A) and conventional arteriogram (B). Elevation of middle cerebral branches from meningioma. Late lateral phases of DSA (C) and conventional arteriogram (D). Meningioma blush. MCA = middle cerebral artery.

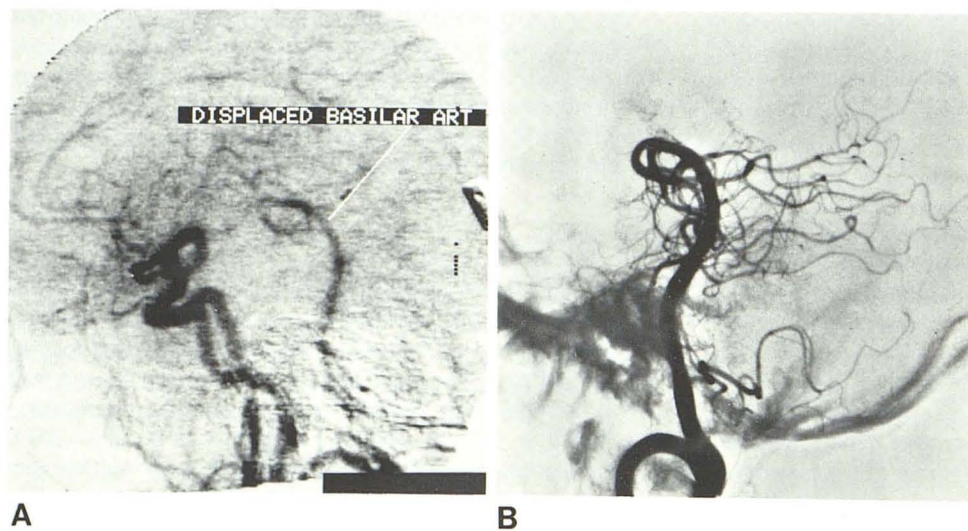


Fig. 2.—Chordoma of clivus in 52-year-old man. Lateral DSA (A) and conventional vertebral arteriogram (B). Avascular mass displaces basilar artery. Carotids on DSA appear unaffected.

Fig. 3.—Right parietal arteriovenous malformation (AVM) in 20-year-old man. Feeding pericallosal branch and early draining vein seen on DSA (A) and conventional arteriogram (B).

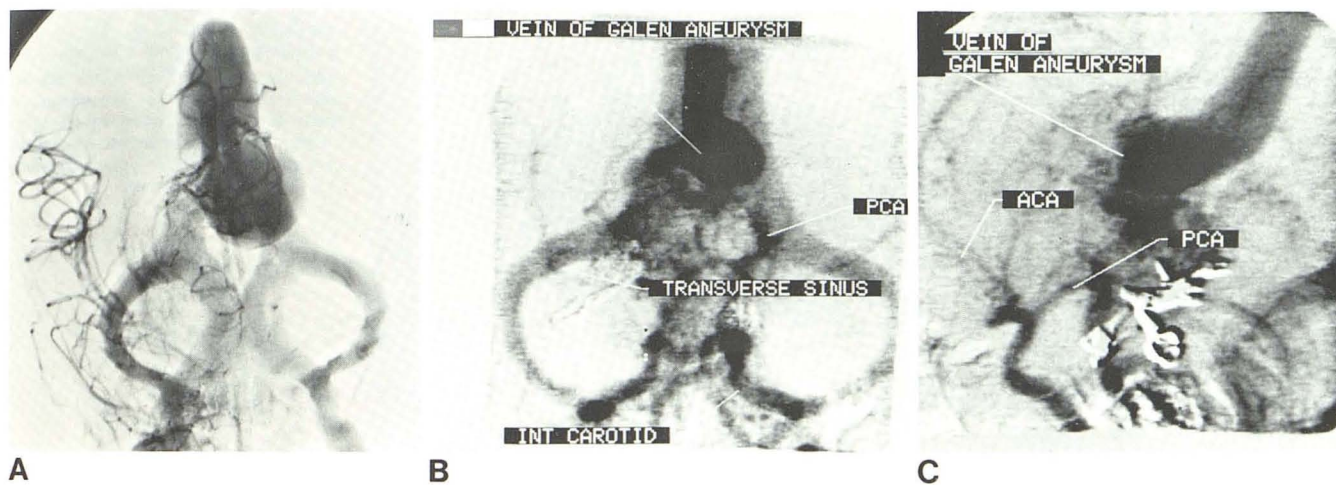
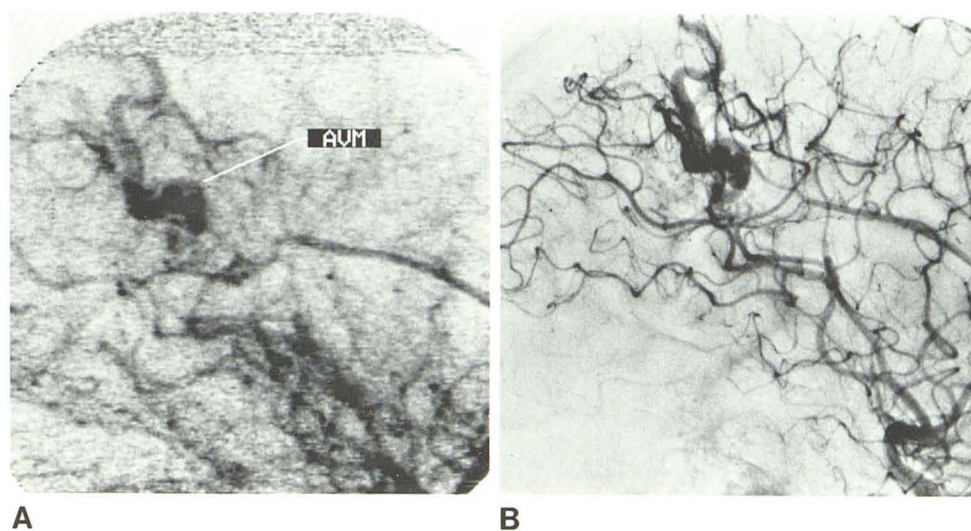


Fig. 4.—Vein of Galen aneurysm causing congestive heart failure in 9-day-old girl. A, Preoperative angiogram. Aneurysm has posterior cerebral artery feeders. B and C, DSA 3 days after surgery to assess results. Surgical clips and continued perfusion of aneurysm.

DSA offers better low contrast sensitivity than conventional film screen angiography because the cesium iodide crystals of the image intensifier absorb a greater percentage of the incident photons than the crystals found in most film screen combinations.

Another reason for better low contrast sensitivity with DSA than with conventional film screen angiography is that conventional film screens are limited by a fixed H and D curve. In the "toe" and "shoulder" regions of the H and D curve the change in the optical density is much less than that produced in the straight line part of the curve. With DSA the change in optical density has a linear relation to the logarithm of the exposure dose. Vessels that overlie bone and air-containing structures are better visualized after DSA subtraction than after conventional film screen subtraction (fig. 6). This is because the contrast changes over these structures are linear with DSA and nonlinear with conventional film screen because of their location in either the "toe" or "shoulder" regions of the H and D curve. The DSA

subtraction images are more accurate because the signal level for iodine will be constant for a given concentration of iodine when the vessel containing it is located over different background densities.

In any subtraction process there will be some degradation of the signal-to-noise ratio, but this is minimal and more than offset by a marked increase in contrast and conspicuity (the degree to which an area of interest stands out from its surroundings). MacIntyre et al. [9] reported that with DSA, object contrast of 0.4% can be visualized. Christenson et al. [5] reported that contrast media concentration as low as 2% within the vessel can be visualized with DSA. Without the use of subtraction, concentrations of contrast material of 40%–50% are required to provide images of equal diagnostic value. DSA can also be post-processed to optimize the image contrast by adjusting the window width and level.

The spatial resolution of our DSA system was not as good as that of standard film screen combinations. The matrix was the limiting factor. With a matrix of 256×256 and

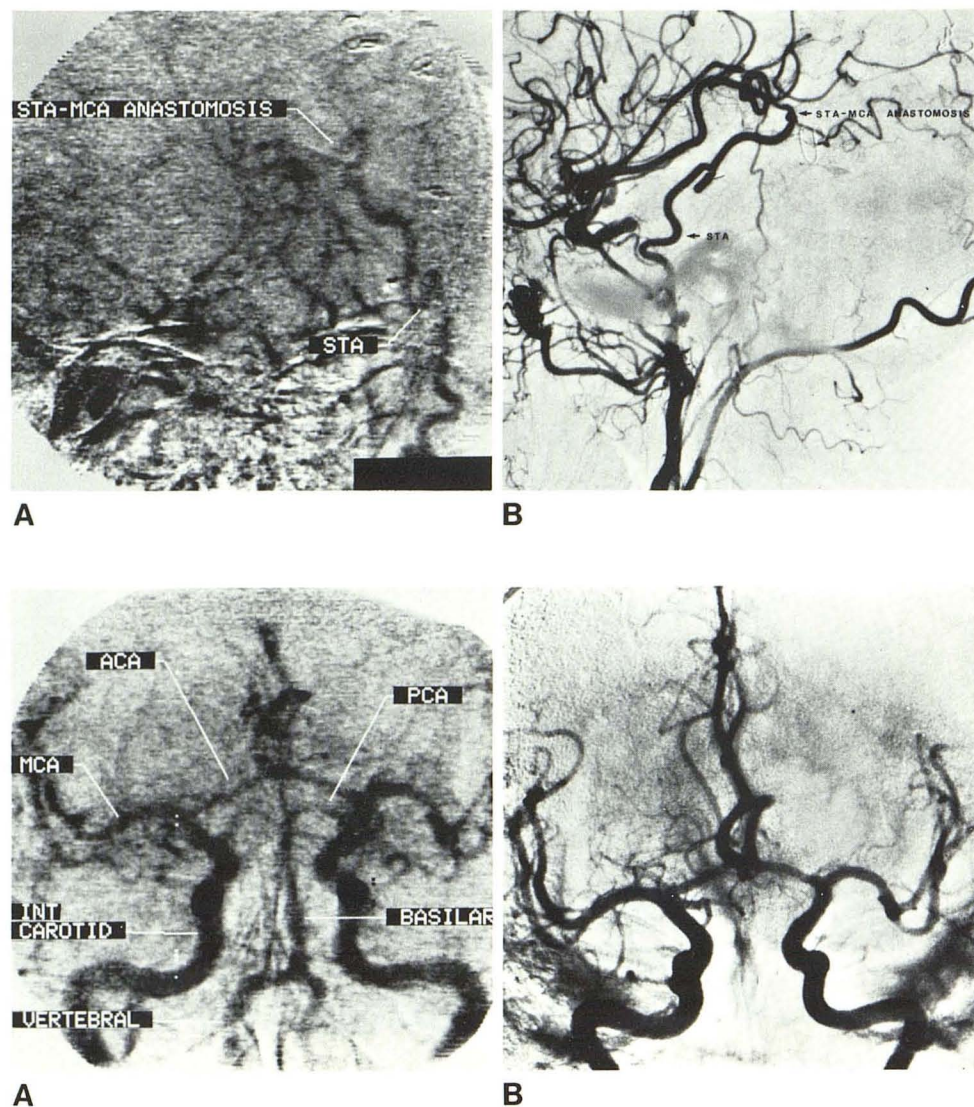


Fig. 5.—Left superficial temporal to middle cerebral artery bypass in 62-year-old man. **A**, 30° left posterior oblique DSA. Anastomotic site of superficial temporal (STA) and middle cerebral (MCA) arteries. **B**, Lateral common carotid injection. Occlusion of internal carotid and good filling of middle cerebral artery from superficial temporal artery bypass.

Fig. 6.—Sellar mass causing bitemporal hemianopsia in 60-year-old man. **A**, DSA. Elevations of A-1 segment of anterior cerebral artery (ACA) and excellent visualization of juxtaseptal carotids. **B**, Composite of conventional angiogram for comparison. MCA = middle cerebral artery, PCA = posterior cerebral artery, INT = internal.

114.3 mm image intensifier field, theoretically 1.1 line pairs/mm can be visualized ($256 \div 114.3 \times 2 = 1.1$). Recently, we began using a digital subtraction system with a matrix of 512×512 . The theoretical limitation of this system is 2.2 line pairs/mm; 1.8 line pairs/mm resolution was measured using an 11.4 cm image intensifier field. Conventional film screen combinations have a spatial resolution of five to six line pairs/mm. In DSA systems, spatial resolution is also limited by the 525 line TV system and by image intensifier blur. The image intensifier blur results from the spread of light within the thickness of the detector crystals.

Although the spatial resolution of conventional film screen angiography is superior to the spatial resolution of DSA, DSA can replace conventional intracranial angiography in many circumstances. DSA is as accurate as conventional angiography for evaluating the large intracranial vessels. In the last 25 patients evaluated at our institution, DSA replaced conventional angiography for assessing the location of the carotid arteries and the possibility of a carotid artery aneurysm prior to transphenoidal surgery.

Combined with CT, DSA can replace conventional angiography for determining the preoperative extent and vascularity of tumors including meningiomas. Meningiomas located over the convexity in the parasagittal region fed primarily by the external carotid artery were not visualized as well with DSA as with conventional angiography with selective external carotid catheterization, but DSA was very useful in assessing the status of the superior sagittal sinus in patients with parasagittal meningiomas. In one patient, partial obstruction of the dural sinus could be appreciated on DSA that was not apparent on conventional angiography. In other locations, the capillary blush of the meningioma was as well visualized with DSA as with conventional angiography.

DSA can replace conventional angiography for evaluating atherosclerotic involvement of the large intracranial vessels and obstruction of the large and medium-size intracranial vessels. Since this comparative study, we have examined three patients with DSA who have had hemifacial spasm due to dolichoectasia of the basilar artery. The dolichoectatic basilar artery was well defined in these three patients by

Fig. 7.—Normal dural venous sinuses, anteroposter (A) and lateral (B), on 22.9 cm field.

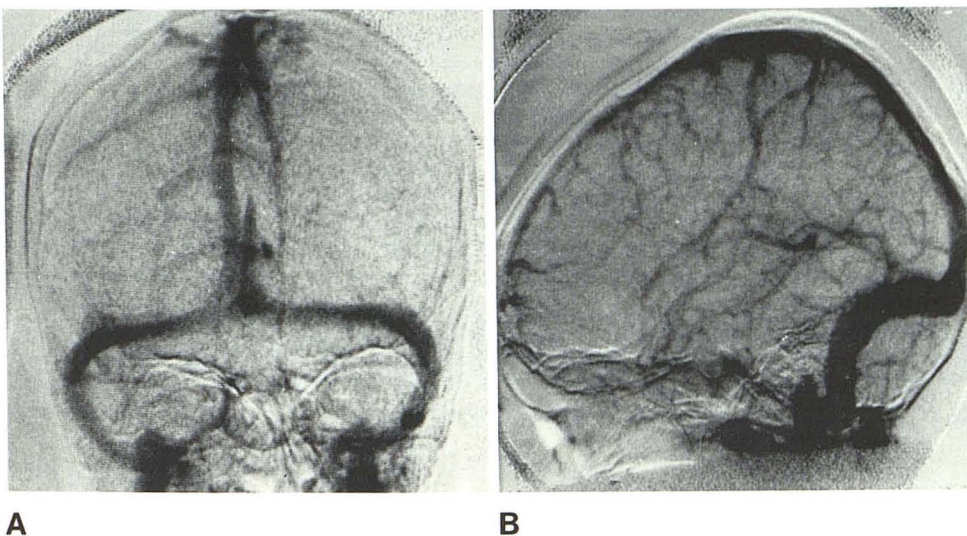


Fig. 8.—A 25° oblique off-lateral view to evaluate juxtaseal carotid for atherosclerotic disease.

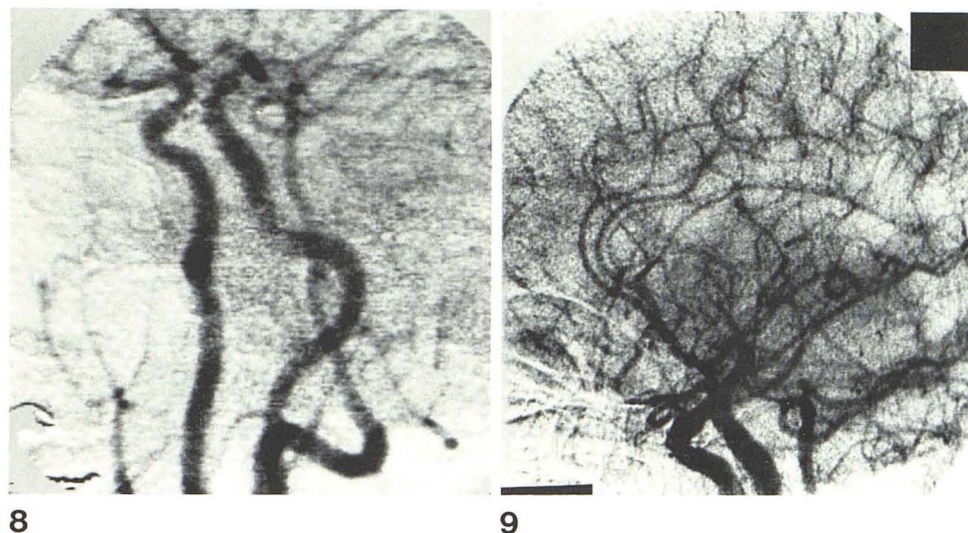
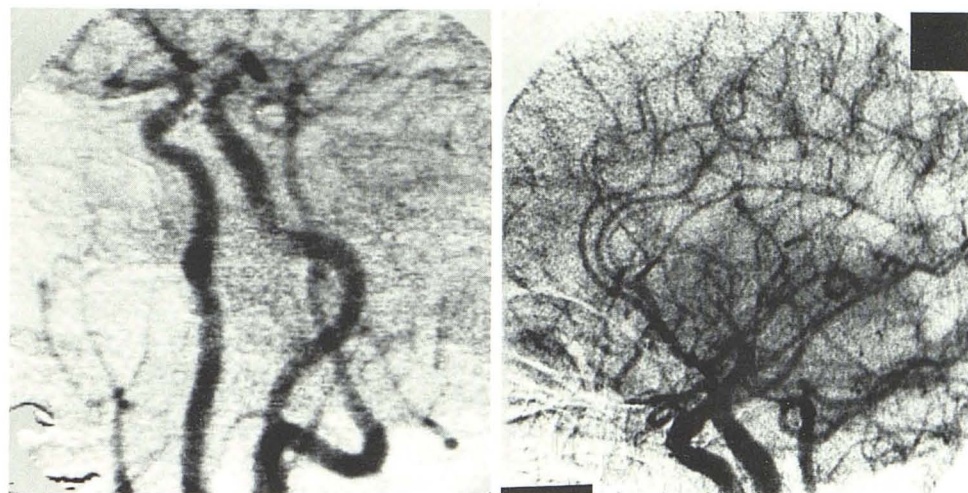


Fig. 9.—Lateral intracranial view of DSA on 526 × 526 matrix using 0.6 mm focal spot.



adding a Water projection to the anteroposterior and lateral projections. We now use DSA to monitor the patency and size of extracranial to intracranial anastomoses.

The dural sinuses can be more accurately evaluated with DSA than with conventional angiography (fig. 7). With conventional angiography the dural sinuses contain a mixture of opacified and nonopacified blood, but with DSA all the dural sinuses of the brain are simultaneously opacified so that impingement and obstruction of the dural sinuses can be more easily diagnosed. The simultaneous opacification of all intracranial vessels also allows for more physiologic evaluation of cross-filling or collateral flow in occlusive disease.

However, simultaneous opacification of many vessels can also be a disadvantage because of overlap. In evaluating patients for atherosclerotic disease of the carotid arteries, in addition to right and left posterior oblique views of the common carotid artery bifurcation, we added a 25° off-lateral oblique view to visualize the juxtaseal carotids (fig. 8).

Likewise, because of vessel overlap and limited spatial resolution, DSA is not adequate to replace conventional angiography for the initial detection of small aneurysms, but it can be used to monitor arterial spasm and to evaluate the results of surgery. Combined with high resolution CT, DSA can be an accurate means of screening for aneurysms as a cause of symptoms in patients with specific cranial nerve palsies.

DSA is not as accurate as conventional angiography in a definitive preoperative evaluation of arteriovenous malformations, but when done preoperatively, often it can be diagnostic and subsequently can be used to evaluate arteriovenous malformation after surgery and/or therapeutic embolization.

The experiences we have described were with an initial prototype system. With further technical refinements, improvements can be expected. We have observed improved spatial resolution in changing from a 256 × 256 to 512 × 512 matrix (fig. 9). Undoubtedly, other improvements will follow.

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