Digital Subtraction Cerebral Angiography by Intraarterial Injection: Comparison with Conventional Angiography

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Digital Subtraction Cerebral Angiography by Intraarterial Injection: Comparison with Conventional Angiography

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For 4 months, a prototype digital subtraction system was used to obtain images of the cerebral vasculature after intraarterial contrast injections. In 12 instances, the intraarterial injections were recorded with both a digital subtraction unit and conventional direct magnification film-screen system. The digital subtraction and conventional film subtraction images were compared and graded for quality and information content by three skilled observers. In addition, quantitative measurements of contrast-detail performance and spatial resolution were obtained on both the digital system and the screen-film imaging chain. In a clinical setting, both the digital subtraction and conventional film-screen systems provided similar quality images and angiographic information. Contrast-detail curves demonstrated that digital subtraction angiography outperformed conventional film technique for low-contrast objects. Digital subtraction angiography also reduced the time required to obtain the angiogram, markedly reduced film cost, and lowered the contrast agent burden.

Digital subtraction imaging of the extra- and intracranial cerebral vasculature after intravenous injections of contrast material is becoming an established screening procedure [1–3]. Patient motion, superimposition of multiple vessels, contrast agent burden, and suboptimal resolution [4] restrict the diagnostic utility of this method. Early work has suggested, however, that digital subtraction imaging of intraarterial contrast injections can provide images of sufficient diagnostic quality to obviate conventional film-screen angiography, thus reducing film cost, and possibly decreasing time required for the examination [5, 6]. For 4 months, we have evaluated intraarterial cerebral digital subtraction angiography (DSA). In selected instances, a comparison of digital and film-screen angiography was made in the same patient. In addition, quantitative measurements of spatial resolution and contrast sensitivity were obtained for both the digital and film-screen systems.

Subjects and Methods

Equipment

The DSA unit (DF 100, Diasonics, Inc.) was a prototype, the essential components of which included a progressively scanned video camera with a 1000:1 signal-to-noise ratio, interfaced with a 9-inch- (22.9 cm) diameter, triple-mode, cesium iodide image intensifier (Fluoricon 300, G.E. Medical Systems). Exposures were pulsed using a 0.6 mm focal spot x-ray tube (Maxi 100, G.E. Medical Systems). Typical exposure factors were 70–85 kVp, 600 mA, 0.013–0.030 sec. Mask mode subtraction images were recorded on a multiformat camera (Matrix Instruments).

Conventional 1.8–2× magnification arteriograms were obtained with Quanta III screens and Cronex 4 film (duPont, Inc.), using a 0.16 mm or 0.2 mm biased focal spot tube (Maxi 125, G.E. Medical Systems).

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Clinical Studies

Twenty-two patients were studied after conventional percutaneous selective catheterization of the carotid and/or vertebral arteries. The patients were 14–82 years old and exhibited a broad spectrum of pathology (table 1). A total of 50 angiographic serialograms were obtained using a mask mode digital subtraction technique. In 12 instances, images were also recorded on the conventional film-screen system. Contrast injection rates for the conventional angiograms were standard (8 ml volume, 5 ml/sec rate in the internal carotid artery; 10 ml volume, 8 ml/sec rate in the common carotid artery; 9 ml volume, 6 ml/sec rate in the vertebral artery).

When the patients were studied with DSA, the contrast volume used was typically 60%–80% that of the conventional arteriographic study. The rate of injection was also decreased by a similar factor. Conventional film subtractions of selected key images were obtained. We then matched the digital and conventional subtraction images, and three of the coauthors evaluated the matched pairs, grading them on a 1–3 scale (1 = inadequate; 2 = adequate; 3 = excellent). Three separate categories of information were evaluated: large vessel (>1 mm) resolution, small vessel (<1 mm) resolution (e.g., anterior choroidal, lenticulostriate, etc.), and image contrast within the vessels. The points awarded in each category were then summed for both the digital and the conventional film angiograms and compared. In addition, a judgment was passed on each study as to its overall diagnostic quality.

Quantitative Measurements

A conventional lead-bar test pattern was used for measurements of the spatial resolution of both the digital and screen-film imaging systems. A Lucite phantom was used to analyze the trade-off between spatial resolution and contrast sensitivity. Holes of progressively smaller diameter and depth were drilled through a 2.54-cm-thick Lucite block, the smallest holes measuring 0.5 mm (fig. 1). Measurements of x-ray intensity transmitted through the solid block of Lucite and through different thicknesses of Lucite corresponding to that thickness remaining after the holes were drilled were made using a calibrated ionization chamber (MOH model

TABLE 1: **Clinical and/or Radiologic Diagnosis in Patients Studied with DSA**

Pathology	No. Patients
Tumor	4
Carotid atherosclerosis	3
Vertebrobasilar occlusion	3
Trauma	3
Aneurysm/subarachnoid bleed	3
Intraventricular bleed	1
Cryptic arteriovenous malformation	2
Spontaneous cavernous/carotid fistula	1
Other	2
Total	22

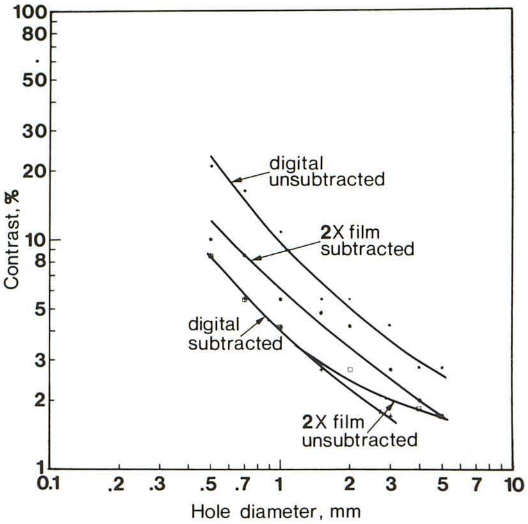

Fig. 2.—Contrast-detail curves for conventional film-screen and DSA images obtained by plotting smallest diameter hole visible at any given contrast level (see text). Imaging system performance improves as curve is closer to origin, since a smaller-sized object can be visualized at a given object contrast level.

TABLE 2: **Comparison of DSA and Conventional Angiography**

	Total Score*	
	DSA	Conventional
Large vessel resolution	99	100
Small vessel resolution	75	83
Contrast density	102	95
Diagnostic study?	All	All

* Totaled for 12 studies by three observers in each category. Scores: 1 = suboptimal; 2 = good; 3 = excellent.

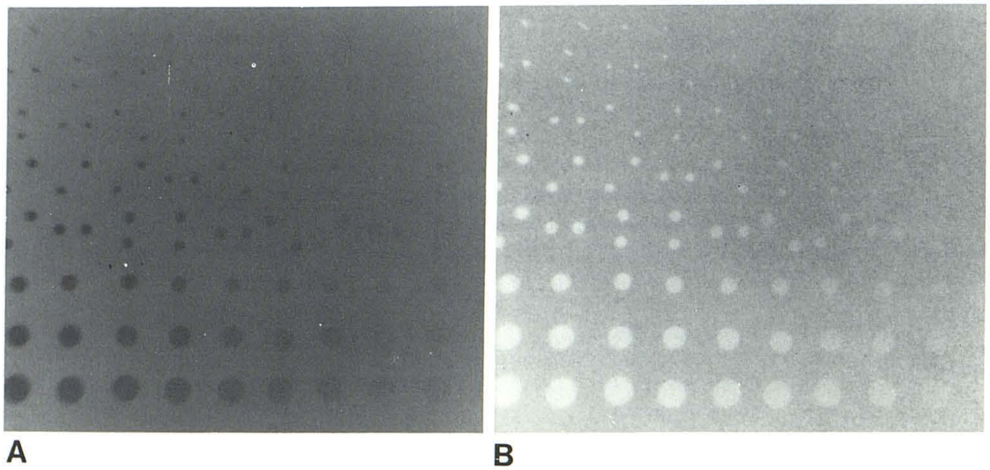

Fig. 1.—Contrast-detail phantom. **A**, Original film-screen image of Lucite phantom (magnification ×1.8) with holes of varying diameter drilled to progressively shallower depths from left to right. **B**, Conventional film subtraction shows increase of random (quantum) noise on image of phantom.

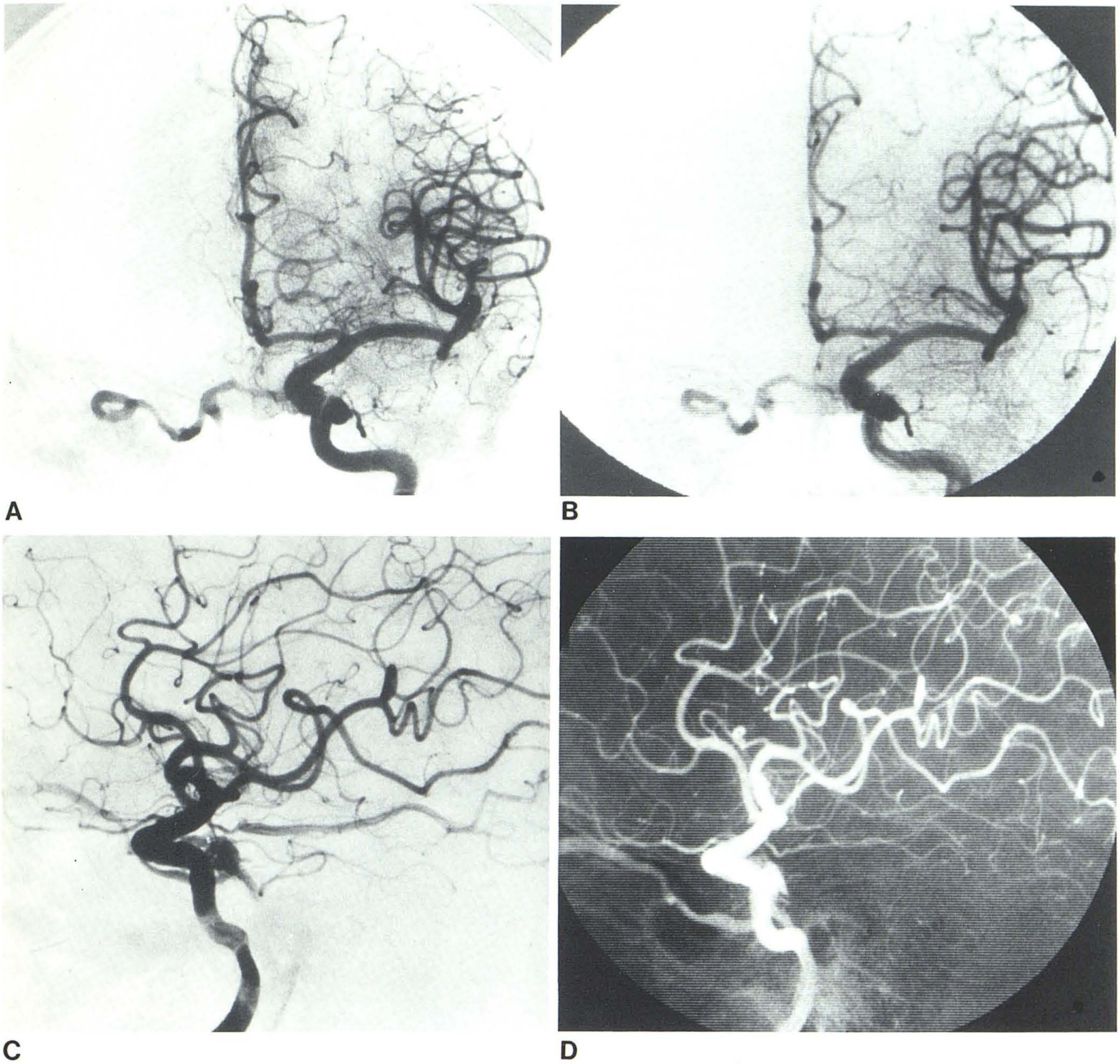

Fig. 3.—Spontaneous dural arteriovenous communication in 42-year-old woman with right exophthalmos. Left internal carotid angiography. **A**, Selected conventional subtraction of angiogram, AP view (magnification ×1.8). Abnormal arteriovenous communication with filling of contralateral (right) cavernous sinus and superior ophthalmic vein. **B**, Matched digital subtraction, AP view. Comparable detail of anterior choroidal artery, ophthalmic artery, and larger vessels. Digital subtraction was obtained earlier in flow sequence compared with conventional subtraction, accounting for slight differences in number of vessels filled. **C**, Conventional subtraction angiogram, magnification ×2, in lateral projection. **D**, DSA, in the lateral projection (reversed polarity). Abnormal dural communication in posterosuperior cavernous sinus region, with retrograde filling of right superior ophthalmic vein and basilar venous plexus.

1015). The subject contrast for each hole depth was defined as a percentage difference in measured x-ray intensity transmitted through the original Lucite block as compared with that transmitted through the thickness of Lucite remaining after the hole was drilled. For these measurements, the ionization chamber was placed in the image plane and the x-ray field size was not changed. The diameter of the smallest hole visible at each particular depth (contrast) was then plotted on a graph (fig. 2). Separate curves were obtained for nonsubtracted and subtracted digital images and nonsubtracted and subtracted film images.

Results

Our clinical data summarized in table 2 show that both techniques provided equivalent large-vessel resolution (>1 mm). Vessels less than 200 μm in diameter were not as well resolved on the DSA images, as would be predicted from both the theoretical and measured limits of spatial resolution of the two systems. Overall image contrast was superior in the DSA images despite the lower contrast volume and

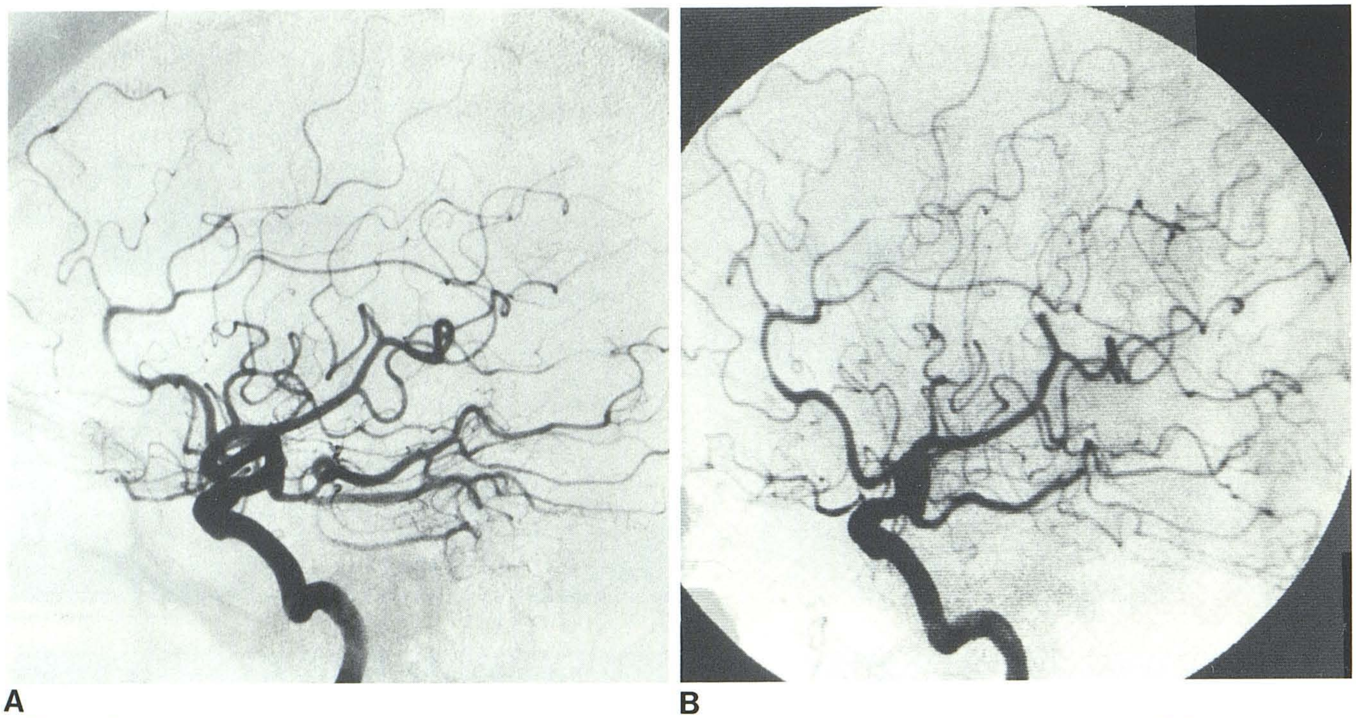

Fig. 4.—Encasement of callosomarginal artery due to metastasis to falx in 60-year-old woman with lung carcinoma. **A**, Conventional subtraction arteriogram, magnification ×2 (right internal carotid artery injection). Encasement of callosomarginal artery. Incidentally, mild atherosclerotic narrowing in anterior cerebral artery at rostrum of corpus callosum. **B**, DSA (later phase in flow sequence). Encasement of callosomarginal and incidental narrowing of anterior cerebral artery. Comparable small vessel detail.

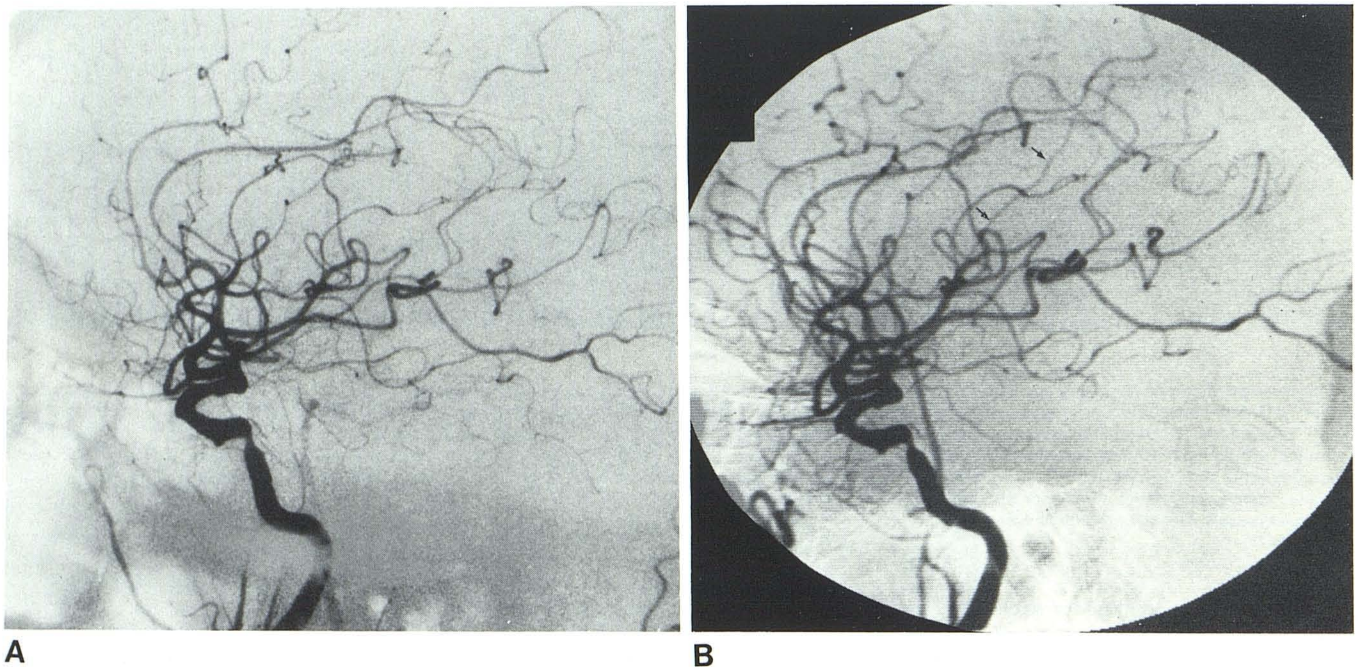

Fig. 5.—Atherosclerosis of precavernous and cavernous segment, right internal carotid artery, in 62-year-old man with recurrent left arm transient ischemic episodes. **A**, Selected subtraction of lateral projection from right common carotid arteriogram. Marked stenosis of precavernous carotid, with ulceration in inferior aspect of cavernous segment of this vessel. **B**, Similar image from DSA study several days later. Patient was evaluated for superficial temporal artery–middle cerebral artery bypass, and original arteriogram failed to depict superficial temporal artery. DSA study shows lesions of carotid siphon, and superficial temporal artery is filled (*arrows*).

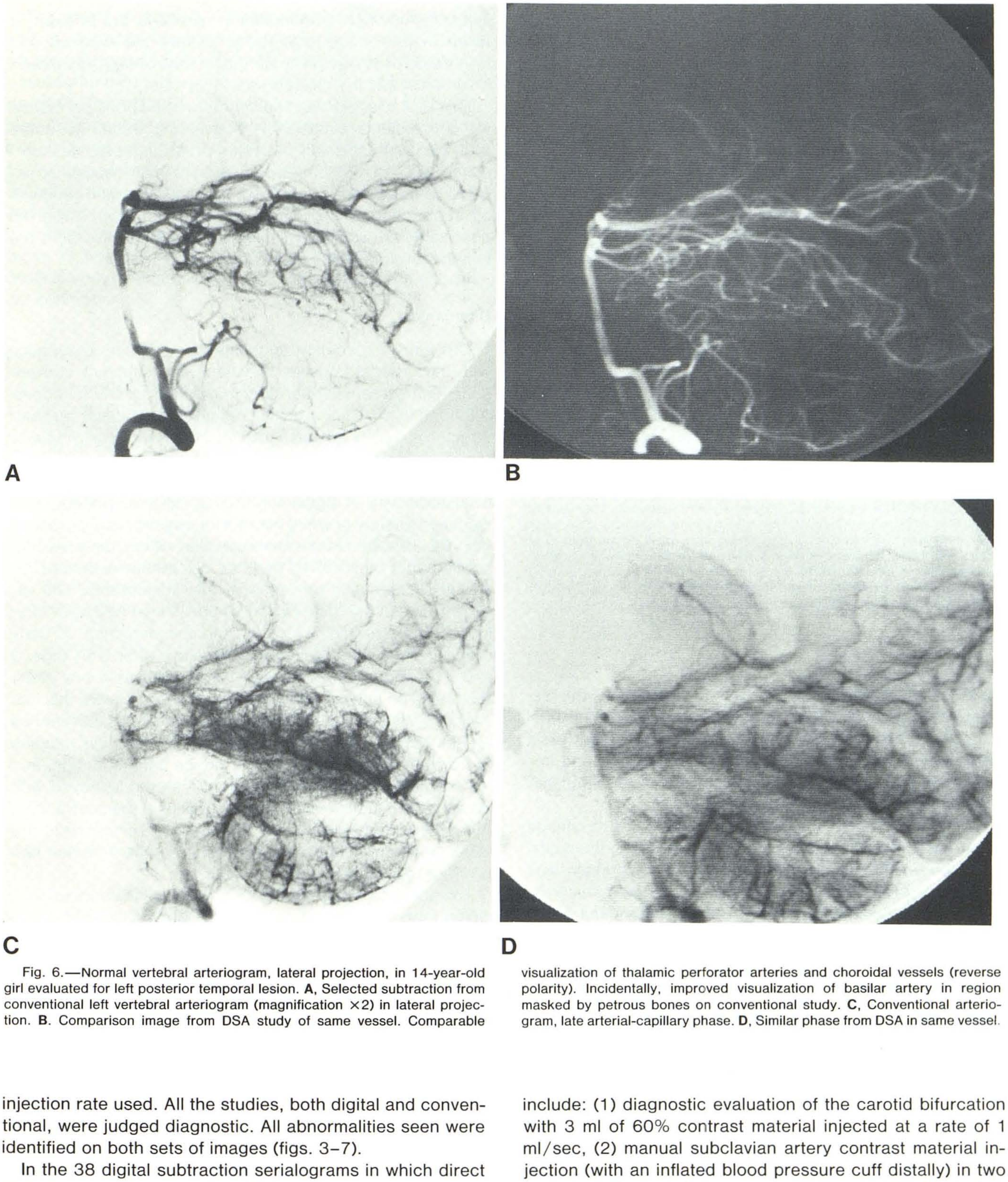

Fig. 6.—Normal vertebral arteriogram, lateral projection, in 14-year-old girl evaluated for left posterior temporal lesion. **A**, Selected subtraction from conventional left vertebral arteriogram (magnification ×2) in lateral projection. **B**. Comparison image from DSA study of same vessel. Comparable visualization of thalamic perforator arteries and choroidal vessels (reverse polarity). Incidentally, improved visualization of basilar artery in region masked by petrous bones on conventional study. **C**, Conventional arteriogram, late arterial-capillary phase. **D**, Similar phase from DSA in same vessel.

injection rate used. All the studies, both digital and conventional, were judged diagnostic. All abnormalities seen were identified on both sets of images (figs. 3–7).

In the 38 digital subtraction serialograms in which direct comparison with conventional film technique was not obtained, the information content and quality was comparable to that generally obtained with conventional angiograms and proved invaluable in patient management. Clinical examples include: (1) diagnostic evaluation of the carotid bifurcation with 3 ml of 60% contrast material injected at a rate of 1 ml/sec, (2) manual subclavian artery contrast material injection (with an inflated blood pressure cuff distally) in two patients with acute brain stem symptoms to identify basilar artery occlusion, (3) a hand (3 ml) common carotid artery injection in a patient with a fluctuating neurologic deficit caused by an evolving infarction. Several patients with sub-

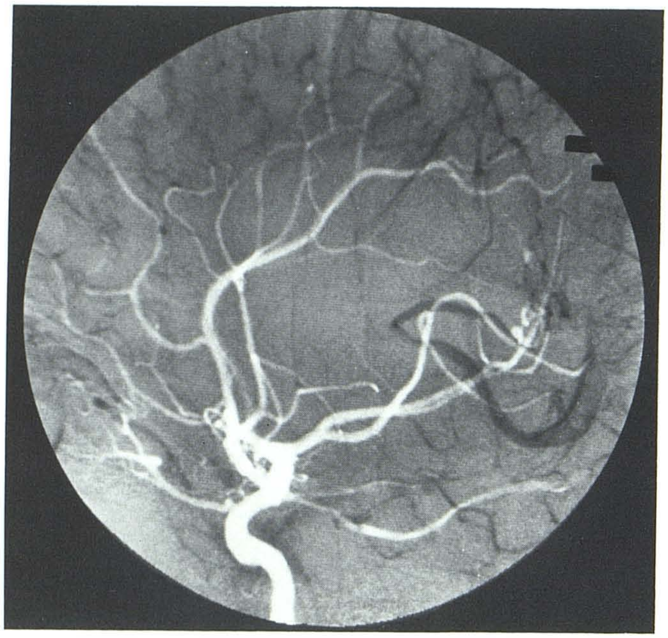

Fig. 7.—Arteriovenous malformation in 15-year-old girl with intracerebral hemorrhage on CT; emergency arteriography prior to removal of hematoma. Lateral view of right internal carotid injection (volume, 5 ml; rate, 3 ml/sec). Digital subtraction of frame in capillary phase from mask (frame from early arterial phase) shows abnormal venous drainage (*black*) of low-flow arteriovenous malformation into internal cerebral vein and vein of Galen. Arterial feeding vessel, a posterior sylvian branch of middle cerebral artery (*white*), supplies small tangle of vessels representing malformation.

arachnoid hemorrhage from aneurysmal rupture who exhibited symptoms of spasm were evaluated with intraarterial DSA. All studies were completed much more expeditiously since subtracted images could be viewed during and immediately after the actual injection without awaiting film development and photographic subtraction.

A standard resolution wedge showed that, in the image plane, the limits of spatial resolution obtained with the digital prototype equipment, as measured on the hard copy, was 2.0 line pairs/mm (11.4 cm mode of the image intensifier). The conventional film-screen system resolution was 5 line pairs/mm.

The contrast-detail phantom results (fig. 2) demonstrated that DSA images provided superior object detection. Unsubtracted film-screen images performed as well at high subject contrast levels. However, holes of 1.6 mm depth giving low subject contrast (<3%) were not visualized on conventional nonsubtracted and subtracted film, even when their diameters were 2 mm. We were surprised to find that detection of the smallest holes with conventional film subtractions was inferior to that on unsubtracted images. This is explained by the more pronounced grain or image noise on conventional film subtractions (fig. 1). This increased noise is in fact expected since the subtraction process increases random or quantum noise in the subtraction image by $\sqrt{2}$ (1.4) compared with the unsubtracted image. Indeed, the subtracted film curve we observed shifts upward by roughly a factor of 1.4 compared with the curve for the unsubtracted image.* Although DSA likewise increases the amount of noise in the image, the ability to vary the contrast and brightness of the image, in particular, narrowing the window, helps bring out the desired detail [7].

Removal of superimposed structure is the principal reason for conventional subtraction methods. It should be noted that the contrast-detail phantom used for these measurements did not contain superimposed, high-density structures such as bone. Had these been present and removed by subtraction, improvement of hole detection at a given contrast level would have been more striking for both the film-screen and DSA techniques.

Discussion

Our early experience suggests that DSA in conjunction with intraarterial contrast injections can supplant conventional film-screen angiography in most, if not all, instances. Although there is some loss of detail in the smallest vascular structures, rarely are such vessels important in arriving at a diagnosis or directing management, especially since the advent of computed tomographic (CT) scanning. The contrast sensitivity of digital subtraction technique offers sufficient conspicuity of small vessels for any practical purposes (fig. 6). This contrast sensitivity also offers promise that subtle tumor blushes will be more discernible with the DSA in comparison with conventional film angiograms. The venous phase of the cerebral circulation is also well seen after intraarterial contrast injection, and the detection of early draining veins may prove more sensitive after DSA (figs. 3 and 7). Although patient motion is a problem in any study that relies on a mask and subsequent subtractions, this has not been a significant problem in the arterial injection studies (in contradistinction to intravenous DSA). The low volumes of contrast material used do not induce patient motion, and the high concentrations of contrast material achieved with intraarterial injections improve the quality of the subtraction. Also, the ability to reregister the image in reference to the mask is helpful in decreasing effects of patient motion and is offered by several manufacturers.

The ability to obtain and store angiographic information in digital form has several advantages. Manipulation of image contrast and brightness levels allows one to see "through" vessels. This is not possible with conventional filming. Quantification of data is also possible once it is in the digital format. The ability to measure increase in density in a region of interest versus time may permit relative blood flow analysis [8, 9]. Data storage is simplified. Hard copy can consist only of selected subtraction images stored on one or two sheets of film. The entire study can be saved on magnetic tape for subsequent recall. An average of $30 to more than $200 per study can be saved in film costs alone with such a system. Ultimately, film changers may be eliminated with significant attendant cost savings.

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* A subtraction image is formed from two, nearly equally exposed films. Thus, in background areas, each film has nearly the same amount of noise since noise is principally due to quantum mottle. If the standard deviation of the noise in each film is N, the standard deviation of noise in the subtraction image, N_{sub}, is $N_{sub} = \sqrt{N^2 + N^2}$ or $N_{sub} = N\sqrt{2}$.

The ability to shorten time required for the examination and to decrease the contrast injection volumes and rates also translates to a safety benefit, especially in the high-risk patient with a fluctuating neurologic deficit or impaired renal function. The efficiency of imaging provided by DSA technique is especially useful in cases where repeated injections and imaging are necessary. For example, interventional techniques such as embolization and repetitive studies such as spinal arteriograms will definitely be benefited by the technique.

In short, our early experience suggests that the advantages of intraarterial digital angiography are sufficient to obviate conventional film-screen angiography in most clinical settings.

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Addendum

Since the original submission of this manuscript, another 57 cerebral serialograms were obtained in 22 more patients after intraarterial contrast injection with DSA imaging. All the studies were diagnostic, and the quality of images, we believe, has continually improved as operator experience with technical factors has accumulated. In addition, we have obtained one spinal arteriogram and performed embolization of a T11 vertebral body metastasis (the artery of Adamkiewicz was easily identified). In this case, DSA saved considerable time.