Arterial injection-digital subtraction angiography

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The authors report on a series of 60 patients who underwent arterial injection-digital subtraction angiography (AI-DSA) for evaluation of suspected cerebrospinal disease. High-quality images were consistently obtained, facilitating accurate diagnosis of a wide variety of traumatic, inflammatory, and neoplastic conditions. As experience has accumulated, the AI-DSA technique has all but supplanted conventional film-screen serialangiography at this institution. Important advantages of AI-DSA include reduced procedural time and decreased contrast agent burden, which mean increased patient safety. Film costs can also be markedly reduced. Moreover, image quality (information content) is not significantly affected. The technique is especially useful in emergency situations, in cases where multiple arterial injections and serialangiograms are required, and in cases in which transcatheter embolization is carried out. We feel these considerations will insure broadened application of this diagnostic modality as the AI-DSA equipment becomes more widely available.

KEY WORDS - angiography - cerebral artery - carotid artery - digital subtraction angiography

DIGITAL subtraction angiography (DSA) is fundamentally different from conventional angiography, beginning with the x-ray source and method of image acquisition. Typical DSA apparatus utilizes pulsed exposure, with the fluoroscopic x-ray tube (rather than an auxiliary "overhead" tube) located beneath the table surface. Photon flux radiated through the patient is detected by an image intensifier rather than a film-screen device. A television camera reads the image on the output phosphor of the intensifier. After amplification, the video signal is rapidly digitized and stored in computer memory. The memory is a rectilinear matrix, typically composed of 512 x 512 distinct elements. Each element of the matrix, or pixel (picture element), retains a binary digital code representing the relative number of x-ray photons transmitted through the patient at that corresponding matrix location. The composite of all the pixels yields an image. Individual composite images obtained after the arrival of contrast material may then be electronically subtracted from an image obtained before contrast material had appeared in the region studied (mask image). The resulting subtracted image shows the vascular structures, free of the background soft tissue and bone densities. Studies have shown that intravascular iodine contrast agent levels as low as 2% may thus be detected, whereas 40% to 50% concentrations would be required to produce comparable results without subtraction. Such contrast sensitivity has allowed use of this technology for visualization of arteries after intravenous injection of radiographic contrast material. However, selective arterial studies are still necessary in many cases of central nervous system disease.

Recent advances in digital fluorography equipment have resulted in improved spatial resolution of DSA. Increased signal-to-noise ratio in television cameras, more efficient image intensifiers, as well as more powerful computers allowing for rapid analog-to-digital conversion and increased memory are some of the factors responsible for this improvement. Coupled with the superior contrast resolution of DSA and the capacity for fast framing rates, the clinical application of DSA can be extended to intra-arterial diagnostic and therapeutic cerebrospinal angiography. In this paper we present our experience with 60 consecutive cases studied with arterial injection (AI)-DSA. In all instances, diagnostic studies were obtained in a safe and expedient manner.

Clinical Material and Methods

Our examinations were initially performed with a prototype and, more recently, with a production
model DSA unit.* The digital images were acquired on a 512 × 512 × 8 matrix. Specific equipment parameters in the imaging chain included a 1200-mA x-ray generator, a 0.6/1.2-mm focal spot water-cooled x-ray tube, and a trimode (4½, 6, and 9 in.) cesium iodide image intensifier† coupled to a 1000:1 signal-to-noise ratio television camera. The Plumbicon television camera utilizes a progressive scan read-out of its phosphor. Typical exposure factors were 70 to 85 kV potential, 600 mA, with 13 to 30 m/sec exposure times. Image quality was maximized using multiple-mask subtraction (remasking) and reregistration of the mask in reference to the contrast image to correct for patient motion, when needed. Selected diagnostic images were then recorded on "hard copy" film using a multi format camera.§

The patients ranged in age from 8 to 82 years. Arterial access was gained via the groin in all patients by means of the Seldinger technique. Patient positioning, catheter placement, injection volume, and framing rates varied depending upon the indications for examination. Generally, the volume and rate of contrast agent injection was 50% to 80% that of a conventional arteriographic study. In most instances, standard patient positioning was utilized when evaluating the cerebral vasculature. Occasionally, oblique positioning of the head was used; for example, in delineating small aneurysms or in evaluating a subdural hematoma. Anteroposterior, lateral, and oblique views were used for visualization of the extracranial carotid vessels while anteroposterior exposures were used for delineation of the spinal vasculature. A typical exposure sequence for a cerebral study was 2/sec for 4 seconds and 1/sec for 6 seconds. Appropriate adjustments were made for evaluation of suspected vascular lesions; for instance, 4 exposures/sec for 4 seconds, then 1/sec for 6 seconds, for study of an arteriovenous malformation. Occasionally, hand injections were used in patients with recent transient ischemic attacks, or in those with stroke-in-evolution who were thought to be at greater risk for angiographic complications. Similar techniques were also useful for selective spinal arteriography.

### Results

The entities listed in Table 1 indicate the variety of angiographic diagnoses facilitated by Al-DSA in a 10-month period. The frequency of trauma cases and the sequelae of acute vascular events reflect the spectrum of pathology anticipated at an acute-care facility such as ours. Normal studies were obtained in six patients. In four of these, the examination was done as an emergency to exclude vascular injury after the patient had sustained penetrating trauma or basal skull fractures traversing the carotid canal. The remaining two normal determinations were made in studies to exclude the presence of aneurysm: one was in a patient with subarachnoid hemorrhage, the other in a patient with a computerized tomography (CT) scan suggesting an unruptured aneurysm. Both of the latter also had subsequent negative conventional angiograms with magnification. The initial 12 patients in our series all had conventional angiograms for comparison. In none of these early cases was additional information obtained that aided in either diagnosis or surgery.²

The Al-DSA was found especially useful in a number of instances: 1) where CT was unavailable and an emergency study was required immediately prior to operative intervention (Fig. 1); 2) when stroke-in-evolution was the presenting diagnosis and emergency endarterectomy was contemplated (in this setting, hand injection allowed optimal evaluation of the carotid bifurcation in an uncooperative patient with minimal risk, as the rate and volume of contrast injection is greatly reduced); 3) when multiple injections were needed, such as in preoperative aneurysm delineation or in spinal angiography, where the study duration and contrast agent burden become items of concern. The following case reports help to illustrate practical applications of the above methods.

### Illustrative Case Reports

**Case 1**

This 45-year-old man was discovered at the bottom of a stairwell, minimally responsive. Clinical examination revealed a right third nerve palsy and retinal hemorrhages. Computer malfunction precluded ob-

<table>
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<th>Diagnosis</th>
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</tr>
<tr>
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<tr>
<td>carotid atherosclerosis</td>
<td>8</td>
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<tr>
<td>arteriovenous malformation</td>
<td>6</td>
</tr>
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<td>1</td>
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* DF 100 digital subtraction angiography unit manufactured by Diasonics, Inc., 1545 Barber Lane, Milpitas, California.
† Fluoricon 300 image intensifier manufactured by General Electric Medical Systems, P. O. Box 414, Milwaukee, Wisconsin.
‡ Plumbicon television camera manufactured by Diasonics, Inc., 1545 Barber Lane, Milpitas, California.
§ Camera manufactured by Matrix Instruments, Inc., 230 Pegasus Avenue, Northvale, New Jersey.
Arterial injection-digital subtraction angiography

taining an emergency CT scan to help determine if the patient suffered from an acute subdural hematoma or a vascular accident (the primary initial diagnostic considerations). An AI-DSA was rapidly performed and demonstrated an 8-mm right middle cerebral artery aneurysm with an associated intratemporal mass due to hematoma (Fig. 1). Both carotid arteries were studied. The patient was taken to the operating room, having spent less than 20 minutes in the radiology department.

Case 2

This 64-year-old man was admitted with amaurosis fugax and recurrent left hemispheric transient ischemic attacks. A No. 5 French catheter was positioned in the left common carotid artery and a cautious hand injection of contrast material revealed a concentric atherosclerotic plaque narrowing the proximal internal carotid artery (Fig. 2). Additional disease was discovered intracranially in the proximal cavernous carotid artery.

Case 3

This 68-year-old patient acutely developed a left hemiparesis. A prior study had shown a plaque at the origin of the right internal carotid artery, with associated moderate stenosis. An AI-DSA cerebral study was performed with contrast material injected into the

Fig. 1. Case 1. Lateral view of a digital subtraction angiography image after injection of the right common carotid artery. The arrow indicates an aneurysm of the right middle cerebral artery trifurcation. Note elevation of the roof of the Sylvian triangle and narrowing of the supraclinoid internal carotid artery due to an intratemporal hematoma. The right anterior cerebral artery filled from a left carotid injection.

Fig. 2. Case 2. Arterial injection-digital subtraction angiography images in a patient with transient ischemic attacks. Left: Hand injection of contrast material shows a concentric plaque with narrowing at the left internal carotid artery origin. A broad area of ulceration is seen distally. Right: Lateral cerebral view reveals severe atherosclerosis involving the cavernous carotid artery. Note the detail of the small arterioles.
right common carotid artery. Occlusion of the right middle cerebral artery was well demonstrated. As shown in Fig. 3, display options allow the radiologist to simultaneously record delayed retrograde flow in the right middle cerebral artery branches via the anterior cerebral artery collateral vessels with the early arterial phase superimposed. Occlusion of the proximal middle cerebral artery was demonstrated in this way.

Case 4
This 21-year-old man presented with left triceps weakness and a seizure disorder. A preliminary CT scan following contrast administration revealed an oblong region of low attenuation with intense irregular enhancement, suggesting a vascular lesion. An AI-DSA was then performed (Fig. 4), revealing a typical arteriovenous malformation.

Case 5
This 58-year-old man with known hypernephroma developed severe back pain and signs suggesting compression due to metastatic disease involving the cord at T-11. Low-volume injections into the lower thoracic aorta revealed a relatively vascular lesion deriving its blood supply from thoracolumbar radiculomedullary branches. Subsequently, selective hand injections were made into multiple intercostal arteries. The right and left intercostal arteries at T-11 supplied the tumor (Fig. 5). On the left side, an abundant supply to the lesion was noted, without visible contribution to the anterior spinal artery, and therapeutic embolization was performed prior to radiation therapy. On the right side, although branch vessels were supplying the metastatic lesion, the artery of Adamkiewicz was clearly identified, precluding embolization.

In another patient with transient ischemic attacks of the spinal cord, low-volume thoracic aortograms were useful in delineating the artery of Adamkiewicz prior to surgical intervention for severe scoliosis.

Case 6
This 26-year-old homosexual man was initially admitted to our psychiatric ward because of subacute mental deterioration and partial aphasia. On detailed physical examination, a slight right hemiparesis was noted. A CT scan showed several punctate infarcts in the left hemisphere. Review of the patient's medical history revealed a positive test for venereal disease 6 years previously. Antibiotic treatment at the time had been terminated after one dose of penicillin because of “allergy,” and the patient was lost to follow-up study until the current evaluation. An AI-DSA showed vasculitis affecting the intracerebral vessels. Irregular changes in the caliber of the vessels were seen with multiple foci of stenosis (Fig. 6). The diagnosis of syphilitic cerebrovasculitis was corroborated with serum and cerebrospinal fluid analysis.

Discussion
Several advantages of AI-DSA over the conventional film-screen technique have caused us to substitute AI-DSA for conventional arteriography in many instances. It is a safe and expedient procedure pro-
FIG. 4. Case 4. Left: Computerized tomography (CT) scan obtained before administration of contrast material shows a mixed-density lesion without mass effect in the medial right frontal lobe. Center: On the CT scan after contrast injection the lesion exhibits nonhomogeneous enhancement. Right: Arterial injection-digital subtraction angiography, oblique view, reveals a typical arteriovenous malformation with a large-caliber frontal vein draining into the superior sagittal sinus.

Generating optimal diagnostic results, which is the goal of every angiographer. The length of the angiographic procedure has been identified as a major factor related to neurological angiographic complications. The DSA method minimizes catheter time for several reasons. Exposures are visualized fluoroscopically and digital subtraction is almost instantaneous (real time). This virtually eliminates the customary delay of 5 to 10 minutes between separate angiographic series while the results of film processing and/or conventional subtractions are being obtained. With immediate feedback, the radiologist can safely advance a catheter selectively from one vessel to the next, administering hand-injected doses of contrast material. This has a particularly useful application in carotid artery (Fig. 2), spinal (Fig. 5), and intraoperative studies that necessitate repetitive injections in one or more vessels.

The excellent ability of DSA to detect contrast material allows a decrease of the rate, volume, or concentration of contrast material injection compared to that used with conventional equipment. Besides the diminished risk of renal toxicity with DSA, there are other benefits. Patients with altered blood-brain barriers are less likely to experience cerebral toxicity. Another benefit of the reduced bolus of contrast material is the diminished jet effect at the catheter.

FIG. 5. Case 5. Arterial injection-digital subtraction angiography in a patient with cord compression due to hypervascular metastatic renal cell carcinoma involving T-11. Left: Anterior view after left T-11 intercostal artery injection showing contribution to the lesion. Center: Same vessel as in left after successful embolization. Right: On the right side, the artery of Adamkiewicz (arrow) was well demonstrated, precluding embolization of the right T-11 intercostal artery.
tip as contrast agent is being injected, lessening the chance of dislodging a fragile intimal plaque or causing a dissection. This has particular significance with respect to carotid bifurcation disease. In patients requiring spinal angiography, low-volume thoracic aortograms using DSA may be accomplished with reduced risk of inducing cord ischemia or toxicity. Subsequently, selective injections of the intercostal arteries contributing to the suspected lesion may be made. This obviates the time-consuming and tedious conventional film processing after injecting numerous intercostal arteries.

One economic consideration is the savings in film cost realized by DSA. The approximate cost of film for a typical conventional cerebral angiography series ranges from $75.00 to $175.00 (the cost is even higher with angiographic evaluation of aneurysms or spinal angiography). This compares to an approximate cost of $10.00 for DSA hard copies.

In recent years, DSA of the carotid vessels after intravenous injection of contrast material has become accepted.2,3,5 This method involves bolus injection of a large volume of contrast material into a central vein, followed by fluoroscopic exposure over the vascular bed of interest. Significant drawbacks exist. Superimposition of multiple vessels may obscure structures of interest (such as small aneurysms). Severely stenotic lesions may simulate occlusion, possibly denying an occasional patient consideration for surgery. Considerable dilution of contrast medium occurs during transit through the pulmonary circuit, detracting from image quality. Also, the large volume of contrast material used sometimes provokes patient motion, degrading image quality and limiting the number of allowable injections. Diagnostic studies of such relatively large structures as the carotid bifurcation are obtained in only 60% to 80% of cases.5 For these reasons, much of the initial excitement over venous injection DSA has subsided.

Because of these limitations of venous injection, selective angiography by arterial injection will probably continue to be utilized in most hospitals. The benefits of AI-DSA discussed here suggest that this technique may replace conventional serial arteriography as a definitive diagnostic procedure.

References

Manuscript received November 8, 1982.
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