Progress in Cerebrovascular Disease

Digital Subtraction Angiography in Cerebrovascular Disease

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SUMMARY Digital subtraction angiography (DSA) is a valuable tool in the investigation and treatment of patients with cerebrovascular disorders. In this paper, the experience of the Cleveland Clinic with intravenous DSA (more than 5,000 studies) and intra-arterial (IA) DSA is reviewed.

THE INTRAVENOUS INJECTION of contrast medium for the visualization of vascular structures was introduced 43 years ago by Robb and Steinberg. This technique never gained widespread popularity because of the technical problems in obtaining consistent images of good quality. Also, the amount of contrast medium that had to be injected to achieve adequate visualization of large arteries was substantial and timing of the circulation was difficult.

The advent of computer technology has permitted a reassessment of the role of intravenous angiography in the evaluation of cerebrovascular disease. Important contributions to the development of this technique have been made by groups at the University of Wisconsin (Madison, Wisconsin), University of Arizona (Phoenix, Arizona) and Kiel Kinderklinik (West Germany). With intravenous (IV) digital subtraction angiography (DSA), the extracranial and intracranial vessels can now be visualized clearly on either an inpatient or an outpatient basis. This paper reviews the experience of the Sections of Cerebrovascular Diseases and the Department of Neuroradiology with DSA during the initial two years of its application at the Cleveland Clinic Foundation.

Methodology

More than 5000 IV-DSA examinations have been performed at the Cleveland Clinic since March 1980. Initial studies were performed on a specially-designed prototype digital subtraction system (Technicare Corporation) with a 256 × 256 matrix. Studies performed since January 1981 have been carried out on production DSA units (Technicare Corporation) with a 512 × 512 matrix.

The x-ray tube (A-292 Eimac) on the production units has a nominal focal spot selection of 0.6/1.2 mm and a heat capacity of 400,000 heat units. A 1000 milliamp generator (Septar, CGR Medical Corporation) is used. X-rays are detected using a 22.5-, 15- and 11.25-cm cesium iodide image intensifying tube (Thompson-CSF). A 16:1 grid with 40 lines/cm is used. The output phosphor of the image tube is scanned with a video camera with a lead oxide tube. The video signal from the camera is logarithmically amplified and digitized for storage in the imager, which has two 512 × 512 × 12 memories. A PDP 11/34 computer (Digital Equipment Corporation) is used for image processing.

Before the arrival of contrast material at the region of interest, fluoroscopic images are converted to digital data for storage in one of the memories. These digitized data, termed the "mask image," are in either a single frame or the integration of several frames. The subsequent images, also digitized, have the mask image subtracted from them, and the resultant images are viewed in real time (fig. 1).

A 20 cm 16 gauge angiocatheter is inserted into a peripheral arm vein in the antecubital fossa. A small test injection (approximately 2ccs) of diatrozoate meglumine and diatrozoate sodium (Renografin-76) is fluoroscopically observed to insure that the tip of the catheter is in a vein at least as large in diameter as the catheter and that there are no sharp curves in the vein between the catheter tip and the subclavian vein. If the vein is considered inadequate, the catheter is repositioned into a larger vein, inserted into another arm vein, or inserted through a femoral vein.

For extracranial studies, Renografin-76 (40cc) followed by a 5% dextrose solution (20cc) are injected at a rate between 12 and 20cc/sec. depending on the size of the arm vein. For intracranial studies, 50cc of Renografin-76 is used. Up to 5 injections are performed depending upon the patient’s weight, age and renal function.

The carotid bifurcations are initially studied with 70 degree right and left posterior oblique projections. These views have been found to most frequently show the separate origins of the internal and external carotid arteries without superimposition of the vertebral arteries. Additional views are obtained with lesser or
greater degrees of obliquity if the arteries are not ade­quately visualized on the initial studies. With careful positioning, both carotid bifurcations can be included within the 11.25cm image intensifier field.

Visualization of the carotid siphons is frequently inadequate using the standard anteroposterior and lateral views of the head. A 30° off lateral view of the region is frequently helpful in viewing the carotid siphons. In order to visualize the parasellar internal carotid arteries, the Water’s view is most helpful.

Experience with DSA

Technical Considerations

IV-DSA is accurate, safe and can be performed on an outpatient basis. Less material and personnel are required than with conventional angiography. Complications associated with an intra-arterial injection are obviated.

High quality image tube TV camera systems have advantages over film-screen combinations. The cesium iodide crystals in the image tube have a greater detector efficiency than crystals used in conventional film-screen combination. There is relatively noiseless electronic amplification of the light signals in the modern image tubes. When the output phosphor of the image tube is scanned with a low noise video system, small differences in radiation exposure (contrast sensitivity) are more faithfully detected. Overall this results in a better low contrast detectability in the DSA equipment than conventional film-screen studies.

The most important process, however, is the subtraction. The elimination of needless background information or superficial detail results in a marked increase in contrast and conspicuity (the degree to which an area of interest stands out from its surrounding). Because of this, contrast medium concentration as low as 2 per cent within the vessel can be visualized with DSA. Without the use of subtraction, concentration of contrast materials of 40 to 50 per cent are required to provide images of equal diagnostic value. The electronic subtraction images are more accurate than the film-screen because the signal level for iodine will be constant for a given concentration of iodine even when the vessel containing it is located over different background densities.

The digital memory and electronic subtraction produce real-time subtracted images and the capability to re-mask instantly. This obviates the time consuming and expensive process of manual film-screen subtraction.

The major limitations of DSA are related to the spatial resolution, contrast concentration in the region of interest, overlap of opacified structures, image in-
The spatial resolution is inferior to conventional film-screen studies. The theoretical spatial resolution of the system is 2.2 line pairs per mm with a 512 x 512 matrix. In reality, following intravenous injection, the spatial resolution is probably considerably less because of the low contrast concentration in the region of interest. Factors affecting spatial resolution include the television line system, matrix, image intensifier blur, and concentration of iodine in the region of interest. In situations where high spatial resolution is required (e.g., in the evaluation of small intracranial vessels), a selective intra-arterial injection can be made which will increase the contrast concentration and provide high quality examinations requiring less contrast than the conventional film-screen study. In this situation, the spatial resolution — although inferior to conventional film-screen — is probably adequate for the overwhelming majority of diagnostic situations.

Some radiologists prefer to use an angiocatheter positioned in the superior or inferior vena cava for the administration of the contrast medium. This technique was thought to have the advantages of reducing the risk of venous extravasation, faster injection rates, and delivery of a more discrete bolus of contrast medium. The use of an arm vein offers the advantage of easier catheter insertion which can be performed by a technician prior to moving the patient into the examination.
area. In our experience, the technique (i.e., arm vein) has been associated with a very low incidence of venous extravasation (i.e., less than 1 per 1000 cases), and the resolution of vascular structures in the cervical region has been found to be comparable to studies performed using vena cava catheterization. It is unclear at this time as to whether the vena cava catheter technique offers any advantage in the visualization of intracranial vessels.

Initial studies were frequently impaired by movement artefact, particularly swallowing during the extracranial studies. This has become less of a problem despite the fact that the techniques used have not changed substantially. Reduction of movement artefact has been attributed to improved facility in the performance of the examinations and experience of the
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FIGURE 6. IV-DSA (oblique view of the head) 6 months after superficial temporal artery to middle cerebral artery vein graft bypass shows a widely patent graft with filling of the ipsilateral middle cerebral artery branches. The contralateral internal carotid artery and basilar artery were clearly visualized.

technicians. The use of nonionic contrast media may also reduce swallowing artefact, but its great expense at the present time obviates its use with IV-DSA. In some instances of patient movement, the computer technique of mask shift (i.e., reference frame shift) can be used to enhance the resolution of the vessels of interest.

Comparative Studies With Conventional Angiography

Early in our experience, extracranial IV-DSA examinations were compared with conventional angiography in visualizing normal and diseased carotid bifurcations (fig. 2). The IV-DSA examinations were rated as good or excellent if the separate origins of the internal and external carotid arteries were clearly demonstrated. The IV-DSA examinations were rated as good or excellent bilaterally in 60% of patients; good or excellent on one side only in 23%; poorly visualized bilaterally in 17%. Ulceration of a carotid atherosclerotic plaque in four patients was demonstrated by both IV-DSA examination and conventional angiography; ulceration in 4 other patients was seen only with conventional angiography. Analysis of more recent institution-wide data indicates good or excellent IV-DSA visualization of both carotid bifurcations in more than 85% of patients studied.

The intracranial vessels were examined in 55 patients undergoing both IV-DSA and conventional angiography. The IV-DSA studies provided as much information as conventional angiography in 65% of the patients. In 22% of the patients, the IV-DSA examination provided diagnostic information but there was thought to be a substantial chance of misinterpretation. The IV-DSA studies were not diagnostic in 13% of the patients. The fourth order intracranial vessels, well demonstrated by conventional angiography, were visualized in a relatively low proportion of the IV-DSA studies.

Application to Cerebrovascular Disorders

1. Brain ischemia: Two hundred and five IV-DSA examinations (129 extracranial; 76 intracranial) were performed on 130 patients with clinical findings of suspected brain ischemia seen in the cerebrovascular surgery section between March 1980 and April 1982. The results of these studies are presented in Tables 1 and 2. The carotid bifurcations were adequately visualized in 96% of patients undergoing extracranial examinations. Lesions of the extracranial internal carotid artery, including ulceration, were clearly demonstrated. Proximal vertebral artery occlusive disease was rarely seen on the extracranial examinations as the viewing field was usually above the level of origin of this artery. Arch views in 9 patients with suspected occlusive disease of the intrathoracic arteries showed subclavian artery stenosis in 4 and aortic stenosis in one. Occlusive disease of major intracranial arteries was usually well demonstrated by IV-DSA (fig. 3). Technically unsatisfactory examinations in 11% of the intracranial studies were usually the result of vessel...
Intracranial IV-DSA (A) of a 46-year-old woman with acute headache and left hemiparesis shows a small, right frontal AVM. The avascular area posterior to the AVM represents mass effect from an intracerebral hematoma. The postoperative study (B) shows successful obliteration of the lesion.

Conventional angiography, obtained in approximately 60% of the cases, consistently confirmed the IV-DST findings. IV-DSA examinations frequently obviated the need for conventional angiography. Some patients having satisfactory extracranial and intracranial studies underwent carotid endarterectomy without further contrast studies. The number of patients undergoing carotid artery surgery without conventional angiography continues to increase. Conventional angiography with visualization of the arteries of interest is still performed on candidates for extracranial to intracranial bypass surgery.

Table 1. Extracranial IV-DSA in 129 Patients with Suspected Brain Ischemia

<table>
<thead>
<tr>
<th>Findings</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>29</td>
</tr>
<tr>
<td>Unilateral ICA ulceration</td>
<td>7</td>
</tr>
<tr>
<td>Unilateral ICA stenosis (mild)</td>
<td>14</td>
</tr>
<tr>
<td>Unilateral ICA stenosis (severe)</td>
<td>15</td>
</tr>
<tr>
<td>Bilateral ICA stenosis</td>
<td>15</td>
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<tr>
<td>Unilateral ICA occlusion:</td>
<td></td>
</tr>
<tr>
<td>without contralateral ICA stenosis</td>
<td>14</td>
</tr>
<tr>
<td>with contralateral ICA stenosis</td>
<td>14</td>
</tr>
<tr>
<td>Bilateral ICA occlusion</td>
<td>7</td>
</tr>
<tr>
<td>Unilateral ECA stenosis</td>
<td>3</td>
</tr>
<tr>
<td>Subclavian artery stenosis</td>
<td>4</td>
</tr>
<tr>
<td>Aortic stenosis</td>
<td>1</td>
</tr>
<tr>
<td>Technically unsatisfactory</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>129</td>
</tr>
</tbody>
</table>

Legend: ICA = internal carotid artery.

Table 2. Intracranial IV-DSA in 76 Patients with Suspected Brain Ischemia

<table>
<thead>
<tr>
<th>Findings</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>35</td>
</tr>
<tr>
<td>ICA stenosis</td>
<td>7</td>
</tr>
<tr>
<td>Unilateral ICA occlusion</td>
<td>19</td>
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<tr>
<td>Bilateral ICA occlusion</td>
<td>4</td>
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<tr>
<td>Unilateral MCA occlusion</td>
<td>3</td>
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<tr>
<td>Moya-moya syndrome</td>
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<tr>
<td>Basilar artery stenosis</td>
<td>1</td>
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<tr>
<td>Technically unsatisfactory</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>76</td>
</tr>
</tbody>
</table>

Legend: ICA = internal carotid artery; MCA = middle cerebral artery.
The role of IV-DSA in the diagnosis of an arteriovenous malformation (AVM) is similar to that for intracranial aneurysm. Conventional angiography is necessary in most cases when surgery is contemplated. However, the technique appears to be a useful screening procedure for identifying patients with suspected intracranial anomalies and may provide insight into the flow patterns in the region of the malformation.

Postoperative Evaluation

1. Carotid endarterectomy: Extracranial IV-DSA clearly shows the carotid arteries after surgery. Sixty studies performed one week after carotid endarterectomy demonstrated a patent internal carotid artery. Eleven operated arteries had mild irregularity at the bifurcation and 19 internal carotid arteries had slight narrowing at the distal end of the arteriotomy (fig. 5). One patient with a small, diffusely diseased internal carotid artery was found to have occluded silently. Thirty-five extracranial studies one month to seven years after surgery showed normal-appearing carotid arteries. Irregularity at the bifurcation and slight narrowing of the internal carotid artery at the distal end of the arteriotomy were not seen. One patient with a normal extracranial study one week after carotid endarterectomy was found to have internal carotid artery stenosis distal to the operative site 8 months following surgery.

IV-DSA studies have been particularly useful in the urgent evaluation of patients symptomatic after carotid endarterectomy. Set-up time and performance of the examination was easier and quicker than for conventional angiography. Two patients with postoperative transient ischemic attack had normal extracranial and intracranial studies. Two other patients who developed neurological deficits had extracranial studies which showed occlusion of the operated carotid artery. Both patients had been shown preoperatively to have small, diffusely diseased internal carotid arteries. Surgical reopening of the arteries revealed recent thrombosis. Repeat studies two days after thrombectomy and saphenous vein patch grafting showed widely patent internal carotid arteries.

2. Bypass surgery: Patients undergoing anastomosis of the superficial temporal artery to a branch of the middle cerebral artery were initially studied using an-
teroposterior and lateral views of the head. This technique proved unreliable in assessing bypass patency. The subsequent use of magnified, oblique views has allowed the demonstration of bypass patency in more than 90% of patients whose bypasses were found to be patent with conventional angiography. All patients with superficial temporal artery luminal diameter greater than 2mms had bypass patency confirmed with IV-DSA.

IV-DSA examinations confirmed the patency of all patients undergoing extracranial to intracranial vein bypass surgery. This included 4 patients with common carotid artery to middle cerebral artery bypass; 2 patients with superficial temporal artery to posterior cerebral artery bypass; and, 13 patients with superficial temporal artery to middle cerebral artery bypass (fig. 6).

3. Aneurysm and AVM surgery: IV-DSA was particularly useful in assessing patients undergoing intracranial surgery for aneurysm or AVM and showed the successful obliteration of an aneurysm in 25 patients and AVM in 9 patients (fig. 7). Conventional angiography was not necessary in this group of patients.

Intracranial Veins

During an IV-DSA examination, there is bilateral simultaneous opacification of the cerebral vasculature and clear demonstration of the dural sinuses and larger
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FIGURE 11. IV-DSA of the aortic arch in a woman with vertebrobasilar insufficiency showed occlusion of the left subclavian artery (A). A later image showed retrograde filling of the left vertebral artery and subsequent anterograde filling of the distal left subclavian artery (B).

cerebral veins (fig. 10). Confusing filling defects due to unopacified blood entering the dural sinuses frequently seen on conventional angiograms are not a problem. The IV-DSA is usually of sufficient quality so that when combined with CT, IV-DSA can replace conventional angiography for diagnostic purposes in most patients with abnormalities of the larger intracranial veins and sinuses.

IV-DSA can be used preoperatively to evaluate normal anatomical variations of the venous outflow to determine which sinuses may be safely occluded if necessary during surgery in the region of the temporal bone, jugular fossa, and base of skull. Changes from tumors, trauma, infections, and asymmetries of position and size as a variation of normal can easily be demonstrated. In particular, it appears to be the most effective means of evaluating the superior sagittal sinus and distinguishing a large jugular bulb from a neoplasm.

Arterial DSA

Intra-arterial (IA) DSA examinations have some advantages over conventional angiography. Small volumes of contrast medium can be used because of the improved contrast resolution of the digital subtraction technique. Less selective catheter placement is required for IA-DSA studies in order to provide images of comparable quality. Also, selection of the images of interest by the radiologist reduces substantially the amount of film needed to record the necessary information and thereby results in considerable reduction in cost. Representative IA-DSA’s of the intracranial vessels and the aortic arch are shown in figures 8 and 9.

DSA and Blood Flow

There appears to be a promising future for the utilization of digital data to provide quantitative information. Not only will diagnostic anatomic information be provided to clinicians, but there is also a potential to acquire functional images such as flow studies. Data indicates that the digital numbers obtained by DSA correlate linearly with the amount of transmitted radiation. Whether the correction factors for scatter radiation are necessary to achieve more consistent results is unanswered. This far, however, with or without correction factors, the digitized television signal has given a good approximation of the iodine concentration in the field of view. Plotting the digital number against time in the region of interest after an intravenous injection provides a valuable determination of the appearance, accumulation, and clearance of the contrast agent in organ systems.

IV-DSA provides some insight into the distribution of blood flow and flow patterns since all vessels fill simultaneously with contrast and “real time” images are obtained. In two cases of subclavian artery occlusion, a flow pattern of vertebral steal was clearly demonstrated by reviewing the sequential images (fig. 11). The technique has also been useful in identifying collateral flow patterns through the Circle of Willis in cases of major cerebral artery occlusive disease.

The results of Xenon-133 inhalation regional cerebral blood flow (rCBF) using 8 detectors over each hemisphere and the pattern of cortical artery filling on DSA have been compared in patients with unilateral internal carotid artery occlusion. Patients with reduction of rCBF on the side of internal carotid artery occlusion had delayed cortical artery filling on IV-DSA. The presence of symmetric hemispheric opacification of cortical arteries on DSA was thought to indicate adequate interhemispheric redistribution of...
blood flow and patent interhemispheric collateral channels, but not necessarily normal rCBF. The presence of bilateral reduction of rCBF and symmetrical cortical artery filling on DSA could represent an "interhemispheric steal."

**Contrast Reactions**

Contrast reactions are potentially the most serious complications of the procedure. In a previous review of 300,000 cases, the incidences of adverse reactions to contrast occurred in approximately 5%. There were 18 fatal reactions in this large group of patients.9

In our experience with more than 5,000 IV-DSA examinations, we have had no significant morbidity from contrast reactions. Transient renal dysfunction which occurred in one patient could have been the result of the contrast. We feel that adequate hydration of patients prior to IV-DSA together with routine blood tests of renal status (i.e., creatine, electrolytes) should minimize the potential risks to the kidney.

**References**

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