DIGITAL SUBTRACTION ANGIOGRAPHY (DSA) is a relatively new technique which integrates digital data collection and computer processing to produce a medical image. X-ray signals are detected electronically rather than on film and then converted to digital form, to be processed by a computer before being displayed. The rapid development of new techniques in TV, digital electronics and image intensifiers in the early 1970s led to more interest in the electronic recording of medical images. The exquisite contrast sensitivity of early prototype units led to renewed interest in the techniques of intravenous angiography originally described by Robb and Steinberg.\(^1\) By the early 1980s, intravenous DSA had been accepted as a potent neuro-diagnostic tool and the applications of digital technology using arterial injections were being expanded.

Intravenous DSA

When digital imaging was first introduced, the intravenous injection capabilities were the applications which were emphasized and although they are still valid, the initial enthusiasm has been tempered by clinical experience. The advantages of intravenous DSA (IV-DSA) over conventional angiography are well known, including the lowered risk to the patient, the ability to perform the examination on outpatients and the decreased cost of the study. Disadvantages relate to the decreased spatial resolution (2 line pairs per mm vs 5 or 6 line pairs per mm for conventional angiography), the high incidences of misregistration artifacts, and the limitations and risks involved in the use of high volumes of contrast material.

Applications

A. Extracranial Occlusive Disease

One of the earliest applications of IV-DSA was in the investigation of carotid artery disease in the neck. Interest has centered on the investigation of patients with asymptomatic carotid bruits and in symptomatic patients with TIA's or completed strokes who may be candidates for endarterectomy (fig. 1). Patients with nonspecific symptoms which may relate to carotid disease and postoperative endarterectomy patients (fig. 2) are also frequently studied.

Intravenous DSA has been shown by several authors to compare very favourably with conventional angiography in the detection of atherosclerotic disease at the carotid bifurcations, when excellent quality images have been obtained.\(^2\)\(^,\)\(^3\) Sensitivity and specificity rates for detecting stenoses greater than 60% range from 89%\(^2\) to 93%.\(^3\) These rates drop appreciably for stenoses less than 40% diameter as the poor spatial resolution makes it difficult to accurately define and quantitate minimal disease.\(^4\) In our institution, a comparison study between intravenous DSA and conventional angiography in 36 patients showed a sensitivity of 93% and a specificity of 91% for stenoses greater than 40%.

A major problem with intravenous DSA has been clinician acceptance of images which are less sharp than the conventional angiograms they have been used to for many years. Radiologists have reported diagnostic quality images in 60%\(^2\) to 93%\(^3\) of patients, yet most clinicians feel that only an excellent quality intravenous DSA is truly comparable to conventional angiograms. Excellent quality studies have been seen much less frequently, ranging from only 46% in our series of 248 patients to 62%.\(^4\) A recent paper which emphasized the limitations of IV-DSA\(^2\) reported that excellent quality visualization of both carotid bifurcations...
FIGURE 1. Sixty-five year old patient with an asymptomatic right carotid bruit. A: IV-DSA image of the right carotid bifurcation. A small smooth plaque is identified at the origin of the internal carotid artery. The margins of the plaque are shown (black arrows). B: High resolution B-mode ultrasound of the right carotid bifurcation, longitudinal view. Weakly echogenic material on the posterior wall of the proximal internal carotid artery is shown (white arrows), consistent with a small atherosclerotic plaque. C: Right common carotid arteriogram, lateral view. The small smooth plaque is again seen (margins shown by white arrows).

FIGURE 2. Sixty-three year old female with left carotid endarterectomy performed three months previously. The carotid bifurcation has a normal post-operative appearance (thick arrow). Note the severe stenosis of the right carotid bifurcation on this oblique view (long arrow).
could only be seen in 26% of patients and only 48% of the examinations were diagnostic. The remainder were degraded by motion artifact, poor contrast density and vessel overlap. The assessment of a "diagnostic" study is usually a subjective decision by each observer, but general consensus seems to be that diagnostic quality images can be obtained in approximately 70% of all patients studied.2 3 -6

Other problems with intravenous DSA relate primarily to the decreased spatial resolution and include the detection of ulcers7 and the differentiation of very tight internal carotid artery stenosis from complete occlusion.8 The external carotid artery origin is also not reliably imaged with this technique7 and this becomes important when EC/IC bypass surgery is considered. It is becoming clear that intravenous DSA will not make conventional angiography obsolete in the investigation of extra cranial carotid disease. But how often can clinical decisions be made on the basis of this one, relatively non-invasive technique? A recent study of 86 patients with symptomatic cerebral ischemia demonstrated that clinical decisions could be made in 73% of the patients using the intravenous DSA alone, including 50% of the 25 patients who subsequently underwent surgical endarterectomy.8 Many centres will perform endarterectomies on the basis of intravenous DSA alone,9 however more conservative surgeons will often insist on preoperative conventional angiograms to better define ulcers, intraluminal thrombi, external carotid disease and intracranial disease. In our institution, only two endarterectomies have been performed on the basis of intravenous DSA alone after more than 400 examinations performed for suspected cerebrovascular atherosclerosis.

Duplex ultrasound is the other noninvasive technique which has gained acceptance as an accurate method for examining the carotid bifurcations10-11 and the reported sensitivities and specificities for plaque detection are comparable to those of intravenous DSA. A study of 248 carotid bifurcations in patients undergoing both intravenous DSA and duplex ultrasound examinations at our institution showed exact agreement in evaluation of degree stenosis between the two modalities in over 90% of cases using a 3 category
grading system. The choice of which screening test to order for assessing the carotid bifurcation must therefore depend on factors other than diagnostic accuracy. Intravenous DSA provides information about intracranial vessels and the aortic arch which is not available with ultrasound. The DSA images of vascular anatomy are much more familiar to clinicians than the often confusing ultrasound images. Intravenous DSA is however an invasive procedure involving large amounts of contrast material and ionizing radiation. It demands excellent patient cooperation and reasonably good medical status. Ultrasound is noninvasive and can be easily repeated in all but the most uncooperative patients.

**Figure 5.** Forty-one year old male with multiple small bilateral strokes. A: IV-DSA, AP view. The supraclinoid portions of both internal carotid arteries are difficult to identify and the tuft of contrast in the left basal ganglia region is suspicious for the "moya-moya"-like pattern seen with internal carotid artery occlusion (arrow). The vertebro-basilar system is well seen. B: Left common carotid arteriogram. Complete occlusion of the left internal carotid artery is seen. There is filling of the left posterior cerebral artery from a large posterior communicating artery. The "moya-moya"-like pattern is evident (arrow). A similar pattern was seen on the right side.

**Figure 6.** A: IV-DSA, lateral view. A large left paraophthalmic artery aneurysm is identified however the neck is not well seen. B: Left common carotid arteriogram. The aneurysm neck is now visualized (arrow).
In our institution, intravenous DSA, often in conjunction with duplex ultrasound is used as a screening technique for extra cranial carotid atherosclerosis and to follow up carotid endarterectomies. When excellent quality studies showing normal or mildly diseased vessels are shown, no further assessment is usually required. For more significant disease or when poor quality studies are obtained, conventional angiography is performed if surgical intervention is contemplated.

B. Intracranial Disease

The use of intravenous DSA for evaluating intracranial vasculature has not been as widespread as extracranial investigations. Diagnostic quality images have been obtained in up to 65% of patients however the quality is inferior to conventional angiography. The major problem with intracranial imaging is the poor resolution of small vessels rather than motion artifact or vessel overlap.

The two most popular applications for intracranial intravenous DSA include the evaluation of the paraseellar carotid arteries prior to transphenoidal pituitary tumor surgery and the evaluation of venous sinus patency in veno-occlusive disorders or tumor encroachment. Pituitary tumors are now well shown by CT (fig. 3), however in some cases it may be difficult to exclude giant aneurysms or ectasia of the paraseellar internal carotid arteries. Intravenous DSA images can effectively rule out vascular disorders which can simu-
We have examined 10 cases of pituitary tumors and in only one were we unable to rule out aneurysm. In this case, angiography revealed a large ectatic internal carotid artery which was eroding the dorsum sella with no evidence of aneurysm or tumor.

The venous sinuses are well shown with this technique as all intracranial vessels are opacified simultaneously by the large contrast bolus. Sinus involvement by meningiomas can be easily assessed (fig. 4). We have now examined five cases with intravenous DSA and documented venous sinus involvement in two.

Intracranial atherosclerotic disease is not reliably detected unless the disease is of severe degree and involves proximal vessels (fig. 5). Lesser degrees of stenosis, particularly in the horizontal segments of the anterior and middle cerebral arteries are difficult to reliably detect and small vessel disease will consistently be missed by the relatively poor spatial resolution of the system. The origins of the vertebral arteries from...
the brachiocephalic vessels can usually be reliably imaged, however, the basilar trunk and its branches are not consistently seen at diagnostic levels. Large aneurysms greater than 0.5 cms in diameter will be detected in most cases (fig. 6). Intravenous DSA may have a screening role in patients with non-specific neurological symptoms which may be related to aneurysm but detail is not adequate for surgical decision making. Similarly, the technique can detect AVMs (fig. 7) but individual feeding arteries and draining veins cannot be seen with sufficient confidence to plan a surgical or neuroradiologic interventional approach. Post-operative and post-embolization assessment may be feasible in the future but resolution is not yet adequate to rule out small early draining veins which would indicate residual malformation.

Intravenous DSA may have a future role in the post-operative assessment of aneurysm clipping. We have studied five patients post-operatively to assess the adequacy of aneurysm clipping. In two patients a confident diagnosis of satisfactory clipping could be made (fig. 8). In one patient the resolution was not adequate to exclude a small portion of the aneurysm base still filling and vasospasm could not be assessed (fig. 9). In the remaining two cases, contrast dilution and patient motion precluded adequate visualization.

**Intra-Arterial DSA**

Arterial applications of DSA are becoming more popular as the limitations of intravenous techniques are realized. Arterial DSA has several advantages over film screen angiography. Due to the exquisite contrast resolution provided by computer enhancement, smaller volumes of dilute contrast material can be given through smaller, softer catheters. Selective catheterizations are often not necessary as injections can be made from the origins of vessels. These factors make cerebral angiography a much safer and less unpleasant experience, particularly in older patients with tortuous vessels. The studies are also faster than when conventional techniques are used, as electronic subtractions are instantly available. This is of particular benefit in interventional work. Although the spatial resolution is not quite as good (fig. 10) it is adequate for nearly all clinical situations. There is a great saving in film cost, as an entire examination may require only five or six films with multiple images on each film. A routine conventional angiogram may use 60–70 films per case.

In our institution, all elderly patients being investigated with angiography for symptomatic cerebrovascular atherosclerosis are studied in an angiographic suite with digital capabilities. If any difficulty is encountered with selective vessel catheterization, injec-

![Figure 10. A: Left common carotid arterial DSA. This image was obtained with 6.0 cc of contrast material diluted to 50%. B: Conventional right common carotid arteriogram. This was obtained using a 12.0 cc of 100% contrast material.](http://stroke.ahajournals.org/Downloaded_from http://stroke.ahajournals.org/ by guest on January 6, 2016)
Figure 11. A 58 year old male with bihemispheric TIA's. During femoral cerebral angiography, the aortic arch was found to be very tortuous and difficulty was encountered with selective cerebrovascular catheterization. A: Lateral view of right carotid arterial DSA. This view was obtained with an injection of 4.0 cc of 50% contrast material with the catheter tip located at the origin of the right common carotid artery. A tight right internal carotid artery stenosis is shown (arrow). B: Arterial DSA, lateral view of the head. This view was obtained with an injection of 10.0 cc of 50% contrast material with the catheter tip in the proximal right subclavian artery and cuff compression of the right arm. Excellent filling of the right vertebral artery and the right middle cerebral artery via the right posterior communicating artery is seen.

Arterial DSA has been invaluable in the rapid assessment of progress during interventional procedures. All facial and nasal embolization studies are now assessed with DSA and digital capabilities are now being extended to evaluate embolization of intracranial AVMs and aneurysms.

The recent introduction of a portable digital unit at our hospital will soon make possible the intraoperative evaluation of neurosurgical procedures. Preoperative intravenous or arterial catheter insertion will allow intraoperative contrast injections. Using the portable digital unit which now provides digital fluoroscopy and will be adapted to provide hard copy images the patency of carotid endarterectomies and EC/IC bypass, the adequacy of AVM resection and completeness of aneurysm clipping can be easily assessed. The necessity for postoperative angiography will therefore be eliminated in many patients.

Conclusion

DSA is a technology which is still in its infancy. Much of the early enthusiasm relating to intravenous applications has been moderated by equivocal clinical results. Nevertheless it is still a good screening method for atherosclerotic disease at the carotid bifurcations and is comparable to duplex ultrasound. A normal examination of good quality essentially eliminates the need for angiography. It is unlikely that intravenous DSA will replace film screen angiography in the evaluation of intracranial vasculature except for the investigation of the venous sinuses and parasellar internal carotid arteries. Continuing advances in computer and imaging technology will hopefully expand these applications.

Arterial DSA, while still an invasive in-patient procedure in most centres, makes the examination much safer and easier for patients and considerably reduces the cost. The use of smaller, softer catheters to deliver smaller amounts of dilute contrast material will make out-patient angiography a reality. Conventional angiography can be replaced by arterial DSA in nearly all clinical applications.

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