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Digital Subtraction Angiography

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Digital subtraction angiography (DSA) brought the computer into the angiography suite. With it came the capability of rapid subtraction angiography and post processing of the images to optimize image contrast and brightness. DSA is a valuable adjunct to conventional angiography and has added considerable flexibility to the angiographic procedure. Using intravenous techniques, the extracranial carotid and vertebral arteries can be imaged to assess the degree of atheromatous disease with reasonable consistency and accuracy. Arterial DSA can image the intracranial circulation rapidly using smaller doses of contrast material to reduce procedure time and the risk of a complication. DSA is particularly helpful in those patients where severe atheromatous disease or vessel tortuosity preclude selective catheterization. Conventional film angiography remains the gold standard for cerebrovascular imaging.

The role of angiography in the assessment of neurological disease has changed considerably in recent years. Prior to computed tomography (CT), angiography was a primary method of diagnosis. Today, with few exceptions, whenever a patient presents with symptoms of CNS disease, CT or magnetic resonance (MR) is the first diagnostic test. For non-vascular disease, often that is all that is required. Angiography is reserved for selected cases to assess vascular supply to a tumor or vascular complications of inflammatory disease. Even in the vascular disease category, the presence of a stroke or intracranial hemorrhage is first documented by CT or MR. Nevertheless, angiography remains the definitive study for delineating the anatomy of vascular lesions. For example, angiography is required to find the location of vascular occlusion, the location and configuration of the cerebral aneurysm and to demonstrate the feeding arteries and draining veins of an arteriovenous malformation prior to therapeutic intervention. Considering that stroke is one of the more common neurological diseases, cerebral angiography is still a fairly common procedure in neuroradiology.

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the caudate was, nevertheless, lower than the corresponding ratio in the age-matched normal subject. It is quite provocative that the extent of reduction is similar to that report by Mash for the loss of presynaptic (M2) receptors in the cortex of patients with Alzheimer's disease when determined by postmortem in vitro studies (Mash, Flynn, and Potter, 1983).

Recent work has raised questions concerning the primacy of the acetycholine defect in Alzheimer's disease. Somatostatin receptors are significantly reduced in number in the frontal and temporal cortex and the hippocampus (Beal et al., 1985). Because the receptor sites themselves are depleted, studies using labeled somatostatin antagonists would likely find reduced uptake in these regions, perhaps outstripping the reduction in perfusion. Similar receptor mapping could be carried out using the binding sites for corticotropin-releasing factor, a hypothalamic-releasing hormone that is the major physiological mediator of adenohypophyseal corticotropin and beta-endorphin secretion. This hormone has been reported to be depleted in the frontal and temporal lobes and the hippocampus in patients with Alzheimer's disease (Bissette, Reynolds, Kilts, Wilderlou, and Nemeroff, 1985).

These studies may provide very useful in vivo maps of receptor binding. To complement the anatomic information that they provide, it will be necessary to supplement these studies with pharmacologic interventions to more clearly define receptor function. For example, the use of a postsynaptic acetycholine muscarinic antagonist followed by IQNB imaging would permit assessment of the more interesting presynaptic (M2) binding sites. Finally, receptor site labeling alone does not tell us how effectively that receptor is activating the postynaptic neuron. It may be that we will have to develop a family of compounds that can measure aspects of receptor function beyond its binding activity.

At least for the immediate future, SPECT imaging with tracers that assess cerebral perfusion offers the greatest opportunity for the clinical management of the dementias because the perfusion patterns are discriminating and sensitive, because the test is easily performed and because SPECT perfusion imaging may lead directly to the solution of a number of clinical dilemmas in the diagnosis and management of the disease. In the more distant future, however, chemical SPECT imaging may take its place as a complement to physiological SPECT imaging in the community hospital as well as in the tertiary medical center for the routine workup of patients with dementia.

within the head, selective arteriography is the recommended procedure.

The non-invasive vascular laboratory should be an integral part of the clinical evaluation of patients with suspected cerebral vascular disease. Any patient referred to Neuroradiology for asymptomatic bruits should first be evaluated with non-invasive carotid studies. These patients need an angiographic study only if the non-invasive tests are equivocal or show a significant stenosis. Intravenous DSA may be a reasonable first step in patients with TIAs or stroke referrable to a single vascular territory; in these cases, the goal is to obtain diagnostically useful images of the carotid bifurcations in the neck and a superficial evaluation of the intracranial circulation. The non-invasive tests are also helpful to determine whether or not a stenosis identified by IV DSA is hemodynamically significant. In more complex cases of cerebrovascular disease, IV DSA should be bypassed to obtain a selective arterial study (Ackerman et al., 1983).

Intravenous DSA can also be used as a screening procedure in the evaluation of atheromatous vertebral-basilar disease (Hesselink, Teresi, Davis, and Taveras, 1983), although the information obtainable is limited. At present, most stenoses of the vertebral-basilar system are not amenable to surgical endarterectomy; hence, detailed anatomical imaging is not imperative. The image resolution must be sufficient to yield a general assessment of the atheromatous disease of the vertebral-basilar system and to exclude severe stenosis or occlusion of the basilar artery. Stenotic lesions and complete occlusion of the vertebral or basilar artery can usually be seen. In cases of basilar occlusion, the specific site of occlusion cannot always be determined, but early filling of the top of the basilar before visualization of the distal vertebrals and lower basilar artery suggests significant disease of the vertebral-basilar system. However, the resolution is low, and IV DSA often misses minor atheromatous disease and tends to underestimate the extent of disease. If some type of bypass procedure is being considered, selective arteriography is necessary for preoperative evaluation.

Intravenous DSA also has application for evaluation of the major intracranial veins and sinuses (Modic, Weinstein, Starnes, Kinney, and Duchesneau, 1983). As a result of the flush injection, there is no washout of the sinuses with unopacified blood from another territory. Thrombosis or tumor invasion of the superior sagittal sinus can be seen. In cases of neck tumors, IV DSA can be used to assess involvement of the internal jugular vein and the carotid artery.

There are several advantages to IV DSA. Since it is performed with an intravenous injection, there is no risk of embolic stroke due to catheter manipulation. Compared to selective catheterization, IV DSA is easier to perform, takes less time, can be performed on an out-patient basis, is less costly and can be repeated at relatively frequent intervals if necessary. Since little fluoroscopy is required and both carotids are imaged simultaneously, the x-ray

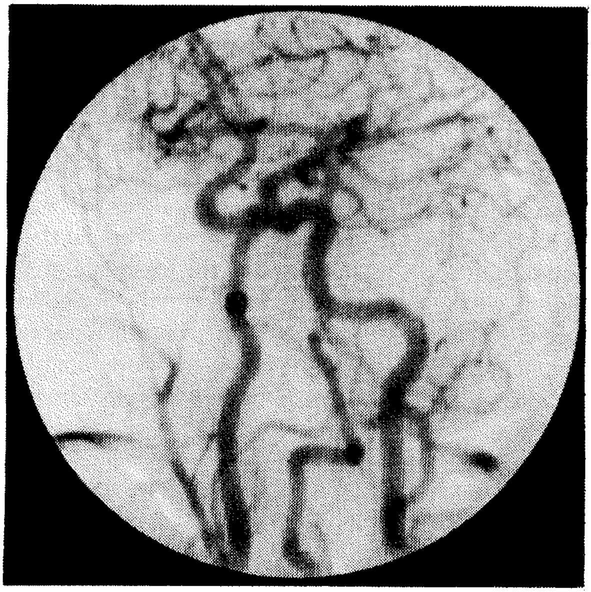

Figure 1B: This oblique view shows the cervical carotid arteries and the carotid siphons.

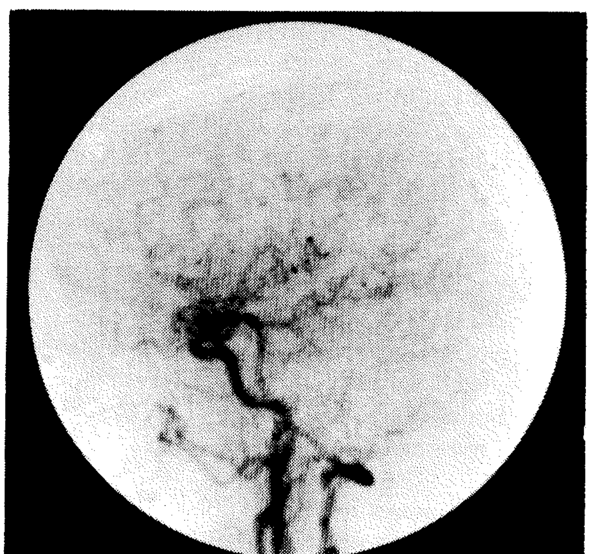

Figure 1C: A lateral view is best for imaging the basilar artery.

The major indication for IV DSA is for the evaluation of arteriosclerotic cerebral vascular disease. The IV DSA images can demonstrate carotid stenoses (Figure 2) as well as atheromatous disease. Large and medium-sized ulcerations can be seen (Figure 3) and the degree of irregularity within an atheromatous plaque can be assessed, but obviously not with the accuracy of a conventional film image. Superficial ulcerations are often missed by IV DSA. The residual lumen of a carotid stenosis can be measured within an accuracy of about 1 mm. If there is some uncertainty about the presence or dimensions of a residual lumen, the additional information from non-invasive tests may obviate the need for selective arteriography, assuming one does not need to see the circle of Willis. In addition, asymmetry of flow to the cerebral hemispheres may help to determine whether or not a carotid stenosis is hemodynamically significant. In cases of significant carotid artery disease, the carotid siphon and middle cerebral arteries often can be adequately visualized to exclude a second major stenosis.

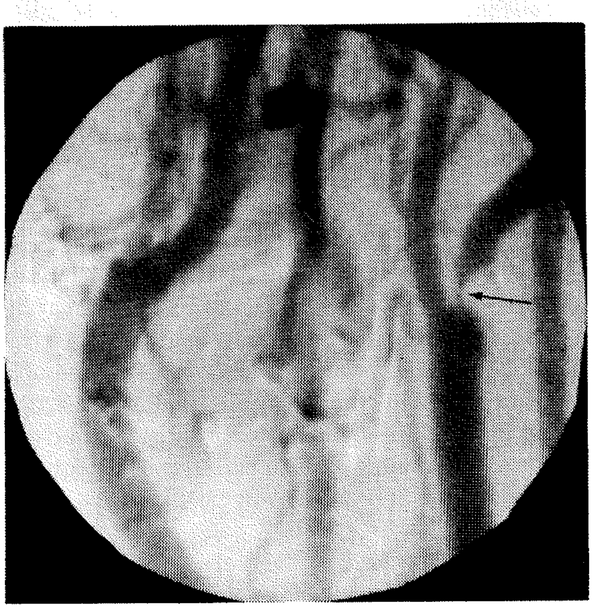

Figure 2: A patient with asymptomatic bruits was found to have a hemodynamically significant stenosis of the left carotid circulation on non-invasive tests. The IV DSA confirmed a tight stenosis (arrow) of the left internal carotid artery. An endarterectomy was performed.

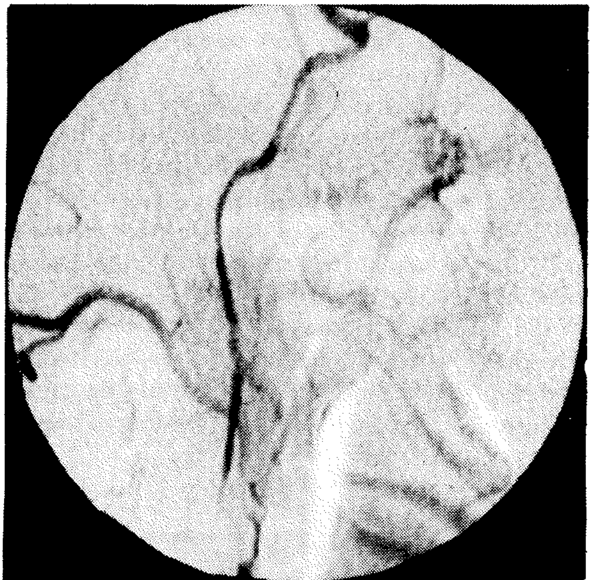

Figure 4B: A later frame demonstrates the "string sign" with delayed filling of a hypoplastic internal carotid artery. The findings indicate a critical stenosis of the carotid artery and an emergency endarterectomy was performed.

patients with severe atherosclerotic disease, tortuosity or stenosis of the proximal vertebral artery often precludes selective catheterization of either vertebral. With arterial DSA, good images of the intracranial circulation can be obtained with an injection in the subclavian artery.

In cases of cerebral neoplasms, the character and location of the lesion has already been delineated with computed tomography or magnetic resonance imaging. Arterial DSA is entirely adequate for the preoperative evaluation of tumor vascularity. Early draining veins and vessel encasement can be identified without difficulty. In addition, any involvement of the major intracranial sinuses can be seen.

The increased contrast sensitivity and the presentation of images in a subtracted format are major advantages of arterial DSA for evaluating tumors in the external carotid circulation. The smaller volumes of contrast material result in less patient discomfort and less patient motion to give better subtracted images. The tumor vessels can be viewed without overlap of bony structures; moreover, there is no waiting for the films to be processed to determine whether or not the injection was adequate. Digital processing can image the venous side of the circulation better than conventional film arteriography; this is particularly valuable in assessing involvement of the internal jugular vein by a glomus jugulare tumor.

Intravenous DSA

Intravenous DSA is performed with a short catheter in an arm vein or a longer catheter positioned in the superior vena cava. For each projection, 30–40 ml. of angiographic contrast are injected at a rate of 15–25 ml. per second. Images are acquired at a rate of one or two frames per second on a 512 × 512 matrix using a six or nine inch mode on the image intensifier.

Routine views of the carotid bifurcation consist of two 65 degree oblique views of the neck (Figure 1A). If a patient is symptomatic, an additional off-lateral view of the carotid siphons is obtained (Figure 1B). If the routine views disclose a significant stenosis in the neck, then an AP view of the head is also obtained to look for asymmetry of flow to the cerebral hemispheres as well as assessment of collateral flow. A lateral view of the head is helpful to screen the basilar artery (Figure 1C). An oblique view with the patient turned to the right is best for imaging the aortic arch. Under optimum conditions, a negative examination consists of three injections of contrast material. Supplementary views are sometimes necessary when overlap of vessels or misregistration of the image occurs. For safety reasons, assuming normal renal function, a limit of five injections (74 grams of iodine) is recommended for any one examination.

Figure 1A: An oblique view of an intravenous DSA shows normal carotid bifurcations and the vertebral arteries.

exposure to the patient is also reduced (Pavlicek, Weinstein, Modic, Buonocore, and Duchesneau, 1982).

On the other hand, IV DSA is not the panacea as was first thought. Distinct limitations exist. IV DSA will not detect small ulcerations within atheromatous plaques as well as conventional film arteriography. At least 10% of the studies are suboptimal. The most common reason for this is misregistration between the image and mask due to patient motion or swallowing. Re-registration and hybrid subtraction techniques reduce, but have not eliminated, these artifacts. Moreover, since the technique consists of a flush injection of contrast material, all arteries are opacified simultaneously. This can result in superimposition of vessels (Turski et al., 1983). From a negative perspective, the data of Foley et al. (1984) reveal that 27% of their studies were inadequate and one-half of the surgical cases required additional selective angiographic studies for confirmation, along with the common failure to adequately see the circle of Willis for evaluation of collateral circulation.

As more experience was gained with IV DSA, it became apparent that it is not a noninvasive procedure. If the bolus injection of contrast material induces a hypotensive episode, a patient with a carotid stenosis is at risk for cerebral ischemia and stroke (Aaron et al., 1984). The risk of an allergic reaction to the contrast material is higher with an intravenous injection than with an arterial injection. The total volume of contrast material represents a significant contrast load for the kidneys, and IV DSA is not recommended in the renal-compromised patient. In patients with a history of angina, we have noted a 40% incidence of chest pain and ischemic changes on ECG during the IV DSA, mostly in those patients who were in an American Heart Association functional class III or IV (Hesselink et al., 1984).

Rarely, there can be technical complications, such as extravasation of contrast material in the arm from a short catheter or into the mediastinum from the centrally placed catheter. We had two cases of mediastinal extravasation, both of which resulted in mild chest discomfort and no morbidity. Phlebitis is another minor complication that has been reported.

Arterial DSA

As we have gained experience with IV DSA, we have learned what its proper role should be in neuroimaging and we have become aware of its deficiencies. To improve the resolution, some researchers have advocated using arch injections (Zimmerman, Goldman, Auster, Chen, and Leeds, 1983) and this technique has gained acceptance in some institutions. More commonly, for arterial digital imaging, the catheter is placed selectively in the artery supplying the vascular territory to be imaged as with conventional film arteriography. A small volume of contrast material is injected and the images are acquired with the digital system as described for IV DSA. The small vessel detail achieved with arterial DSA does not equal that of film screen arteriography, but is surprisingly good and certainly much better than IV DSA. In addition, since arterial DSA involves selective injections, there is not the problem of overlap of vessels that can occur with IV or arch DSA.

One application for arterial DSA is for those cases of arteriosclerotic cerebral vascular disease where IV DSA was unsuccessful or where better detail of the intracranial circulation is desired. Small ulcerations and critical carotid stenoses can be identified without difficulty (Figure 4). In cases of embolic disease, the occluded vessel can be identified as well as retrograde filling of the more distal vessels. Because of the smaller contrast requirements, views of the aortic arch can be obtained routinely in cases of arteriosclerotic disease. Good images of the arch can be obtained with an injection of 15 or 20 cc. of contrast material injected through the same 5-French catheter used for the selective catheterization (Figure 5).

Selective arterial DSA has advantages over both IV DSA and conventional arteriography for imaging the vertebral-basilar circulation. The spatial resolution of arterial DSA is sufficient for imaging the smaller vessels in the posterior circulation. The better contrast resolution permits use of smaller volumes of contrast material to give an added margin of safety. Moreover, in

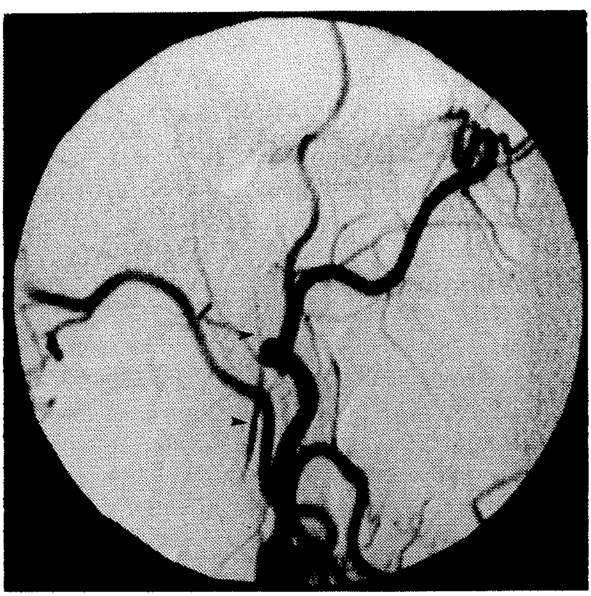

Figure 4A: This patient had an acute onset of fluctuating neurological deficits and was suspected clinically of having virtual or complete occlusion of the right carotid artery. An arterial DSA was performed with the catheter placed selectively in the right common carotid artery. A lateral view of the neck shows prompt filling of the external carotid artery, but only faint opacification of a segment of the internal carotid (arrowheads).

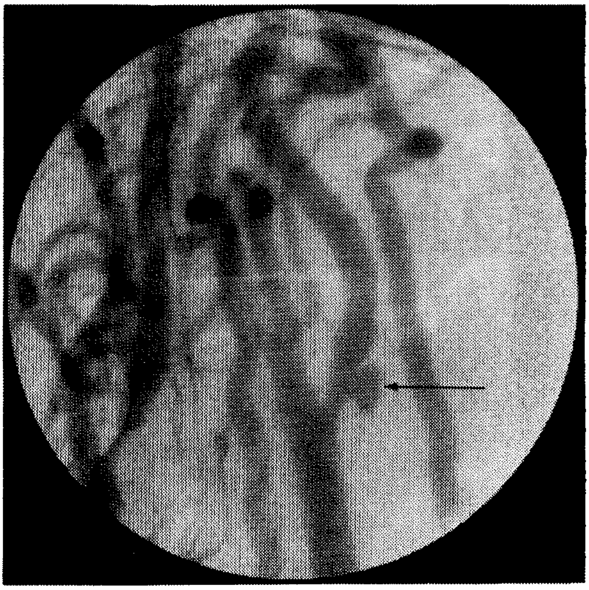

Figure 3: This patient presented with left hemisphere transient ischemic attacks. The IV DSA revealed a large ulcerated plaque (arrow) and a moderate stenosis of the left internal carotid artery.

In a study of IV DSA as a definitive pretherapy examination for cerebral ischemia, Foley et al. (1984), reported that the IV DSA was adequate in 73% of 86 patients. In the surgical subgroups, the IV DSA was adequate as a preoperative study for carotid endarterectomy in 50% of cases.

Intravenous DSA may have difficulty distinguishing a very critical carotid stenosis from complete occlusion of the internal carotid artery. With a very tight carotid stenosis, a trickle of contrast material passing into the cervical internal carotid artery could easily be missed on delayed DSA images. Seeger, Carmody, and Goldstone (1984) reported successful imaging of the "nearly occluded internal carotid artery" by IV DSA in three cases. Nevertheless, in the case of apparent carotid occlusion, if the occlusion does not have the characteristic stump appearance of an old occlusion on the DSA image, or if the clinical history suggests a more acute event, then a selective arteriogram must be done to better delineate the anatomy at the site of suspected occlusion.

If slow flow is observed in the common carotid artery, a view of the arch should be obtained to look for a stenosis at the origin of the common carotid artery. Because of contrast limitations, routine imaging of the aortic arch is not recommended. In cases of suspected embolic disease or small vessel disease

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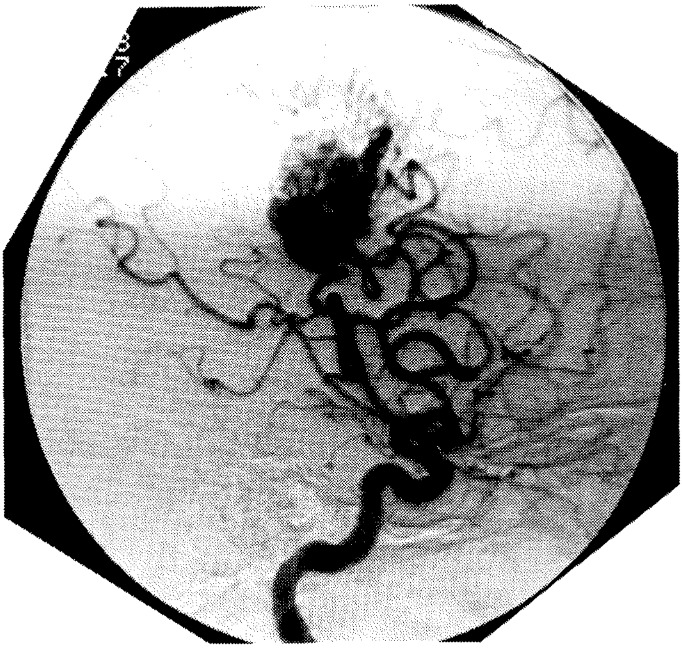

Figure 6A: A lateral view of a carotid angiogram demonstrates an arteriovenous malformation in the parietal lobe. The malformation is supplied by multiple feeding arteries from the middle cerebral artery.

technical complication during that ten minute period. With digital imaging and instant replay of the images, one can determine immediately what additional views are necessary and take those views without delay. Furthermore, since digital imaging requires less than one-half the amount of contrast material, multiple views of the aneurysm can be taken with little additional risk to the patient.

Arterial DSA still has less spatial resolution than conventional film angiography. Therefore, in cases of subarachnoid or intracerebral hemorrhage where a source of the hemorrhage is being sought, a small aneurysm or tiny AV malformation cannot and should not be excluded on the basis of an arterial DSA. Such patients should undergo transfemoral selective film-screen arteriography. Similarly, since visualization of small vessels is required in suspected vasculitis, conventional arteriography is recommended.

Arterial DSA has many of the same inherent risks as conventional arteriorgraphy. Catheter manipulation carries the small but real risk of cerebral embolism by dislodging an atheromatous plaque or from formation of clots at the tip of the catheter. On the other hand, data in the literature indicate that the incidence of complications during an angiographic procedure is directly related to the length of the procedure. Digital imaging not only shortens the procedure by requiring less time for catheter insertion and positioning, but also by furnishing digitized images, which can be viewed immediately in a subtracted format. One does not have to wait for the films to be developed to decide whether or not additional views are needed or whether or not the procedure is finished. Also, the volume and concentration of contrast material can be decreased with arterial DSA. The contrast material requirement depends on the inherent contrast resolution of the digital system. In general, for imaging the intracranial vessels, one can use one-half the amount of contrast material that is used for conventional arteriography. This can be accomplished by decreasing either the volume or the concentration of contrast material or both. For imaging the neck vessels, an even lower concentration of contrast material is adequate.

In cases of atheromatous cerebrovascular disease, one other technique can be used in conjunction with arterial DSA to further reduce the risk of a complication. Since only common carotid injections are necessary, good images can be obtained using hand injections of contrast material with the catheter positioned in the origin of the vessel. This eliminates the risk of introducing guidewires and catheters selectively into diseased arteries.

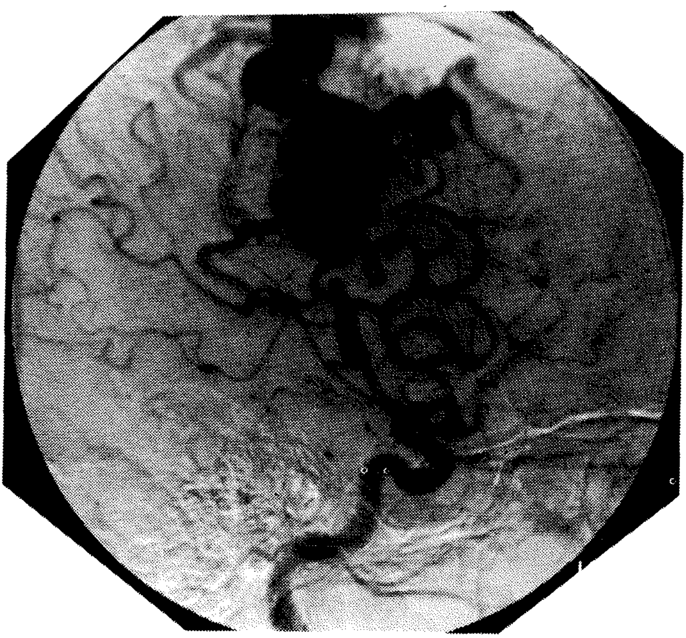

Figure 6B: On a mid-arterial phase film, the venous drainage is predominantly toward the superior saggital sinus.

The capability of rapid filming rates gives DSA an advantage over conventional arteriography for the evaluation of high flow arteriovenous malformations. The multiple arterial feeders to these complex lesions as well as the venous drainage can be delineated (Figure 6). If the angiography suite is equipped with a C-arm, it is relatively simple to perform stereo-arteriography to give the surgeon a three-dimensional picture of the anatomy of the malformations.

Digital imaging is also helpful for delineating the anatomy of some aneurysms. With conventional film imaging, after the standard views are taken, one must wait five to ten minutes to examine the films to determine what additional views are necessary to define the neck of the aneurysm. During that time period, one has the choice of leaving the catheter positioned selectively within the artery or pulling the catheter down into the aorta and reinserting the catheter selectively after it has been determined what additional views are necessary. In either case, there is additional risk of a

Figure 5: An injection of 20 cc of contrast material through a 5-French catheter provides good visualization of the aortic arch and origins of the brachiocephalic vessels.

Role in Interventional Radiology

The ability to observe the subtracted images in real time is particularly helpful for interventional techniques and gives an added margin of safety in these procedures. The digital imaging permits instant replay of the images on the monitor and shortens the procedure time considerably. Conventional subtraction methods can take from 10 to 15 minutes and the neuroradiologist must also leave the angiography suite to examine the images. Another benefit of DSA is that the embolization procedure can be closely monitored to avoid over-embolization of a vascular territory, thereby minimizing the risk of stray emboli.

Conclusion

Digital imaging has assumed an important role in cerebrovascular imaging, and digital capabilities should be part of any modern angiography suite. Many options are now available for imaging the cerebral circulation, including IV DSA, arch DSA, selective arterial DSA and conventional film arteriography. No firm rules can be stated as to when to use each one. Neuroradiologists have learned that digital imaging should be an adjunct to conventional angiography and not a replacement. Clearly, the use of IV DSA has declined considerably in the past few years as the novelty of the new technique wore off. Reasons for the decline include inferior image quality, a significant rate of unsuccessful studies (Foley et al., 1984; Turski et al., 1983), and literature reports of some serious complications (Aaron et al., 1984) from a test that was initially heralded as a less-invasive aternative to conventional angiography. Utilization of IV DSA varies considerably from one institution to another; some guidelines currently in use have been outlined above. To summarize, IV DSA can be used for evaluation of atheromatous disease of the carotid bifurcations. Intravenous DSA is not recommended for evaluation of intracranial aneurysms, AV malformations, cerebral tumors or inflammatory diseases. These diseases require selective arteriographic studies, using either digital or conventional film-screen imaging.