MODERN VASCULAR IMAGING

Lawrence M. Ness, Consultant Radiologist
Lancaster & Kendal Hospitals

It is almost 100 years since Roentgen discovered X-rays and it may seem incredible to realize that vascular radiology is almost as old. The first arteriogram was produced in Germany in January, 1896, only one month after Roentgen's discovery and was achieved by injecting the vessels of an amputated hand. By the early 1920s, several workers sought to obtain in-vivo arteriograms using rather primitive and toxic contrast agents. Arteriograms of the peripheral, pulmonary, aortic and even cerebral circulations were produced by courageous pioneers who, on occasions, even practised self-experimentation! Catheterization techniques, contrast media and radiographic equipment continued to improve and it soon became possible to obtain high quality arteriograms of all the major vascular territories of the body.

Patients and radiologists of the later twentieth century are indebted to the work of these pioneers and also to the astounding technological progress which has made modern angiography a safe, convenient, comfortable and precise technique.

Arteriography reached its zenith in the early 1970s. Up to that time diagnostic arteriography had been used not only to study intrinsic vascular disease but also to demonstrate the circulation of solid viscera, such as kidney, brain and liver, in order to examine disease within these organs. This latter diagnostic function has declined considerably with the advent of modern cross-sectional imaging techniques such as computed tomography, ultrasound and magnetic resonance imaging.

This review article seeks to illustrate the current practice of angiography and to assess future developments.

Arteriography has traditionally been an invasive, uncomfortable and hazardous procedure requiring hospital admission. On occasions, general anaesthesia was required due to the intense pain experienced during injection of conventional ionic contrast media. Two major developments have significantly altered this image. Firstly, the introduction of low osmolar non-ionic contrast agents has eliminated the intense discomfort and side effects associated with injection. These agents are significantly less toxic. Secondly, the introduction of digital subtraction angiography (DSA) in the late 1970s has brought vascular imaging into new clinical areas which were not previously accessible.

DIGITAL SUBTRACTION ANGIOGRAPHY

Digital radiography presents a marked departure from conventional radiography. The images are initially captured electronically rather than on film and are then converted into digital form which permits further manipulation to modify or improve the image. Thus, a suboptimal image can be post-processed using features such as contour enhancement, pixel-shifting (a re-registration process), magnification, reversal and picture integration. Digital systems possess greatly increased sensitivity which allows visualization of images not possible on film radiography.

The principle of digital subtraction works in the same manner as the conventional dark-room subtraction process, which has been used for many years to enhance arteriograms by eliminating superfluous irrelevant background detail, leaving only opacified vessels on the final image. The advantage of digital presentation is that subtracted images are available for viewing immediately after acquisition because the subtraction process is carried out simultaneously by electronic means. This reduces examination time considerably and offers greater control and safety during vascular procedures. The most dramatic development in digital radiography was intravenous digital subtraction arteriography (IVDSA). When IVDSA became available in the late 1970s it was greeted with wild optimism by radiologists, and enthusiasts predicted that all ateriography would eventually be possible using a single peripheral intravenous injection of contrast. Unfortunately, this initial optimism was never completely realized and some institutions abandoned IVDSA completely. Digital subtraction images suffer from an inferior spatial resolution and many clinicians find the unconventional appearance of the images unacceptable when compared to conventional films. The sensitivity and image manipulation of digital radiography, however, far outweigh these drawbacks and provide a superior vascular imaging facility. IVDSA still has an appropriate role in the following areas:

1. **Cervicocranial IVDSA**
   The preferred initial evaluation of the extra-cranial carotid arteries is Colour Doppler ultrasound as it is completely non-invasive. Arteriography is required for the evaluation of equivocal ultrasound findings and for pre-operative confirmation. IVDSA avoids hazardous manipulation of catheters within diseased arteries and eliminates the possibility of embolism. However, a diagnostic study is only achieved in approximately 70% of cases and, therefore, intra-arterial studies remain the preferred technique in this area.

2. **Renal IVDSA**
   The use of IVDSA for renal angiography is not clear. Proponents of the technique claim diagnostic images of the main renal arteries in 90% of the cases with the added advantage of selective renal vein renin sampling at the same time. However, the branch vessels are poorly visualized and this method tends to overestimate stenoses in atheromatous disease and underestimate lesions in fibromuscular hyperplasia. At best, IVDSA provides a minimally invasive method of screening for severe renal arterial stenotic disease.

3. **Aortic and Extremity IVDSA**

Aortic and extremity arteriography form the majority of vascular studies in a general department and are ideally suited to IVDSA. The method avoids interference with diseased extremity arteries which may shortly become the site of a surgical anastomosis. It is also invaluable in the evaluation of post-operative graft patency and eliminates the undesirable need to puncture a graft (Fig. 1).

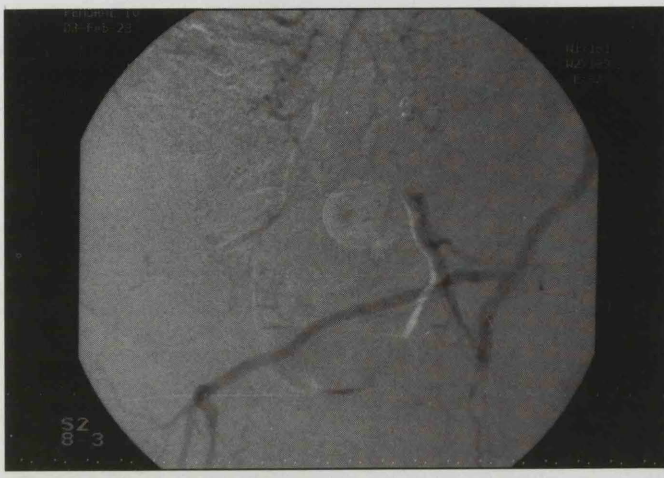

Fig 1 – IVDSA confirms patency of left axillo-femoral and femero-femoral crossover grafts in the pelvis with this outpatient anteriogram

IVDSA TECHNIQUE AND PATIENT SELECTION

IVDSA can be performed as an outpatient procedure with considerable economic advantage for both medical institution and patient. No specific preparation is required but adequate hydration is very important.

The procedure is performed under sterile conditions and local anaesthesia by placing a cannula into an antecubital vein. A guidewire and pigtail catheter are then passed along the basilic vein until the catheter tip lies within the right atrium. A large volume of full strength contrast is injected through this catheter in the space of two seconds, resulting in a momentary feeling of intense heat within the chest, of which the patient should be forewarned and reassured (Fig. 2). Approximately five such injections are required for a peripheral lower limb study. The patient usually spends a total of one hour within the department. A pressure bandage is placed over the venous puncture and the patient is advised to drink plenty of fluid.

A good cardiac output is required for an adequate study and IVDSA may fail in the presence of cardiac failure. The technique requires a high contrast load and this may be undesirable in impaired renal function, diabetes, myeloma and in elderly patients. Patients undergoing a central injection of full strength contrast medium demonstrate ECG changes and occasionally angina attacks may be precipitated. For this reason, IVDSA should be avoided in the presence of severe ischaemic heart disease.

INTERVENTIONAL VASCULAR RADIOLOGY

The percutaneous vascular techniques originally devised for diagnostic examinations have been ingeniously adapted to provide a whole variety of therapeutic procedures. This branch of radiology has expanded dramatically in the past decade and continues to have a profound impact in medicine and surgery. Interventional vascular radiology consists of

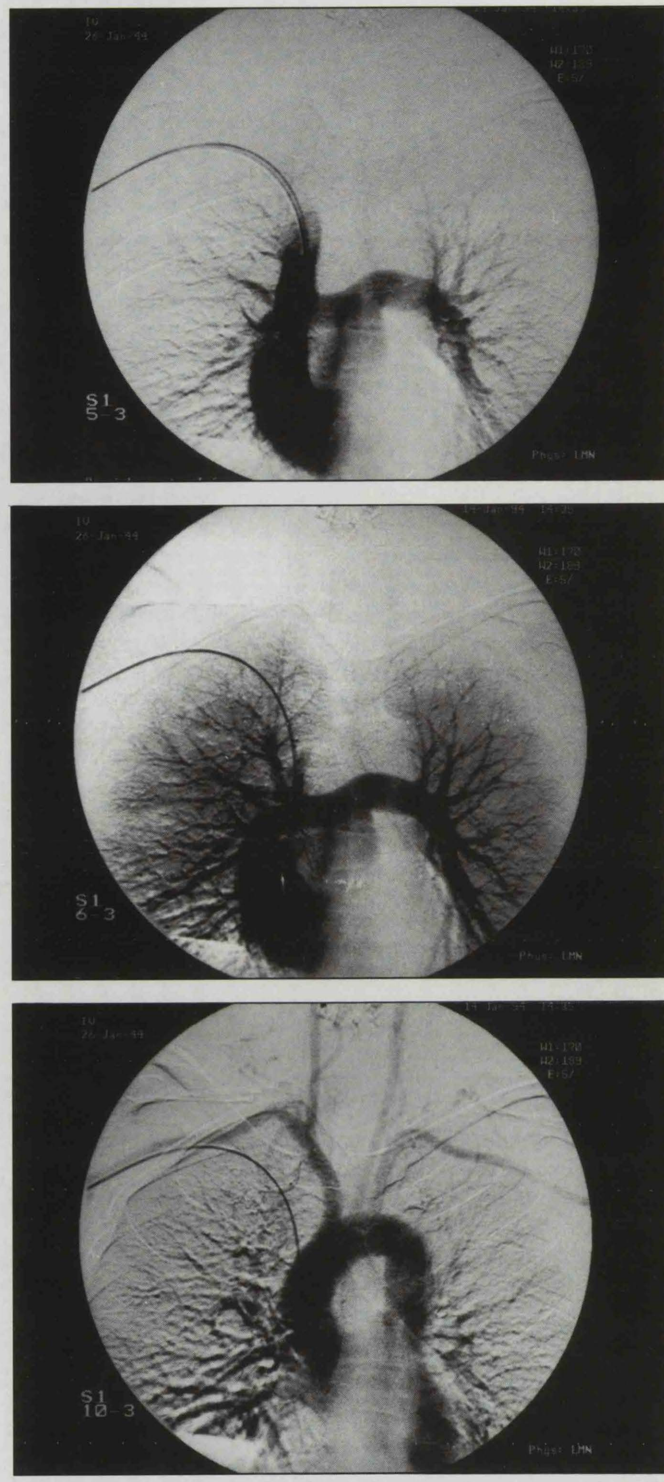

Fig 2 – Demonstration of the cardiopulmonary transit of contrast to form an IVDSA arteriogram of the aortic arch vessels. Contrast injected into the right atrium opacifies the aortic arch 3 seconds later

three main strategies, namely vascular therapy (e.g. infusion of thrombolytic agents), vascular embolisation and vascular dilatation. Only vascular dilatation will be considered further in this review.

Vascular dilatation or percutaneous transluminal angioplasty (PTA) was first performed in 1964 and rapidly became a widely practised technique. Most medical institutions in the U.K. offer a peripheral arterial angioplasty service, producing results with a high success rate and low incidence of complications. It is essential to adopt an integrated approach to the management of vascular disease, involving both radiologist and surgeon, if the reputation of PTA is to be maintained and so that patients receive appropriate therapy for their individual needs and potential complications are managed correctly.

The appeal of angioplasty lies in its endeavour to repair a native vessel and restore normal anatomy and physiology with minimum disturbance to the vascular system (Fig. 3). It is also a relatively minor procedure performed under local anaesthesia (with optional sedation) and associated with shorter hospital admission and cost when compared to surgery. The high surgical and anaesthetic morbidity associated with arteriopaths can be avoided. This was shown in a large prospective study by Jeans et al[1] which investigated the outcome of patients undergoing lower limb PTA and showed an increased number of deaths from cardiac and cerebral vascular causes in those patients in whom PTA had failed and surgery had become necessary.

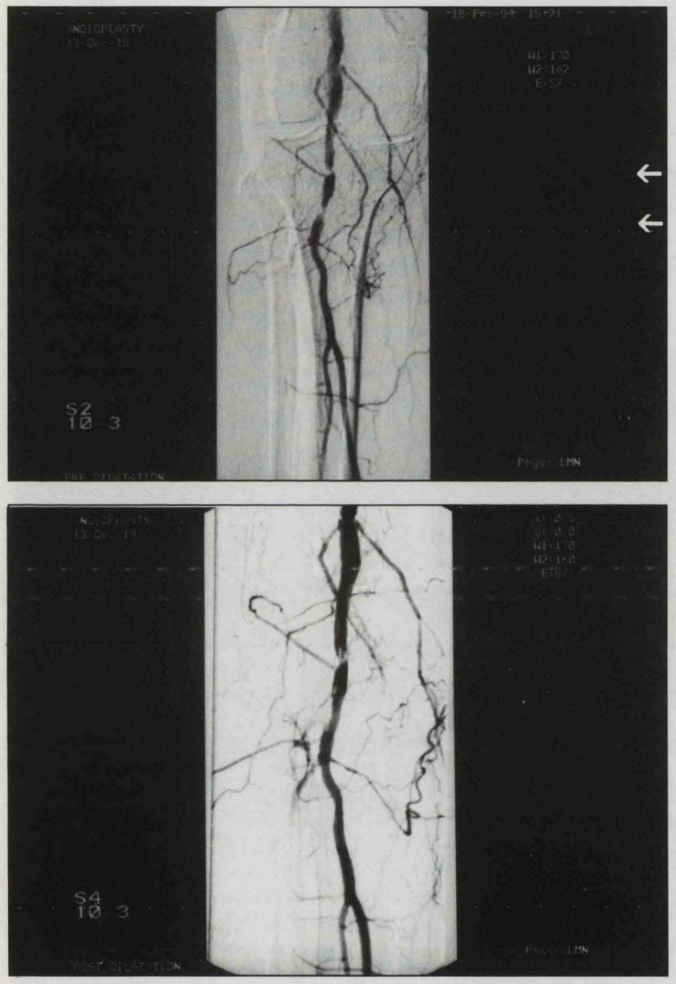

Fig 3 – Angioplasty of these popliteal artery stenoses (arrows) abolished the patient's rest pain and reversed lower limb critical ischaemia a) pre dilatation and b) post dilatation

The ideal lesions for angioplasty are short segment stenoses or short occlusions in the ileo-femoral and popliteal arteries. Dilatation of these lesions is associated with high initial success rate (70 to 90%) and excellent long term patency rate (60% overall after seven years) with poorer results in smaller vessels and when widespread disease is present. It should be stressed that atheromatous arterial disease is progressive and therapeutic benefit from an interventional procedure should be obtained quickly with minimum disturbance to the patient before the disease advances and requires further treatment. Furthermore, in the late clinical presentation of vascular disease, angioplasty performed for limb salvage in critical ischaemia is considerably more cost effective than amputation even if it only achieves freedom from rest pain. Repeated PTA can be performed as soon as three months after an initial procedure if symptoms recur.

Intravascular Stents

PTA has become an accepted means of restoring blood flow to the extremities and long term patency rates are comparable to those achieved surgically. However, the position regarding diffuse athero-sclerotic disease and complete arterial occlusions is less favourable, with low post-angioplasty patency and high complication rates. The concept of providing permanent continuous support to a vessel to maintain patency following dilatation was first realised in 1969 when a coiled spring was placed percutaneously into an artery. A variety of devices has become available since that time and the best results have been obtained with the Wallstent (Schnieder-UK). The Wallstent is a tube woven from stainless steel alloy, giving it elastic and pliable properties. It can be constrained onto a small diameter delivery catheter and when placed within a vessel expands to its original diameter. This exerts a radial force within the vessel, thereby maintaining patency. After approximately three months, a lining of endothelium grows over the stent's surface and the implant is no longer recognised as a foreign body, thus diminishing the risk of stent thrombosis. Patients are placed on oral anticoagulation with Warfarin until endothelialisation has taken place, after which they require only a small daily dose of oral aspirin. The Wallstent has been in worldwide use since 1987 and encouraging results have been obtained with intravascular use. The highest success rates have been obtained within large vessels such as iliac and proximal femoral arteries with significantly inferior results in the femoro-popliteal segments. The unreserved indication for intravascular stent placement is in SVC obstruction where symptoms can be abolished within 12 hours and the long term patency is excellent.

Intravascular stent placement at any site is a permanent, irreversible procedure and careful consideration should be given before committing a patient to this form of treatment. It should not be used as a first-line approach and alternative therapies should be tried initially. Subsequent surgery can be difficult and hazardous in the presence of a Wallstent. Furthermore, these devices are very expensive – costing six hundred pounds each – and their use may not be economically justifiable in every situation. Vascular disease is progressive and PTA may provide an adequate, cheaper alternative which would suffice for a patient and could be repeated. In normal practice, it seems best that the use of intravascular stents is restricted to treating occlusive intimal dissection at angioplasty, recanalising complete occlusions or treating recurrent stenotic disease following repeated angioplasty.

FUTURE DEVELOPMENTS

An insight into the future of vascular imaging is provided for us by exciting developments in three present-day imaging modalities, namely Colour Doppler ultrasound, CT Angiography (CTA) and Magnetic Resonance Angiography (MRA).

Colour Doppler ultrasound combines real-time ultrasound and pulsed doppler to provide a colour display showing blood flow within vessels superimposed upon the grey scale image. The blood flow is assigned a colour, typically red or blue depending upon flow direction relative to the probe. Turbulent blood flow causes colour desaturation and this is displayed as white. Colour Doppler equipment combines all three types of ultrasound and the use of colour simplifies the examination of vessels by instantaneous presentation of flow across the entire field of view and allows precise pulsed doppler analysis of flow at specific points. Colour Doppler ultrasound is limited by the same restrictions of access and penetration as conventional ultrasound and is, therefore, unable to demonstrate the entire vascular system; nevertheless it has found a well-defined role in the assessment of peripheral vessels, particularly the carotid arteries. Colour Doppler examinations are highly operator-dependant, can often be time-consuming and are associated with a higher percentage of non-diagnostic studies.

CT angiography has become possible by a revolutionary modification known as "spiral CT scanning", whereby tissue volume is scanned rather than serial cross-sectional slices. Spiral CT scanners are highly rated, permitting very fast scanning covering up to 60 cm length of tissue in as little as thirty seconds, using less contrast than a conventional CT examination. The volume of tissue examined during dynamic contrast enhancement can then be processed at a work station to demonstrate the vascular anatomy, using either MIP (maximum intensity projection) or 3D shaded surface displays. The accompanying illustrations dramatically demonstrate the capability of CTA (Fig. 4). The 3D display has found initial application in the abdomen to show the relationship of abdominal aortic aneurysms to renal arteries prior to surgery. Non-invasive renal artery imaging is essential in potential renal donors and also in screening for renal artery stenosis. C.T. Angiography (CTA) has been shown to be more accurate in demonstrating accessory renal vessels and stenotic disease than Magnetic Resonance Angiography (MRA) and the results show high correlation with conventional angiography, with the additional bonus of showing the surgeon the 3D relations with adjacent vessels. CTA does not suffer from motion artefact in the abdomen, which severely restricts MRA in this region. MRA and CTA provide similar image quality in the cervico-cranial arterial circulation. The application of CTA to the peripheral arterial system is less clear at present due to the limitations of scan length ability and contrast bolus timing.

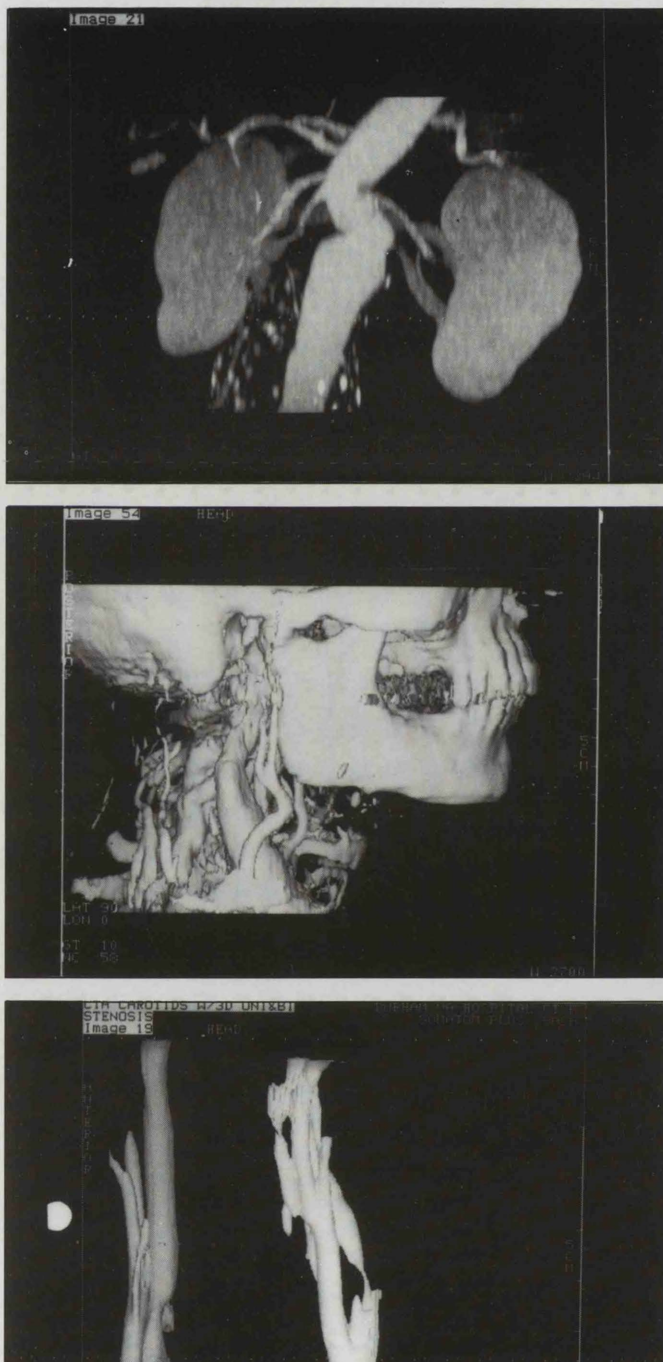

Fig 4 – CTA demonstrates regional anatomy by non invasive technique
a) maximum intensity projection (MIP) showing the relation of renal arteries to an aortic aneurysm
b and c) 3D shaded surface displays.
Note the internal carotid stenosis in (c)
All courtesy of SIEMENS AG

Fig 5 – 3D MRA study of circle of Willis using 3D time-of- flight sequence. This image was obtained without the use of any contrast medium and can be viewed in different 3D projections at a workstation
Courtesy MRI department, St James's University Hospital, Leeds

Magnetic resonance angiography is the most exciting future vascular imaging technique and has achieved the ultimate ideal in diagnostic imaging of providing dynamic 3D vascular images non-invasively without the use of contrast (Fig. 5). MRA is still undergoing research and development and it seems inevitable that considerable areas of diagnostic angiography will eventually be performed by this technique. It has had an immediate impact in cardiac imaging where the combination of multi-planar images and the non-invasive element have revolutionalised the investigation of congenital cardiac disease. Inferior spatial resolution and motion artefacts limit the current use of MRA but technological refinements may eventually overcome these. A specific problem is the inaccuracy in assessing stenotic arterial disease due to blood flow turbulence disturbing the MR signal beyond the stenosis. Carotid plaque ulcerations may not be detected either for similar reasons. However, MRA is more accurate than Doppler Ultrasound in differentiating a severely stenotic vessel from a complete occlusion.

Each of the new imaging modalities will ultimately occupy a clearly defined role in specific clinical situations. It is inevitable that these newer techniques will replace conventional methods but the restricted access and time pressure on high technology diagnostic equipment means that the transition will be slow. Skill in conventional arterial access will still be required to perform interventional procedures.

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