Noninvasive imaging of the aorta has undergone considerable refinement in recent years. This has been brought about by significant technologic advances in computed tomography (CT), magnetic resonance (MR) techniques, and duplex ultrasound (US) scanning. Three-dimensional techniques and shorter acquisition times for CT and MR imaging have made it possible to time the infusion of contrast medium to highlight the aorta and its branches. In addition, improvements in processing and rendering of three-dimensional images have increased the clinical utility of these examinations. As a result, the role of traditional angiography is being gradually restricted to special indications and to patients who may require catheter-based interventions. The utility of imaging tests to establish a diagnosis may not correspond with their value in planning the course of treatment, and the relative merits of these applications will be addressed.

ANEURYSMAL DISEASE

For the initial diagnosis of abdominal aortic aneurysm (AAA), for screening, or to rule out aneurysmal disease, measurement of only the maximal transverse diameter of the abdominal aorta is necessary, and noninvasive duplex US imaging is adequate. More anatomic detail is desirable when preparing for open surgical repair of AAA including the extent of the aneurysm, the location of its neck, anomalies of the renal artery, renal vein, and kidneys, and occlusive disease of branch vessels. During open repair of aneurysms, adjustments to or modification of the operative plan can be made to accommodate morphologic peculiarities. Therefore, CT with 10-mm interval cuts may be sufficient to plan for open repair. However, endovascular repair of AAA is inherently less flexible. More precise definition of aortic morphology is required preoperatively for appropriate patient selection and for sizing of the prosthesis.

OCCLUSIVE DISEASE

For evaluation of aortic and aortic branch vessel occlusive disease, conventional arteriography remains the gold standard. However, recent advances in noninvasive imaging are making it more readily applicable to this group of diseases, so that it can provide an alternative that, in addition to being less invasive, may be associated with decreased morbidity, lower rates of renal and radiation toxicity, and lower cost.

ULTRASOUND

US was the first noninvasive imaging test to be applied to aortic disease and formed the basis for the studies of the natural history of AAA in the 1970s. Technologic improvements, including the combination of B-mode US with pulsed-wave Doppler to form the duplex scanner, and color-flow mapping systems, have increased the utility of US in the diagnosis of vascular disease. The quality of the examination may be affected by patient factors such as bowel gas and obesity as well as by the expertise of the imaging physician or technologist.

For imaging of the aorta, common use of duplex US has been largely limited to evaluation of aneurysmal disease. It is accurate for measuring the maximal transverse diameter of the aneurysm and has been shown to have excellent correlation with measurements on CT and at operation, although one recent study reported that US consistently underestimated aneurysm dimensions compared with CT (Fig. 5–1). By virtue of its ready availability, low cost, and the absence of toxicity, US is particularly suitable for screening, to establish or rule out the diagnosis of AAA, and for surveillance of small aneurysms. More elaborate studies may be difficult owing to the retroperitoneal location of the aorta and its frequent obscuration by bowel gas. Visualization of the renal arteries and iliac arteries is inconsistent, and the test cannot be relied upon for identification of accessory renal arteries. Duplex US is not reliable for demonstrating aneurysmal rupture, although it may be used to confirm the presence of an aneurysm before emergency operation. In a few centers, US is the only preoperative imaging test for aneurysm surgery, but, in general, it has been used much less than CT and MR as a preoperative test and is applied mostly as a screening and surveillance tool. One particular application for which duplex has proven useful is follow-up after endovascular repair of AAA. In addition to the size of the aneurysm sac, it can demonstrate flow in the endograft, endoleaks, and branch vessel flow (Fig. 5–2).

Evaluation of aortic and aortic branch occlusive disease requires demonstration in continuity of the entire aorta and its branches, a task that is particularly challenging for US. Bowel gas may interfere with visualization even in fasted subjects, and retroperitoneal structures may be inadequately visualized in obese subjects. Even in centers that have a special interest in the application of duplex US to occlusive disease, the sensitivity for identification of aortoiliac stenoses more than 50% diameter reduction is 75% to 86%. Similarly, centers with special interest have reported 95%...
accuracy in identifying renal artery stenosis and visceral artery occlusive disease; however, duplex examination of these regions requires special dedication and expertise and has not become the standard approach. Consequently, duplex US has not assumed the central role for investigating aortic and aortic branch occlusive disease as it has for arteries located more superficially such as the carotid artery and the arteries of the lower extremity.

COMPUTED TOMOGRAPHY

CT has been the most widely applied noninvasive aortic imaging test. It delivers good images of thoracic and retroperitoneal structures, regardless of interposed gas and body habitus. It is much less operator dependent than US, and it gives the physician a legible, hard-copy image. With standard CT, information gaps between interval cross-sections could miss finer anatomic detail. With spiral CT, volumetric data are acquired from an entire vascular territory within one 30-second breath hold. This affords acquisition of an image that is free of respiratory misregistration. In addition, more rapid and precisely timed delivery of intravenous contrast bolus is possible, which places a higher concentration of the contrast agent in the structure of interest (Fig. 5–3). The data are usually reproduced as cross-sections at various intervals, but all three-dimensional data are available for processing.

Improvements in high-quality rendering of three-dimensional data have further increased the clinical utility of CT. The technique most often used has been shaded surface display (SSD), which results in a binary pixel image and in loss of most of the scan information; however, it is helpful for evaluating regions with vessel overlap and of aortic branch origin (Fig. 5–4A). Another technique is maximal-intensity projection (MIP), which loses less scan information and is better adapted to grading of stenoses (Fig. 5–4B). A third technique, curved planar reformation (CPR), is operator dependent and labor intensive but is valuable for evaluating the interior of metallic stents or calcified regions (Fig. 5–4C). These advances in processing and rendering of three-dimensional data are applicable to MR as well and have enhanced the capability of these examinations to define the extent and shape of the aortic lesions. In particular, variables that are important for planning endovascular treatment, such as vessel tortuosity or curvature, orthonormal cross-sectional diameters, and pathway lengths, can be measured with great accuracy. In
Figure 5-2 • Color-flow duplex US after endovascular aneurysm repair. (A) Longitudinal view demonstrates flow within the stent-graft without an endoleak. (B) Cross-sectional view of both limbs of the endograft. No endoleak is seen. (C) Longitudinal view of a stent-graft with a large anterior endoleak. (D) Cross-sectional view demonstrates flow in opposite directions in the stent-graft and in the aneurysm sac, respectively. (See Color Figure 5-2.)

Figure 5-3 • Spiral CT demonstrates the infrarenal aorta. Note the detail and contrast enhancement of the renal arteries.
practice, the most common method for determining the maximal diameter of an aneurysm has been manual measurement from the hard-copy scan. This method has a reported interobserver variability of 5 mm or more in 17% of cases. Since the hard-copy scan contains only a fraction of the information acquired, once the newer methods of measurement are validated, reliance on measurement from the source data will be preferable. It should be stressed, however, that the axial images should be reviewed in addition to the images obtained on the three-dimensional reconstructions.

CT has also been found to be reliable for defining the extent of thoracic disease in the chest (Fig. 5-5A). For diagnosis of thoracic aortic dissection, it had reported sensitivity of 93.7% and specificity of 87.1% in 1993, and the accuracy of CT has clearly improved since then (Fig. 5-5B). The signs of thoracic aortic injury on CT are mediastinal hematoma, aortic contour deformity, intimal flaps, pseudoaneurysm, and pseudocoarctation. These lead to CT diagnosis of thoracic aortic injury with a sensitivity of 100% and overall diagnostic accuracy of 99.7%. Takayasu arteritis can also be diagnosed on CT with great accuracy (sensitivity 95%, specificity 100%).

In the abdomen, CT can clearly delineate the size and extent of an aortic aneurysm, the relation of the aneurysm neck to the renal arteries, and concomitant iliac aneurysmal disease. Kidney and renal vein anomalies can be appreciated, and accessory renal arteries identified. CT reliably demonstrates contained rupture of the aneurysm and is the investigation of choice for this indication. The typical CT

Figure 5-4 Three-dimensional representation of spiral CT data. (A) Shaded surface display of a tortuous infrarenal aortic aneurysm. (B) Maximal-intensity projection of an infrarenal aneurysm. (C) Curved planar reformation demonstrates the course of both renal arteries.
appearance of inflammatory aneurysm, the thick enhancing aortic wall, is one of the criteria for diagnosis. In general, the quality of current CT is such that it has largely replaced arteriography for evaluation of aortic aneurysms.

Aortic occlusive disease can also be clearly demonstrated on CT, and obstructive lesions in the aortic branch vessels and the visceral, renal, and iliac arteries can be visualized. Occlusions and high-grade stenoses in the aortoiliac segment are identified with sensitivity of 93%, specificity of 99%, and overall accuracy better than 95%.

For the diagnosis of occlusive disease, the resolution of CT is still not as good as that of conventional arteriography, particularly in smaller, tortuous arteries. Other disadvantages of CT include higher cost than duplex US, ionizing radiation and nephrotoxic contrast agents, and deterioration of the image quality by metal hardware or barium in the scanned region.

MAGNETIC RESONANCE ANGIOGRAPHY

MRA is the newest of the clinically utilized noninvasive imaging tests. Initially, standard two-dimensional time-of-flight MRA was plagued by long acquisition times and breathing motion artifacts. New scanners and faster acquisition times have made it possible to cover a large volume of vascular territories in brief intervals (30 sec) of breath holding. This technique was associated with limited flow-related enhancement, but that has been overcome by “T1-shortening” intravenous contrast agents (gadolinium chelates). With this approach, MRA has become a powerful technique for imaging the abdominal aorta and iliac arteries and produces images that rival CT in quality (Fig. 5–6A). Three-dimensional processing and rendering can be done in a manner identical to CT (Fig. 5–6B). The technique most often employed for 3-D rendering of MR data is the maximum-intensity projection (MIP).

MRA is very accurate for visualizing the thoracic aorta, and it demonstrates aortic dissection with sensitivity of 98.3% and specificity of 97.8%. It is useful for evaluating aortic aneurysms, and aneurysmal dimensions are identical to those at operation. It is comparable to CT for selecting patients with AAA and for planning endovascular repair, but it is less sensitive than CT for identifying accessory renal arteries and grading renal artery stenoses. MRA is useful for follow-up after endovascular repair of AAA (Fig. 5–6C).

Occlusive disease of the abdominal aorta and its major branches can be demonstrated on MRA with resolution satisfactory for diagnosis and for treatment planning. MRA was found to be 100% sensitive and 70% specific for iliac occlusions larger than 50% of lumen diameter. Compared to arteriography, grading of stenoses agreed in 87% of cases, diagnosis of segment patency was very accurate (sensitivity >99%, specificity 100%), and therapeutic plans based on the examinations were identical. Still, its relatively lower resolution as compared with arteriography, and its cost, make it less desirable for evaluating patients with occlusive arterial disease, except in special circumstances such as renal insufficiency.

MRA provides better contrast definition of soft tissue than CT and is not sensitive to calcium. The commonly employed contrast agent gadolinium is non-nephrotoxic, and renal insufficiency is currently the most common reason for obtaining MRA rather than CT. MRA is expensive, and scanners are not readily available. It cannot be used for patients with pacemakers or implanted metallic hardware or in claustrophobic subjects.

SUMMARY

Noninvasive imaging with duplex US, CT, and MRA have largely supplanted conventional arteriography for the diagnosis and evaluation of aortic aneurysmal disease. CT and MRA provide similar information for aortic occlusive
disease with resolution that is still inferior to that of arteriography. With additional improvements, these modalities may largely replace traditional arteriography as a diagnostic tool, and arteriography will likely be reserved for cases in which catheter-based intervention is anticipated.

REFERENCES

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