3 Principles of Vascular Imaging

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Introduction

Imaging plays an increasingly important role in the assessment of postoperative vascular complications, especially as surgical and interventional techniques become more compound. A variety of modalities are available to evaluate and follow truncal and extremity vessels. Advances in imaging technology over the past two decades have greatly expanded the role of noninvasive cross-sectional imaging in the detection of postoperative complications. The American College of Radiology (ACR) has developed specific guidelines, referred to as ACR Appropriateness Criteria (AC) to assist referring physicians and other providers in making the most appropriate imaging or treatment decision for a specific clinical condition.

This review will mainly focus on providing information to healthcare professionals about the most commonly available imaging modalities with their advantages and disadvantages for assessment of postoperative vascular complications. Currently, radiograph, ultrasonography, computed tomography angiography (CTA), magnetic resonance imaging (MRI), and conventional angiography all have been used and compliment one to another by providing supplementary information.

Imaging Modalities and Protocols

CT Angiography (CTA)

Per ACR Appropriateness Criteria [1], CTA is the preferred imaging modality for the evaluation of truncal and extremity arteries due to its precise anatomic definition

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and dynamic contrast visualization. However, it is important to keep in mind the trade-off between fineness of resolution determined by slice thickness and the allowable range to be imaged. An often employed solution is to initially obtain a less detailed examination over a large region of the body, followed by a more resolute scan when allowable focusing on the area of interest.

State-of-the-art technology and standardized protocols are crucial to obtain outstanding image quality to assess postoperative vascular complications. Protocols are often tailored to answer specific questions related to the type of surgery performed. For instance, electrocardiogram (ECG) gating can be critical in patients with type I aortic dissection for visualization of the aortic root as well as presence of post operative complications such as development of pseudoaneurysms (Fig. 3.1). The addition of ECG gating allows minimization of cardiac motion artifact, which is quite significant in the proximal aorta and aortic root.

Moreover, acquisition of multiple phases allows a better characterization of findings given the addition of a time variable. While arterial phase will suffice to assess large vessel hemorrhage, hematoma, dissection, thrombosis, surgical graft integrity, device migration, or presence of postoperative pseudoaneurysm, it may be inadequate for evaluation of contrast extravasation particularly low volume phenomenon. For example, the addition of pre-contrast and delayed phases is critical to evaluate endoleaks after endovascular aneurysm repair (Fig. 3.2). One benefit of the unenhanced phase is to differentiate extraluminal calcification or post-endoleak intervention material from extraluminal contrast seen on contrast-enhanced images. The main advantage of the delayed phase is to detect slow-flow endoleaks that may not be present on arterial phase. Therefore, standard protocol for endovascular repair evaluation is triphasic, including pre-contrast, arterial, and delayed phase (60–120 s after injection). An additional late phase (300 s after injection) can be obtained for higher detection of partial thrombosis in patients with repaired aortic dissection or to better visualize low-flow endoleaks.

CTA is also the preferred modality for assessment of aortic graft infection by demonstrating perigraft inflammation or erosion of adjacent structures, such as an aorto-esophageal fistula. These conditions are supported by pathognomonic imaging findings on CTA such as circumferential graft stranding, circumferential aortic thickening, air in proximity of the graft, loss of plain between the duodenum and

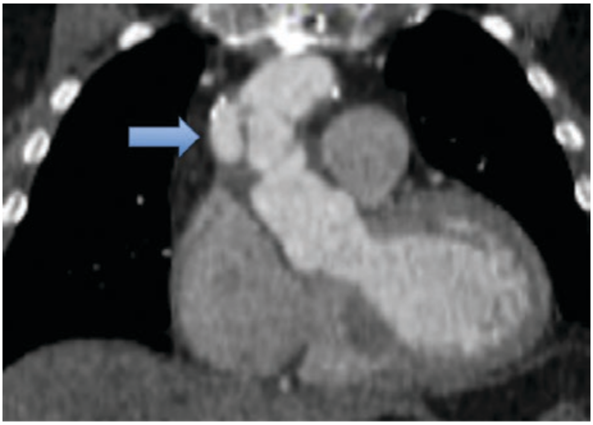

Fig. 3.1 Coronal CTA image demonstrates focal contrast outpouching at the distal graft anastomosis in a patient with prior type I aortic dissection repair consistent with postoperative pseudoaneurysm

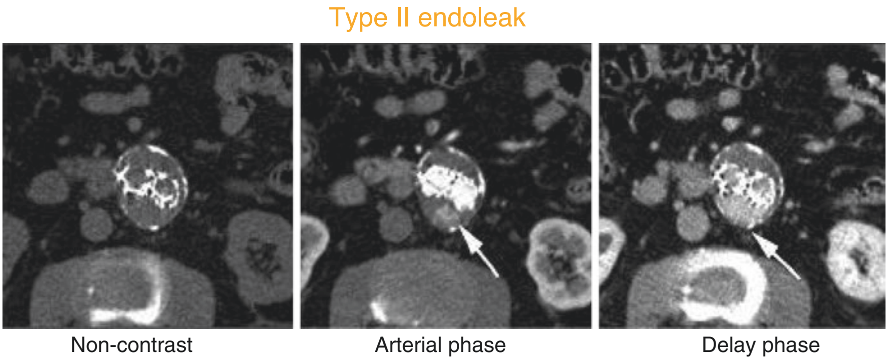

Fig. 3.2 Axial CTA images demonstrate contrast extravasation in the posterior aspect of the excluded aneurysm on arterial phase that increases on delay phase but not present on pre-contrast images consistent with type II endoleak

aorta, anastomotic disruption, and presence of fluid tracking along the length of the graft. Addition of 18F-fluorodeoxyglucose positron emission tomography (PET)/CT is increasing for determination of graft infection presence. This modality demonstrates strong sensitivity of detection when findings are analyzed to include maximum standardized uptake value (SUVmax), uptake pattern, and uptake distribution. However, its availability remains a significant barrier to utilization.

Post-processing techniques have become standard of care and provide more accurate measurements as well as detection of small lesions such as pseudoaneurysms. These techniques include multiplanar reformation, maximum intensity projection, curved planar reformation, and 3D volume rendering. CTA imaging 3D datasets should be reviewed on a workstation with multiplanar reformatting and measurement capabilities. Images should be manipulated such that reported aortic diameters are measured orthogonally to the aortic lumen, as measurements that are off-axis may significantly overestimate the true aortic diameter (Fig. 3.3a, b).

Disadvantages of CTA include potential nephrotoxicity and cumulative radiation dose, especially in younger patients who would require multiple exams along their lifetime. This issue partially has been ameliorated with the development of dual-energy acquisition, which offers the possibility of eliminating the unenhanced phase via the creation of a virtual noncontrast image set.

In patients with renal insufficiency, unenhanced CT can be an alternate exam that can be valuable for identification of aortic size, acute intramural hematoma (IMH), and aortic calcification. Moreover, in the immediate postoperative state, unenhanced CT can delineate complications related to acute aortic syndromes such as mediastinal or pericardial hemorrhage and rupture.

Magnetic Resonance Angiography (MRA)

Magnetic resonance imaging (MRI) of vessels can be performed with and without intravenous contrast and is a viable alternative for imaging a variety of conditions. Due to lack of ionizing radiation, it is an attractive alternative for surveillance of conventional

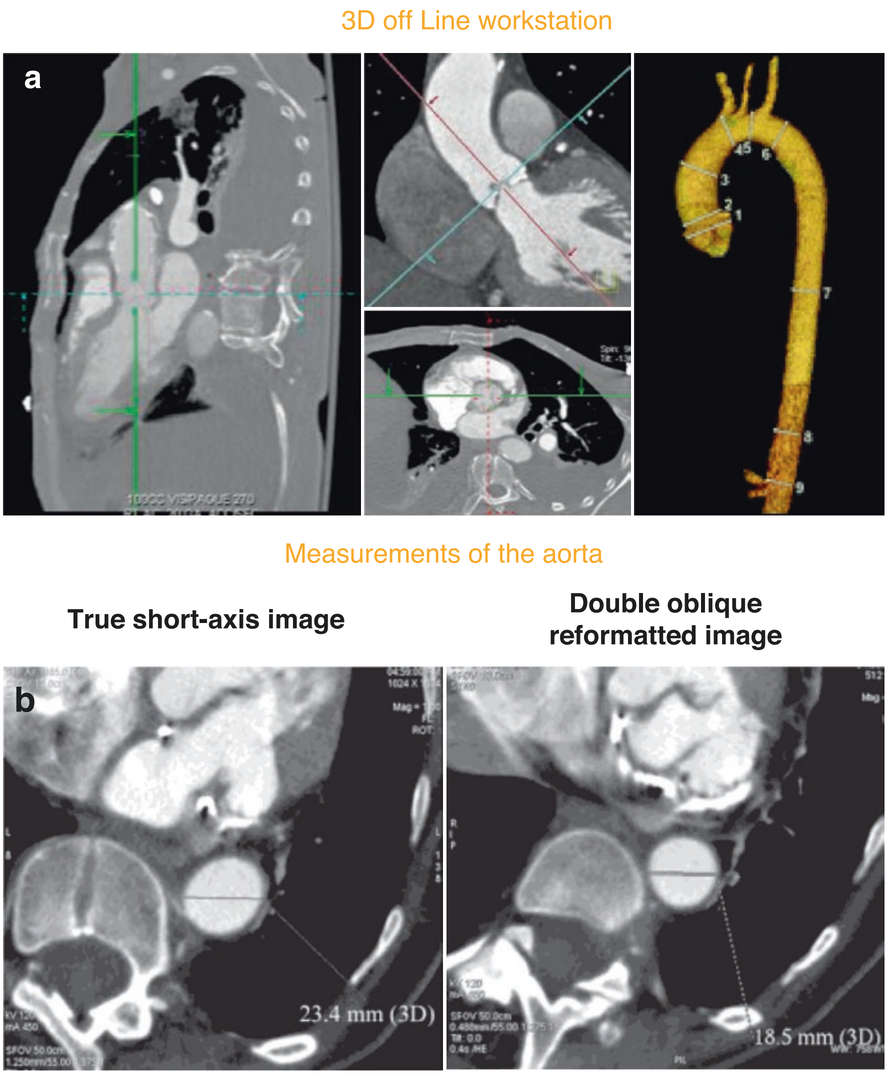

Fig. 3.3 (**a**) Multiplanar reformatting of the thoracic aorta in a 3D offline workstation. (**b**) Multiplanar reformatting of the thoracic aorta in a 3D offline workstation depicted a true short-axis diameter (right) which differs from the diameter obtained with a double oblique reformatted image (left)

surgical repair of the aorta in young patients that require multiple exams. However, in the evaluation of endovascular repairs, metallic stent grafts and other materials can obscure fine details that are often essential in postoperative assessment, resulting in inability to assess stent patency. In those cases, CTA is the preferred modality.

Most MRA protocols have been particularly helpful for evaluation of the lower extremity arteries providing both excellent soft-tissue differentiation and subtracted images demonstrating the vasculature in 2D and 3D representations similar to those provided during conventional angiography. In the current era, the accuracy of CTA and contrast-enhanced MRA (CEMRA) for the detection of hemodynamically significant peripheral artery disease (PAD) has become essentially equivalent, with an edge for CTA in the aortoiliac segment and for MRA in the infrageniculate distribution. Sjoerd et al. analyzed 12 CTA and 30 CEMRA studies and estimated a sensitivity and specificity of 96% (95% CI, 93–98%) and 95% (95% CI, 92–97%) for CTA, and 93% (95% CI, 91–95%) and 94% (95% CI, 93–96%) for CEMRA [2].

Furthermore, MRA is considered effective for lower extremity runoff and feet evaluation of diabetic patients because of its superior ability to detect flow in small, calcified vessels, and the capability to perform an unenhanced MR. Liu et al. found in a prospective study that unenhanced MR angiography with use of flow-sensitive dephasing (FSD)-prepared steady-state free precession (SSFP) sequence allows clear depiction of the foot arterial tree and accurate detection of significant arterial stenosis as compared to conventional contrast-enhanced MR angiography. The average sensitivity, specificity, positive predictive value, negative predictive value, and accuracy of the two readers for unenhanced MR angiography were 88%, 93%, 81%, 96%, and 92%, respectively [3].

Disadvantages of MRI embrace a more time-consuming study than CT, require more hands-on expertise, and necessitate a stable patient.

Other important issues with MRA imaging include poor spatial resolution, inability to detect wall calcification (especially problematic in patients with diabetes and chronic limb-threatening ischemia), and potential development of nephrogenic systemic fibrosis (NSF) in renal failure patients. NSF is a rare disorder that occurs in some individuals with reduced kidney function, who have been exposed to an intravenous contrast material that contains gadolinium. Currently, with the development of new gadolinium-based contrast agents, such as class II agents, the risk of NSF is low or nonexistent. As a result, and in alignment with the ACR Manual Contrast Media Version 2020 guidelines, no screening of any kind is necessary prior to single-dose administration of class II agents (such as Dotarem, Multihance, and Gadavist) as there is no documented risk of harm. Patients on dialysis do not need to alter their dialysis schedule and may be imaged before or after dialysis. Use of class I and III agents does still require pre-procedure renal function screening as they have been associated with NSF in patients with renal dysfunction.

Conventional Angiography

Catheter angiography has largely been replaced by cross-sectional imaging in the evaluation of patients with suspected truncal, head/neck, and proximal extremity arterial pathology. Angiography is still considered in symptomatic patients with coexistent malperfusion or suspected acute interventional complication to allow simultaneous evaluation and possible revascularization of the affected vascular bed. Also, angiography has gained popularity in the hybrid operating room, in which diagnostic and interventional angiography techniques are combined with open surgical repair.

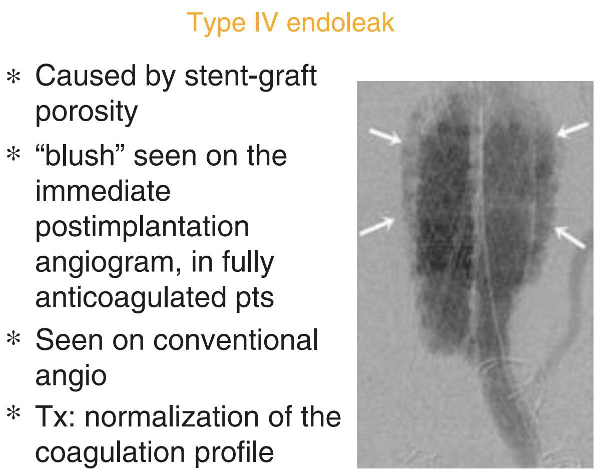

Fig. 3.4 Conventional angiography of the thoracic aorta depicted diffuse periaortic blush (arrows) post implantation of an endovascular stent graft consistent with type IV endoleak

In the postoperative follow-up, conventional angiography is useful for detection of occult leaks such as suspected type IV endoleak, which is not visualized by noninvasive imaging (Fig. 3.4) or nonlocalized gastrointestinal bleeding.

Noninvasive Hemodynamic Testing

Noninvasive testing (NIVT), both before and after intervention, has been used for decades as a first-line diagnostic tool to assess peripheral artery disease (PAD). It is widely available and provides a great deal of information at low cost. NIVT consists of one or more of the following components: the ABI, segmental pressure measurements (SPMs), pulse-volume recordings (PVRs), photoplethysmography (PPG), toe systolic pressure and toe-brachial index (TBI), and transcutaneous oxygen pressure measurement (TcPO2).

The ABI is defined as the ratio between the higher of the brachial artery pressures and the higher of the dorsalis pedis or posterior tibial artery pressures in each leg at the level of the ankle. A normal ABI value ranges between 0.9 and 1.31, a value less than 0.9 is suggestive of PAD, while values >1.3 indicate severe vessel disease, usually chronic. This technique may underestimate PAD by 30% when compared to CTA as demonstrated by Ro et al. [4]. The toe-brachial index (TBI) has been shown to provide a more accurate estimation of the presence of PAD in these subgroups, with a TBI <0.7 considered abnormal [6]. Toe pressures are preferred for hemodynamic assessment of patients with chronic limb-threatening ischemia, especially in people with diabetes.

SPMs compare systolic pressures at sequential levels in the extremities to evaluate for significant drops between one level and the next. A pressure drop of 20 mm Hg between adjacent measurements suggests one or more hemodynamically significant stenoses between them.

PVRs provide a qualitative measurement of limb perfusion. PVRs are created by inflating pneumoplethysmography cuffs to a specified pressure on each limb. Each cuff measures the miniscule change in the volume of the limb under the cuff with each pulse, creating a tracing of volume versus time. The resultant waveforms can be compared to determine segmental disease, providing insight into the quality of arterial blood flow at each station simultaneously.

PPG involves the detection of a transmitted infrared signal through each of the digits. The degree of transmitted signal varies depending on blood volume within the digit. PPG is useful for detection of disease below the knee as well as disease isolated to the forefoot and digits.

TcPO2 measurement allows the determination of the oxygen tension within the tissue. An improvement in the TcPO2 value postintervention compared with preintervention has been validated as an excellent marker of tissue reperfusion.

These tests may be limited by their availability in the office setting and patient resistance to avoiding smoking and caffeine before the test.

Ultrasonography

Duplex US (DUS) is an alternative modality for follow-up of abdominal aortic endovascular aneurysm repair with high specificity for detection of endoleaks and high accuracy for evaluation of aneurysm sac size. The addition of contrast material makes US an even more sensitive and specific test for characterization of endoleaks. Moreover, DUS has a more important role in assessing asymptomatic patients with previous infrainguinal endovascular therapy or bypass. By ACR Appropriateness Criteria, DUS is considered usually appropriate for surveillance in asymptomatic patients with previous infrainguinal endovascular therapy or bypass and can help to determine a baseline for future follow-up [5].

Echeverria et al. [7] assessed the utility of routine duplex surveillance in 379 infrainguinal reversed vein grafts performed at 2 independent teaching hospitals. Only 29% of grafts identified as failing (defined as duplex graft flow velocity (GFV) measurements less than 45 cm/sec) by duplex scan were associated with a reduction in ankle-brachial index of greater than 0.15. Secondary reconstructions were performed in 48 grafts based on detection of a reduced GFV measurement; all such reconstructions were patent after a mean follow-up of 5 months. The authors concluded that duplex surveillance is more reliable in identification of failing vein grafts than in determination of ankle-brachial index [6].

Its use in the chest is impractical given poor acoustic windows.

Radiograph

This procedure may be helpful for assessment of stent migration and stent integrity (fracture) following endovascular repair. However, it is unable to demonstrate other types of post-endograft or surgical graft complications. Radiographs cannot be used as a stand-alone method of follow-up.

Nuclear Medicine

Nuclear medicine scans are not the first choice for evaluation of postoperative vascular complications. However, recent research has shown that (99m)Tc-human serum albumin diethylenetriamine pentaacetic acid ((99m)Tc-HSAD) SPECT proved less sensitive than three-phase CT but depicted endoleaks with volumes 5.2 cm^3 or greater as perigraft radioisotope accumulation. Slow-filling endoleaks can be visualized with (99m)Tc-HSAD SPECT, which can be used to evaluate the efficacy of embolization [8].

Summary of Recommendations

A widespread variety of imaging modalities are available in current clinical practice. Vascular surgeons and referring providers need to be able to use combinations of these modalities at different stages of management.

Lifelong imaging follow-up is necessary in EVAR and TEVAR patients as endoleaks and other graft-related complications may develop at any time. The precise surveillance interval is still in debate and may be procedure and patient specific. CTA is the imaging modality of choice, given its sensitivity for the detection of endoleaks, changes in aortic/aneurysm diameter, and evaluation of false lumen thrombosis. Contrast-enhanced MRA is the preferred imaging modality in young patients requiring repetitive imaging follow-up. Unenhanced MRI is a more suitable modality for diabetic patients with renal dysfunction and peripheral arterial disease.

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