Peripheral Angiography

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PERIPHERAL ANGIOGRAPHY

Peripheral arterial disease (PAD) comprises a host of non-coronary arterial syndromes due to various pathophysiological mechanisms resulting in stenosis or aneurysms in various vascular beds. Atherosclerosis (AS) remains by far the most common cause of this disease process. According to the recently released ACC/AHA guidelines for the management of patients with PAD, it is a major cause of decrement of functional capacity, quality of life, limb amputation, and increased risk of death.\(^1\)

Millions of people worldwide are afflicted with this syndrome.\(^2,3\) While awareness for coronary artery disease (CAD) has significantly increased in the last decade, the awareness, diagnosis, and treatment of PAD remain much underappreciated. With improvement in catheter-based and imaging technology, it was only natural that all specialties involved in the management of vascular disease would involve endovascular therapy of this potentially disabling and lethal disorder.\(^4-6\)

Excellent reviews on PAD are already available in the literature. The ACC/AHA guidelines, Trans Atlantic Society Conference (TASC) Working Group document,\(^7\) the ACC COCATS-2 Paper,\(^8\) provide the basic fundamental material for a physician interested in the management of patients suffering from PAD. Based on literature review and our own experience at the Washington Hospital Center, Washington, DC, and University of Louisville, Louisville, KY, we have tried to focus in this chapter on the general principles of performing invasive peripheral angiography. We have also briefly described noninvasive imaging modalities of computed tomographic angiography (CTA), magnetic resonance angiography (MRA), and carbon dioxide (CO\(_2\)) angiography as their utility relates to each vascular bed. The full details of these other modalities are, however, out of the scope of this chapter. We hope that this chapter will provide the basic understanding in catheter angiography to an operator interested in treating patients with PAD.

Training Requirements

There are considerable differences of opinion that exist among various specialties regarding the optimal training required before certifying operators to safely perform peripheral vascular procedures.\(^9-16\) Specialties including interventional cardiology, interventional radiology, vascular surgery, interventional neuroradiology, interventional nephrology, and interventional neurosurgery all possess basic and unique knowledge that positions them to advance their skills into peripheral angiography and interventions. The ACC COCATS-2 (Tables 20-1 and 20-2) provides guidelines for a cardiovascular trainee who wishes to be certified in the performance of such procedures.\(^9\) A minimum of 12 months of training is required. Completion of 100 diagnostic angiograms and 50 peripheral vascular interventions has been recommended for unrestricted certification. Fifty percent of such procedures should be performed as “primary operator” under the guidance of a mentor who is certified in peripheral vascular interventions. Prior to the performance of invasive procedures, this physician should be knowledgeable in vascular medicine and noninvasive modalities in the diagnosis of peripheral vascular disorders. Before signing off the certificate, the mentor should require the trainee to have exposure in the angiography of various vascular beds. This should also include cases of vascular thromboses and their treatment. Carotid and vertebral artery angiography is excluded from most general guidelines and added skills are required in this vascular territory. The ACC/ACP/SCAI/SVMB/SVS Clinical Competent Statement outlines these requirements (Tables 20-3 and 20-4).

Restricted certificates can be awarded to physicians who achieve satisfactory skills in only certain vascular territories.
CHAPTER 20

TABLE 20-1. Training in Diagnostic Cardiac Catheterization and Interventional Cardiology

Level 1—Trainees who will practice noninvasive cardiology and whose invasive activities will be confined to critical care unit procedures.

Level 2—Trainees who will practice diagnostic but not interventional cardiac catheterization.

Level 3—Trainees who will practice diagnostic and interventional cardiac catheterization.

Maintenance of certification is also required by continuous medical education and performance of 25 peripheral vascular interventions per year. For full details, the reader may refer consensus conference guidelines.

NONINVASIVE IMAGING

Noninvasive imaging is improving at a rapid pace and is replacing routine catheter angiography in many cases.

Magnetic Resonance Angiography

According to the ACC/AHA guidelines, MRA with gadolinium contrast is now a Class I indication (conditions for which there is evidence for and/or general agreement that a given procedure or treatment is beneficial, useful, and effective) and level of evidence A (data derived from multiple randomized trials or meta-analysis) to diagnose the anatomic location and degree of stenosis in the lower extremity PAD; and to select patients who are candidates for endovascular or surgical revascularization. MRA has Type IIb indication (conditions for which there is conflicting evidence and/or divergence of opinion about the usefulness/efficacy of a procedure or treatment. Weight of evidence/opinion is in favor of usefulness/efficacy) and level of evidence B (data derived from a single randomized trial or nonrandomized trials) in patients with PAD to select surgical sites for surgical bypass and for postsurgical and postendovascular revascularization surveillance. Gadolinium is less nephrotoxic and there is no exposure to ionizing radiation. Currently utilized techniques of MRA include time of flight (TOF), three-dimensional imaging, contrast enhancement with gadolinium subtraction, cardiac gating and bolus chase.

With the contrast-enhanced MRA (CE MRA), the sensitivity is 90% and specificity 97% in...
lower extremities PAD as compared to digital subtraction angiography (DSA).21–23 Runoff vessels may, in fact, be better visualized with MRA than DSA.22,23 In the patients diagnosed with critical limb ischemia (CLI), with intraoperative angiography as the standard, MRA had comparable accuracy to standard catheter angiography. Sensitivity and specificity for patent vessels was 81% and 85%, respectively. For the identification of segments suitable for bypass grafting, the sensitivity and specificity of contrast angiography was less than MRA (77% vs. 82%), but the specificity was better (92% vs. 84%).24 A meta-analysis of MRA compared to catheter angiography for stenosis >50% showed that the sensitivity and specificity were 90% to 100%, especially when gadolinium was used.25 Recent studies also show an agreement of 91% to 97% between MRA and catheter angiography.26

MRA, however, tends to overestimate the degree of stenosis and occlusions. It might also be inaccurate in assessing lesions with stents. Another limitation is in patients who have been implanted with automatic defibrillators, permanent pacemakers or who have intracranial coils or clips.27,28 In these patients, MRA is generally contraindicated. Gadolinium is generally considered nephrotoxic, but one study reported nephrotoxicity in patients with baseline renal dysfunction.29 A significant number of patients are also severely claustrophobic during imaging and require alternative testing.

Computed Tomographic Angiography

CTA is considered by ACC-AHA guideline committee to merit a Type Ib indication (usefulness/efficacy is less well established by evidence/opinion) and level of evidence B for diagnosing the anatomic location and presence of stenoses in patients with lower extremity PAD. It is considered as a substitute for MRA in patients who have contraindication to MRA.30–34 This technique was first started in 1992. Image acquisition is very rapid. Images can be rotated in three dimensions, thus bringing into view eccentric lesions that might be missed by two-dimensional catheter angiography. Older scanners had a single detector that acquired one cross-sectional image at a time and was very time-consuming. It also required more contrast load and there was overheating of the X-ray tube. The currently available multidetector CT (MDCT) scanners can acquire 64 slices simultaneously.34–39 Abdominal aorta and the entire lower extremity can be imaged in less than 1 minute.40 One hundred to one hundred eighty milliliters of iodinated contrast is injected at 1 to 3 mL per minute via a peripheral venous

<table>
<thead>
<tr>
<th>TABLE 20-4. Alternative Routes to Achieving Competence in Peripheral Catheter-Based Intervention</th>
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<tr>
<td>1. Common requirements</td>
</tr>
<tr>
<td>a. Completion of required training within 24-month period</td>
</tr>
<tr>
<td>b. Training under proctorship of formally trained vascular interventionalist competent to perform full range of procedures described in this document</td>
</tr>
<tr>
<td>c. Written curriculum with goals and objectives</td>
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<tr>
<td>d. Regular written evaluations by proctor</td>
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<tr>
<td>e. Documentation of procedures and outcomes</td>
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<td>f. Supervised experience in inpatient and outpatient vascular consultation settings</td>
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<td>g. Supervised experience in a noninvasive vascular laboratory</td>
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<tr>
<td>2. Procedural requirements for competency in all areas</td>
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<tr>
<td>a. Diagnostic peripheral angiograms—100 cases (50 as primary operator)</td>
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<td>b. Peripheral interventions—50 cases (25 as primary operator)</td>
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<tr>
<td>c. No fewer than 20 diagnostic/10 interventional cases in each area, excluding extracranial cerebral arteries</td>
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<tr>
<td>d. Extracranial cerebral (carotid/vertebral) arteries—30 diagnostic (15 as primary operator)/25 interventional (13 as primary operator)</td>
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<tr>
<td>e. Percutaneous thrombolysis/thrombectomy—6 cases</td>
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<tr>
<td>3. Requirements for competency in subset of areas (up to 3, excluding carotid/vertebral arteries)</td>
</tr>
<tr>
<td>a. Diagnostic peripheral angiograms per area—30 cases (15 as primary operator)</td>
</tr>
<tr>
<td>b. Peripheral interventions per area—15 cases (8 as primary operator)</td>
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<tr>
<td>c. Must include aortoiliac arteries as initial area of competency</td>
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†The fulfillment of requirements via an alternative pathway is only appropriate if the candidate physician has the cognitive and technical skills outlined in Table 20-4 and is competent to perform either coronary intervention, interventional radiology, or vascular surgery. These alternative routes for achieving competency are available for up to 5 years following publication of this document.

‡Vascular areas are (1) aortoiliac and brachiocephalic arteries, (2) abdominal visceral and renal arteries, and (3) infrapopliteal arteries.
line. The radiation exposure is typically one-quarter of that in catheter angiography.

With the single detector scanners, the sensitivity for occlusions was 94% and specificity was 100%. For stenoses greater than 75%, the sensitivity and specificity dropped significantly to 36% and 58%, respectively, when maximum intensity projection was used and improved to 73% to 88% when each slice was individually analyzed. With the MDCT, the sensitivity for stenoses greater than 50% was 85% to 100% and the specificity was 92% to 100%.

CTA is useful in selecting patients who are candidates for endovascular or surgical revascularization. It also provides useful information about associated soft tissue structures that may affect decision making in the optimal endovascular treatment of PAD, e.g., vascular aneurysms. In one study, it showed that popliteal artery stenosis and occlusions occurred because of aneurysms, cystic adventitial disease, or entrapment. Other advantages are patient comfort, and compared to DSA, it is noninvasive, less expensive, delivers less radiation (approximately one-fourth) and has better contrast resolution. The major limitation of CTA is the risk of contrast-induced nephropathy (CIN). Other drawbacks include lack of accuracy with single detector scanners, lower spatial resolution than DSA, venous filling obscuring arterial imaging, decreased accuracy in calcified vessels, and asymmetrical opacification of legs. The accuracy and effectiveness of CTA is not as well delineated as that of an MRA. Treatment plans based on CTA have not been compared with those of contrast angiography in lower extremity PAD.

Carbon Dioxide Angiography

CO₂ angiography is not available in most centers and generally reserved for patients with history of contrast allergy or renal dysfunction with creatinine clearance less than 20 mL per minute. The use is generally limited to arteries below the diaphragm to minimize the risk of cerebral embolism. DSA equipment is required for CO₂ angiography.

**CONTRAST ANGIOGRAPHY**

In spite of tremendous improvements in noninvasive imaging, catheter-based invasive iodine contrast catheter angiography remains the gold standard for the diagnosis of PAD in patients considered for endovascular intervention. It is the most widely available modality for the imaging of the vasculature. It is the only universally accepted technology for guiding percutaneous peripheral vascular interventions. Millions of angiographic procedures have been performed worldwide since William Forssman in 1929 passed a catheter from his own arm vein into his right atrium. In the early period, direct punctures of the vessels of interest were performed. This technique has essentially been abandoned and replaced by percutaneous needle access. Safe and good quality angiography requires adequate equipment, well-trained team of staff, and strict adherence to well-established principles.

Catheter angiography has a Class 1 ACC/AHA indication for delineating the anatomy in patients who require revascularization. Modern technology has permitted the use of smaller diameter sheaths and catheters, less toxic contrast agents, better imaging equipment in angiographic suites requiring less contrast load, thus decreasing the risks to the patient for adverse effects. Invasive angiography procedures, however, are still associated with rare but potentially devastating complications. The risk of severe contrast induced reaction is 0.1%–3%. There is significant risk of CIN in patients with baseline renal dysfunction, patients with diabetes mellitus, those with low cardiac output states or those who are dehydrated. Any combination of these is more adverse than an individual risk factor.

Informed consents should be obtained prior to the procedure from all patients after fully explaining all the risks, benefits, and alternatives. History of contrast-related allergic reactions should be documented and appropriate pretreatment should be administered. Decisions regarding revascularization should be made with complete anatomic assessment of the affected arterial territory including imaging of the occlusive lesion as well as of the inflow and outflow vessels. Noninvasive imaging techniques should be combined with vascular imaging for the information. DSA should be used to eliminate dense background tissues. Selective and superselective catheter placement should be done for better enhancement of vasculature and to reduce the contrast load and radiation exposure. Imaging should be done in multiple angulations to uncover vessel overlap, and transstenotic pressure gradients be measured in ambiguous lesions. In patients with renal dysfunction, appropriate hydration should be given prior to the procedure. Patients should be followed up within 2 weeks of the procedure to assess their renal function, the access site, and to make sure that they have not suffered adverse effects like atheroembolism.

Radiological Equipment

Peripheral angiography frequently requires imaging of large areas, which in the absence of a large field of view, will require multiple injections and significant contrast load. A 14-inches (36-cm) image intensifier is recommended (Figure 20-1). Cineangiography at 15 to 30 frames per second (FPS) is excellent for imaging of the moving beating heart. Imaging of static structures with radiopaque bones in the background, e.g., blood vessels, especially the smaller branches will be suboptimal with this technique. Therefore, the technique of DSA should be utilized for peripheral angiography. In this technique, the patient is required to stay motionless during images; otherwise the image will be distorted. In carotid angiography, the patient should also be instructed not to swallow to prevent motion. In modern angiographic suites, ability to acquire DSA images has cut down on the contrast and radiation exposure. In DSA, a precontrast “mask” image is first obtained. Following contrast injection, subtraction of this image allows enhanced filling of the vasculature with masking of nonvascular structures like bones, air, and calcium.
They are classified as ionic or nonionic agents. The high atomic number and chemical versatility of iodine makes it ideally available in current angiographic suites.

Gadolinium or CO₂ angiography should be done in laboratories equipped with DSA; otherwise, the image quality is likely to be poor. "Road mapping," also called "trace subtract fluoroscopy," is usually available in catheter laboratories equipped with DSA capability. This is a very useful technique during interventional procedures. This can be conceptualized as fluoroscopy without the radioopaque background. A small amount of contrast is first injected to fill the vessel and the image is stored in memory as a mask. When the catheter is advanced under normal fluoroscopy, this mask is subtracted, thus allowing visualization of both the moving catheter and the vessel. The image in road mapping will appear white in contrast to DSA, where it will be black. Additional software, enabling quantitative angiography to measure lesion length and diameter should also be ideally available in current angiographic suites.

**Examination Console**

Highest kilovoltage peak (KVP) is required for cerebral and abdominal angiography, lowest for the extremities, and intermediate for the thorax. Frame rate is generally 2 to 3 FPS for arterial imaging. It is decreased for venous imaging due to long cine runs. Frame rate is increased for cases requiring gadolinium contrast. Newer laboratories will typically have the settings on the console that can be adjusted to optimize adequate imaging of each vascular bed.

In the imaging of the legs 12- to 15-inch image intensifier is required. A longer table is also desirable. Where these are not available, the patient can be positioned in reverse with feet facing the head end of the table. Multiple injections maybe required in the legs to image all the arteries. Depending on the operator and the staff experience, either a "stepped mode" method, which requires contrast bolus at each imaging site, or an "interactive" method where a single bolus of contrast is given in the abdominal aorta and the table is automatically set to "chase" down the bolus all the way to the feet are utilized for angiography. In our own experience, the stepped mode technique produces better images with the flexibility of changing the amount of contrast and angles during imaging. It may however require slightly larger contrast load and exposes operators to more radiation.

In the "interactive" method, after the bolus is given, a DSA run of both the lower extremities is obtained followed by a "dry run" used for subtraction. This technique is sometimes limited by unequal visualization of both legs in larger patients or in the patients who have flow-limiting lesions in a segment of the vessel causing delayed filling distally. Patients may also be unable to lie motionless or hold their breath for the entire duration of the time required for imaging of all the segments. If free movement of the table is not confirmed prior to the automatic runs, there is a danger of pulling out of the imaging catheter and the sheath. We recommend suturing the sheath if using this method.

**Radiation Exposure**

Peripheral angiography procedures are typically more time consuming than coronary procedures. Frustration can easily set in during a difficult case especially if the staff is not completely familiar with the equipment and trouble shooting of the modalities commonly used, e.g., DSA, road mapping, bolus chase etc. Also, many laboratories have trainee fellows and less experienced operators trying to learn this increasingly popular skill. Basic principles to prevent radiation exposure can thus be overlooked.

Maximizing distance from the X-ray source is the best way to reduce exposure. Most procedures by the right-handed individuals are done from the right side of the table. Right anterior oblique (RAO) angulation moves the X-ray tube away from the operators, thus exposing them less to radiation than left anterior oblique (LAO) angles. Protective lead shields, good-quality lightweight aprons, thyroid collars, and leaded eyeglasses should be used as a habit. Use of DSA and road mapping will further cut down on fluoroscopy time. Radiation badges should monitor radiation exposure of each operator and staff.

**Intravenous Contrast Agents**

All current contrast agents are iodine-based. The high atomic number and chemical versatility of iodine makes it ideal for vessel opacification. They are classified as ionic or nonionic and further differentiated into high-osmolar, iso-osmolar, and low-osmolar based on their osmolality. Low- and iso-osmolar agents cause fewer side effects, e.g., hypotension, bradycardia, angina, nausea, and vomiting. They also cause less heat sensation and are better tolerated in peripheral angiography. The nonionic agents cause less allergic side-effects and may also be less nephrotoxic. The nonionic, hypo-osmolar and iso-osmolar agents are more expensive.
cases. Many agents are commercially available in the market based on their ratio of iodine to ions and concentration of sodium (that determines their osmolality).

High-osmolar ionic ratio 1.5 agents contain three atoms of iodine for every two ions, e.g., Renografin (Bracco), Hypaque (Nycomed), and Angiovue (Berlex). Their sodium concentration is roughly equal to that of blood, making their osmolality very high (>1500 mosm/kg). They cause significant pain and are generally not tolerated well by patients undergoing peripheral angiography.

Low-osmolar ionic ratio-3 agents have three atoms of iodine for every one ion and are low osmolality agents. Their osmolality is roughly twice that of blood, e.g., Ioxaglate (Hexabrix, Mallinkrodt).

Low-osmolar nonionic ratio-3 agents are water-soluble and do not have any ions, e.g., Iopamidol (Isovue, Bracco), Iohexol (Omnipaque, Nycomed), Ioversol (Optiray, Mallinkrodt). Their osmolality is also twice that of blood and cause burning in many patients.

Iso-osmolar nonionic ratio-6 agents have osmolality equal to that of blood (290 mosm/kg). They are very well tolerated by patients. Most commonly used is Iodixanol (Visipaque, Nycomed). It has fewer incidences of allergic reactions than Ioxaglate and has shown no major increase in adverse coronary events like intravascular thrombosis, vessel closure, or perioperative myocardial infarction. There is also some data suggesting less nephrotoxicity with them.

In all patients with renal dysfunction, intravenous hydration with normal saline at 1 mL/kg/h along with N-acetylcysteine (mucomyst) 600 mg orally twice a day should ideally be started 12 to 24 hours prior to the procedure. Gadolinium contrast or CO₂ angiography is another option in such patients.

Diagnostic Catheters and Guide Wires

Vascular access is commonly obtained with an 18-gauge needle that will accommodate most 0.038 inch or smaller wires. A smaller 21-gauge needle with a 0.018-inch wire is available in “micropuncture kit” (Cook, Bloomington, IN) that can be used for difficult femoral, brachial, radial, or antegrade femoral approaches (Figure 20-2). For a nonpalpable pulse Doppler, integrated needle (smart needle) can be used. Wires are available in 0.012 to 0.052 inch in diameter. Most commonly used are wires of 0.035 and 0.038 inch. In a standard guide wire, a stainless steel coil surrounds
a tapered inner core. A central safety wire filament is incorporated to prevent separation in case of fracture. Typically they are 100 to 120 cm in length but can also be 260 to 300 cm. Wires are available when wire position needs to be maintained for catheter exchanges. Long wires are frequently required in peripheral angiography, more so than in coronary angiography and their use is encouraged when in doubt.

The tip of the wires can be straight, angled, or J-shaped. Some wires have the capability of increasing their floppy tip by having a movable inner core. Varying degrees of shaft stiffness, e.g., extra support, to provide a strong rail to advance catheters in tortuous anatomy versus extremely slick hydrophilic with low friction for complex anatomy have made peripheral vascular angiography and interventions a viable and many times a preferred treatment of PAD. Every angiographic suite should have an inventory of such wires. The 0.035-inch wires used in our laboratory are standard J-shaped, Wholey, Straight and Angled Glide, Amplatz Super Stiff, and Supracore. Among the 0.018-inch wires inventory are the Steel Core and V18 Control. In addition to 0.014-inch coronary wires, we frequently use Sparta Core wire in renal and other peripheral vascular interventions. Glide wire (Terumo wire) is very useful in tracking most vessels but carries the risks of vessel dissection and perforation. It should not be used to traverse needles because of the potential of shearing.

Numerous catheters are available (Figures 20-3 to 20-5) and every operator should develop his own skill and “feel” of catheters he uses in peripheral angiography. An “ideal catheter” should be able to sustain high-pressure injections, to track well, be nonthrombogenic, have good memory, and should torque well. Catheters are made of polyurethane, polyethylene, Teflon or nylon. They have a wire braid in the wall to impart torqueability and strength. They are available in different diameters and lengths. They can have an end hole, side holes, or both end and side holes. When using the femoral approach, short-length catheters (60–80 cm) are adequate for angiography of the structures below the diaphragm, whereas long catheters (100–120 cm) are needed for carotid artery, subclavian artery, or arm angiography. Five- to six-French catheter (1-F catheter = 0.333 mm) diameter catheters are most commonly used. Three- to four-French catheters are used for smaller vessels. Side-hole catheters are safe and allow large volume of contrast at a rapid rate with power injectors, e.g., pigtail, Omniflush, Grollman. They are commonly used for angiography of ascending aorta, aortic arch, and abdominal aorta.
End-hole catheters are very useful in selective angiography using manual hand injections. For DSA, 5-F catheters are sufficient. Omniflush catheter can be advanced over the wire beyond the aortic bifurcation and then pulled back to engage the contralateral common iliac artery for selective angiography of the leg. For type-1 aortic arch, a 5 F JR4 will be adequate for carotid, vertebral, subclavian artery angiography, and for nonangulated renal arteries. Simmons, Vitek, SOS, and Amplatz catheters are very useful in certain situations but require added skills and careful manipulation. Heparin should be used with the use of these latter catheters. Simple curved catheters, e.g., Berenstein, Cobra, and Headhunter, are also useful in angulated renal arteries and vertebrals.

**Vascular Access**

Meticulous technique to achieve vascular access is essential for a successful angiographic procedure. In patients with PAD, the success or failure of a procedure will significantly depend on the correct choice of access site. Every effort...
should be made to learn the vascular anatomy and direction of blood flow if the patient had previous bypass graft. Prior noninvasive studies like MRA, CTA, and Duplex ultrasonography (US) should be reviewed prior to the angiography. Peripheral bypass grafts in general should not be punctured for 6 to 12 months after surgery.

Most common vascular sites are common femoral artery (CFA) and brachial artery (BA). Fluoroscopy should be routinely used to identify bony landmarks to avoid puncturing the artery too low or too high.

**Femoral Approach**

CFA is ideally suited because of its large caliber that can accommodate up to 14-F sheaths percutaneously and its central location, enabling access to all vascular territories. When compared to the arm approach, there is less radiation exposure but more incidence of bleeding and delayed ambulation. Both retrograde (toward the abdomen) and antegrade (toward the feet) CFA punctures are routinely done. For the antegrade approach, micropuncture technique using 21-gauge needle with 0.018-inch wire is recommended. It should always be done under fluoroscopy and should not be done in very obese patients. It limits arteriography to the ipsilateral leg, but provides a better platform for interventions if needed. Patients are typically placed in reverse with the feet facing the head-end of the table, allowing maximum mobility of the image intensifier around the limbs. The skin puncture is made at the top of the femoral head. A less acute, less than 45-degree angle is usually required for smooth insertion of the sheath and catheters. Long tapered introducer-sheath instruments are sometimes needed. A short 4- to 5-F sheath should be introduced first and a cine angiogram performed to confirm access in the CFA, and wire position in the superficial femoral artery (SFA) before inserting the larger and longer sheaths and initiation of anticoagulation (Figure 20-6). An ipsilateral 30 to 50 degrees angulation will open up the superficial and deep femoral artery (DFA) bifurcation. Anticoagulation can be reversed at the end of the procedure for early removal of sheath and to decrease the incidence of bleeding.

**Brachial and Radial Approach**

For radial artery (RA) and 5- to 6-F sheaths and for brachial artery 5- to 7-F sheaths can be used. The biggest
advantage with these approaches is less bleeding and early ambulation. There are however more ischemic complications. These approaches require crossing the great vessels of aorta and great care should be exercised to avoid causing embolic strokes.

For BA approach, the arm is abducted and the puncture is made at the site of maximum pulsation. Micropuncture technique is recommended. When using this approach, one should be aware of the need for longer length catheters if angiography and intervention of the lower extremities is anticipated. Left brachial approach has approximately 100 mm greater reach than the right brachial approach. Wholey wire, glide wire, and other soft wires should be used with these approaches to minimize trauma and spasm of the vessels.

For RA approach, more skill is required. RA is superficial and lies against the bone. It has no major veins or nerves in the vicinity. Its smaller size, however, limits the use of some devices and larger stents. Hydrophilic sheaths and guiding catheters of up to 6- to 7-F are now available and can be used with this approach. They can accommodate most current balloons and stents. There is approximately a 3% incidence of RA occlusion postprocedure. Allen’s test should be performed prior to cannulating RA to confirm the ulnar artery patency (Figure 20-7). There is, however, some controversy regarding the absolute value of Allen’s test. The success rate of this approach is 95%. The wrist is extended and the arm abducted in supine position. Using micropuncture technique, puncture is made 1 to 2 cm proximal to the wrist crease. After sheath insertion, the arm is brought back in the adducted neutral position. Right arm is preferred to preserve left RA for future bypass surgery if needed. Minimal local anesthesia is administered. Five F long hydrophilic sheath is a good choice. Heparin 2500 to 5000 units should be given directly in the sheath. Radial arteries are very prone to spasm and vasodilators should be used. Nitroglycerin 100 to 200 mg and Verapamil 1 to 2 mg is directly given through the sheath. A short cineangiogram should be performed to look for any
anomalous arteries. One should look for radial recurrent artery. The sheath should be removed immediately after the procedure. Activated clotting time (ACT) check is not necessary. Compression straps, e.g., Hemoband (Hemoband Corp., Portland, OR) are placed directly over the puncture site. Pressure is maintained for approximately 90 minutes for diagnostic and 180 minutes for interventional procedures. Access site complications are very uncommon.

Other Vascular Access Sites
PA is uncommonly accessed. The patient has to lie prone. Puncture is performed under fluoroscopy and micropuncture technique is recommended. Axillary approach is more popular among interventional radiologists. Left axillary artery is preferred. The patient needs very close monitoring for bleeding after axillary artery puncture because even a medium-sized hematoma can cause nerve compression. BA cut down is very uncommon now. It is used in less than 10% of cases and should be performed only by experienced operators. Lumbar aortic punctures are again sometimes used by radiologists in patients who have extensive PAD. Patient is placed prone. This site is only used as a last resort because in case of bleeding complications direct pressure cannot be applied and patient will likely require open surgical repair of the bleeding vessel.

Local Vascular Complications
Society for Cardiac Angiography and Interventions (SCAI) has reported an incidence of 0.5% to 0.6% local vascular complications. These complications comprise vessel thrombosis, dissection (Figure 20-8), bleeding, which can be free hemorrhage, retroperitoneal bleeding, or access site hematoma, arteriovenous fistula (Figure 20-9), distal embolization, or false aneurysm (pseudo aneurysm). The operator should be well versed in the diagnosis and management of these complications. Adequate specialty care should be readily available at the facility where such procedures are performed.

Thoracic Aorta and Aortic Arch Angiography
Noninvasive modalities like MRA and three-dimensional CTA should be performed if available prior to invasive imaging. Angiography provides 2D imaging and may underestimate the tortuosity of various vessels (Figure 20-10). CTA and MRA will also provide information about the type of aortic arch, and anomalous origin of any vessel from the arch (Figure 20-11).

Thoracic Aorta
Commonly approached via right CFA utilizing 4- to 6-F sheath and diagnostic catheters. Pigtail or tennis racquet catheter is advanced over a soft J-tip guidewire under fluoroscopy. In cases of coarctation of the aorta, anteroposterior and lateral views are obtained with the contrast injected proximal to the coarctation. For cases of patent ductus arteriosus, selective aortic angiography is very sensitive in demonstrating small shunts and supercedes the sensitivity of right heart catheterization with stepwise oximetry. For cases of thoracic aortic aneurysms (TAA), MRA and CTA are again very useful initial tools (Figure 20-12), but catheter angiography is still considered essential to delineate the aneurysm and its relationship to the branches in the chest and abdomen. Endovascular thoracic aneurysm repair (ETAR) or open surgical repair is planned, then coronary, brachiocephalic, visceral, and renal arteriography should also be performed. For the diagnosis of thoracic aneurysms, angiography is performed in the ascending thoracic aorta above the aortic valve using 30 to 40 mL of iodinated contrast at 15 to 20 mL/s using power injection. TAA is less common than abdominal aortic aneurysm (AAA) but the incidence is increasing as the median age of the population is also increasing. It also has a higher incidence of rupture than AAA. Untreated, the mortality is greater than 70% within 5 years of diagnosis. Open surgical repair has a mortality of 10% to 30%, spinal cord injury 5% to 13%, respiratory failure 25% to 45%, myocardial infarction 7% to
20%, and renal dysfunction 8% to 30%. Chronic obstructive pulmonary disease (COPD) and renal failure are strong predictors of rupture. In one series, the rupture rate was high for aneurysms greater than 6 cm. In another series, no rupture was reported in aneurysms less than 5 cm. Mean size for rupture was 5.8 cm. With ETAR, the mortality and the morbidity has been reported to be much less.

In cases of thoracic aortic dissection, angiography has a sensitivity of 80% and specificity of 95%. Noninvasive modalities like CTA, MRA, and transesophageal echocardiography have taken over as the initial diagnostic tools; however, cardiothoracic surgeons will still require an angiogram for additional information about coronary and branch vessel involvement and the competence of the aortic valve prior to aortic repair. A pigtail or tennis racquet catheter is advanced over a soft wire typically via the right CFA approach. Most of the aortic tears are at the greater (outer) curve and to avoid entry into the false lumen, the catheter is used to direct the wire toward the inner curve. Frequent contrast injections should be utilized to check the catheter position. Entry into the false lumen is not uncommon and if that occurs, the catheter should be gently retracted and advanced into the true lumen.

Aortic Arch

Catheter angiography is still considered the gold standard, but 3D CTA and MRA are excellent for imaging the aortic arch and should be considered prior to considering arch angiography. CFA is the most common access site. Brachial or radial approaches can be used in cases of suspected aortic dissection and in patients with severe iliofemoral or abdominal atherosclerotic disease. A pigtail catheter is positioned above the sinus of Valsalva and 40 to 60 mL of nonionic iso-osmolar contrast at the rate of 20 cc/s is injected with a power injector. Both cine and DSA imaging can be used. For a cine angiogram, 30 FPS and for DSA, 4 to 6 FPS are commonly used. LAO at 45 degrees angle opens up the aortic arch and the great vessels in most cases. DSA allows a lower contrast load of 30 mL injected at 20 cc/s.

Carotid and Cerebrovascular Angiography

Catheter angiography is the gold standard for aortic arch, cervical, and cerebral angiography. A major drawback for angiography in this territory has been the risk of strokes. There was 1.2% incidence of stroke in the hands of radiologists in the ACAS trial. In a later study performed by cardiologists, the risk was 0.5%. Proper patient selection and the procedural volumes and the technical skill of the operator are important predictors of this risk.

Carotid Artery

Many patients with carotid artery disease are asymptomatic. History and physical examination are therefore not very sensitive in detecting carotid artery disease. Carotid duplex ultrasound, CTA, and MRA should be utilized as the initial diagnostic tools [Figure 20-13]. Invasive angiography
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FIGURE 20-10. CTA showing extremely tortuous carotid arteries making endovascular intervention an undesirable option in such cases. Courtesy: Robert Falk MD, 3-DR Louisville, KY.

remains the gold standard in patients considered for carotid artery stenting (CAS). The landmark North American Symptomatic Carotid Endarterectomy Trial (NASCET), European Carotid Artery Surgery (ECAS), and Asymptomatic Carotid Artery Stenosis (ACAS) trials were all based on angiography.

Brachiocephalic (BC) artery arises as the first great vessel from the aortic arch and divides into right subclavian (RSC) and right common carotid arteries (RCCA). RCCA almost always arises from the BC and rarely as a separate branch from the aorta. It may come from a single common carotid trunk that also gives rise to left common carotid artery (LCCA). RCCA further divides into right internal carotid artery (RICA) and right external carotid artery (RECA) at the fourth cervical vertebra. The angle of the mandible is a good bony landmark for the bifurcation of the CCA. ECA gives numerous branches (Figure 20-10). LCCA arises 75% of the time as a separate branch from aorta, 10% to 15% of the time as a common origin with the BC, and approximately 10% of the times from the BC (bovine origin) (Figure 20-11). ICA can be divided into four segments82 (Figure 20-11).

a. Prepetrous (cervical). Between the CCA bifurcation and the petrous bone. This segment does not give rise to any

FIGURE 20-11. CTA nicely showing a “bovine” aortic arch. There is also severe stenosis of the left internal carotid artery and the aortic arch is also “type 3” making carotid artery stenting an unsuitable option in this case. Courtesy: Robert Falk MD, 3-DR Louisville, KY.

FIGURE 20-12. CTA showing thoracic aortic aneurysm. Courtesy: Robert Falk MD, 3-DR Louisville, KY.
CHAPTER 20 • FIGURE 20-13. CTA of carotid arteries showing patent stent in the right common and internal carotid arteries (arrows). Courtesy: Robert Falk MD, 3-DR Louisville, KY.

major branches and is the most common site of carotid stenosis involving the ostial and the proximal portion of the artery.

b. Petrous. This segment courses through the petrous bone and makes a 90-degree L-shaped angle on angiogram.
c. Cavernous. This is the part through the cavernous sinus.
d. Supraclinoid. This segment gives ophthalmic, posterior communicating, and anterior choroidal branches before terminating as the middle and anterior cerebral arteries. Ophthalmic artery supplies the ipsilateral retina and optic nerve and is a source of important collateral route between ICA and ECA. Posterior communicating branch connects ICA with posterior cerebral artery to provide communication between the anterior and posterior circulation. The area supplied by ACA and MCA is referred to as “carotid territory of the brain.”

Angiography
Angiography is considered to be the gold standard for the diagnosis of extracranial and intracranial carotid artery disease. For complete cerebrovascular circulation, carotid angiography should be done in conjunction with aortoarch and selective vertebral angiography. Knowledge of arch anatomy and presence of proximal AS and tortuosity are crucial in the appropriate selection of the catheters for selective angiography. For Type-I or Type-II arch, 5 F JR4, Davis, HH (Meditech Watertown, MA), or Berenstein catheters are adequate. In patients with bovine arch Vitek catheter is often needed. For Type-III arch (elbowed), reverse curve catheters like Simmons (Angiodynamics, Queensbury, NY) or Vitek are often required. Simmons catheter can be very useful as it “travels up” the carotid artery and does not get dislodged. Its use, however, requires more skill.

Meticulous technique and double flushing is recommended once the catheter is beyond the aortic arch. Diluted low- or iso-osmolar contrast is injected at 4 to 6 mL/s for a total of 8 mL for CCA angiography using DSA at 4 to 6 FPS.

Cerebral circulation imaging should be continued into the venous phase to rule out any venous anomaly (Figure 20-14). Multiple projections and angulation are sometimes needed for optimal visualization. In most cases, a straight AP and lateral or 30 to 40 degrees ipsilateral angle will open up the bifurcation to assess the lesion (Figures 20-15 and 20-16). RAO projection opens up the bifurcation of the BC artery. In patients who are undergoing carotid or vertebral interventions, cerebral angiography should be performed before and after the intervention, for comparison, in the event of suspected embolic stroke. It also provides information about intracranial aneurysms and atherosclerotic disease. A straight PA cranial view to bring the petrous bone at the base of the orbit (Towne’s view) will nicely outline the cerebral circulation in most cases (Figure 20-17).

For assessment of the severity of carotid stenosis, the methodology used by NASCET investigators is most popular. This method compares the stenotic area with the most normal appearing artery distal to the stenosis.

Vertebral Artery
Left vertebral artery originates as the first branch of subclavian artery. In 3% to 5% of cases, it may arise directly from the aorta between LCCA and LSCA. Very rarely, it may originate distal to LSCA. Right vertebral artery can...
**FIGURE 20-15.** Severe stenosis of right internal carotid artery.

**FIGURE 20-16.** Severe carotid artery stenosis in a patient with previous carotid endarterectomy. Courtesy: John Laird MD, Washington Hospital Center, Washington, DC.

**FIGURE 20-17.** (A) Right and (B) lateral view of cerebral angiography in AP (Towne’s view).
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FIGURE 20-18. CTA showing “Circle of Willis.”
Courtesy: Robert Falk MD, 3-DR Louisville, KY.

Vertebrobasilar system can originate from RCCA and duplication of vertebrals can occur at any level. It originates from the superior and posterior aspect of the RSCA. The two vertebrals converge to form the basilar artery at the base of the pons (Figure 20-18).

It can be divided into four segments:

V-1: From the origin to the transverse foramen of the fifth and sixth cervical vertebrae.
V-2: Its course within the vertebra until it exits at C2 level.
V-3: Extracranial course between the transverse foramina of C2 and base of skull where it enters foramen magnum.
V-4: Intracranial course as it pierces the dura and arachnoid maters at the base of skull and ends as it meets the opposite vertebral artery (Figure 20-14).

Intracranial part gives anterior and posterior spinal branches; penetrating branches and posterior inferior cerebellar artery (PICA), which gives supply to dorsal medulla and cerebellum. Left vertebral artery is usually dominant and stenosis of the dominant vertebral is likely to cause symptoms.

AS is the dominant pathology involving the ostium and proximal extracranial segment of the VA. Surgical revascularization carries significant mortality and morbidity approaching 20%. With rapidly improving skills and technology, endovascular revascularization is becoming a very attractive option for these patients.

Angiography

Subclavian and vertebral artery angiography is commonly performed from the CFA approach. For patients with severe lower extremity PAD with no femoral access or who have Type-III aortic arch ipsilateral brachial approach can also be used. Unfractionated heparin (3000-5000 units) are given when using the brachial approach. RA can also be used for angiography and in addition to heparin vasodilators should also be given with this approach. AP, RAO and LAO projections will open up the SCA and VA. RAO cranial angle will show the origin of internal memory artery (IMA). JR4 catheter is usually adequate for straight aortic arch. For elongated aortic arch, Yitek, Head Hunter, or Simmons 1 or 2 are used (Figure 20-19). For vertebral artery, 3 to 4 mL/s for a total of 6 mL of contrast is generally sufficient. Nonselective angiography with a blood pressure cuff inflated on the ipsilateral arm will improve the visualization of ostial disease. Ostia are also better seen in the contralateral oblique projections and V2 and V3 segments are better seen in PA and lateral views or ipsilateral oblique views. Intracranial segments are best seen in steep 40 degrees PA cranial (Towne’s) view and crosstable view.
Subclavian, Brachiocephalic, and Upper Extremity

This vascular bed constitutes approximately 15% of symptomatic extracranial cerebrovascular disease. Right subclavian artery (RSCA) arises from BCA on the right and LSCA is the last major branch from the aorta on the left. In 0.5% population, RSCA arises as the terminal branch from the descending thoracic aorta and courses over to the right toward its normal distribution to the right upper extremity. Rarely, RSCA and RCCA may have separate origins from the aorta instead of a BCA. It gives vertebral, IMA, and thyrocervical trunk (TCT) from its first segment. TCT gives inferior thyroid, suprascapular, and transverse cervical branches. SCA becomes axillary artery at the lateral margin of the first rib that in turn becomes BA at the anatomic neck of the humerus. Opposite to the neck of radius, BA divides into ulnar and radial arteries (Figure 20-20). In approximately 1.3% of cases, RA originates from the axillary artery and in 15% to 20% of cases from the upper BA. Ulnar artery helps to form the superficial palmar arch and the RA the deep palmar arch (Figure 20-21).

Angiography

Angiography is generally needed in patients presenting with arm claudication, and in other causes of arm ischemia, e.g., blue digit syndrome, severe digital ischemia, and blunt and penetrating trauma with vascular injury to these vessels. CTA and MRA are useful to delineate arch anatomy. Stepwise angiography with iso-osmolar contrast is preferred. Contrast of 5 to 10 mL with hand injection using DSA will give good visualization of these vessels. JR4 catheter is routinely used (Figures 20-22 and 20-23). Vitek or Simmons catheter maybe required depending on the take off of SCA or BCA. Vitek catheter is advanced under fluoroscopy and positioned in the descending thoracic aorta with the curve facing the right side of the arch and the tip facing north. Catheter is gently advanced and each great vessel is selectively engaged. After completion of the angiogram, the catheter is removed over a wire. Simmons catheter is reshaped in the ascending thoracic aorta and is gently withdrawn to engage each vessel selectively. It is also removed after straightening with a wire.

Orthogonal oblique views will visualize SCA and its branches. LAO for RSCA and RAO for LSCA will give good views of these vessels (Figures 20-24 and 20-25). Patient’s arm should be adducted to the neutral position during angiography. For axillary artery and BA angiography, catheter is advanced into distal SCA. Usually a long 300 cm Wholey, Magic Torque or a Stiff Shaft Angled Glide wire is used to exchange the JR4, Vitek, or Simmons catheter for a straight 4- to 5-F Glide catheter or a multipurpose catheter. Axillary artery is angiographed in adducted arm position and BA in an abducted position with forearm supine. For the forearm and hand angiogram, the diagnostic catheter is further advanced into the distal BA. Forearm should be supine, fingers splayed and thumb abducted. PA projection
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FIGURE 20-22. Hundred percent occluded left subclavian artery. Dual injection technique is demonstrated with 5-F JR4 catheter in the subclavian artery and 6-F long shuttle sheath in the ascending aorta. 
Courtesy: John Laird MD, Washington Hospital Center, Washington, DC.

FIGURE 20-23. Left subclavian artery widely patent after stenting. 
Courtesy: John Laird MD, Washington Hospital Center, Washington, DC.

FIGURE 20-24. Critical stenosis of the origin of innominate artery seen on angiogram performed via right radial artery. Aortic arch is not clearly opacified due to the stenosis. Right common carotid artery is patent (arrow head). 
Courtesy: John Laird MD, Washington Hospital Center, Washington, DC.

is adequate. Vasodilators are given intraarterially due to the spasmodic nature of these arteries. For borderline lesions a translesional gradient can be measured using a 0.014-inch pressure wire or simultaneous measurement of pressure between 4- and 5-F catheter tip placed distal to the lesion and the side port of a long 6-F sheath positioned in the distal aorta. Vasodilators can be used to augment the gradient. A gradient greater than or equal to 15 mm Hg in SCA and BCA is considered significant.

Abdominal Aorta

Atherosclerotic disease is very common with more involvement of the infrarenal abdominal aorta. Abdominal aorta starts at the level of the diaphragm (T12) and continues anterior to the spine and to the left of inferior vena cava. It bifurcates at L4 level into the right and left common iliac artery. AA is 15 to 25 mm in diameter and larger in males and older populations. It gives rise to the celiac trunk at T12-L1, superior mesenteric artery (SMA) at L1-L2, and inferior mesenteric artery (IMA) at L3-L4 level. Renal arteries originate posterolaterally at L1-L2 level below the origin of the SMA. Four pairs of lumbar arteries originate below the renewables.

Abdominal aorta is considered to be aneurysmal when the anteroposterior diameter is 3 cm. Diagnosis is based
on formulas that adjust for age or body surface area or by calculating the ratio between the normal and dilated aortic segments. The prevalence of AAA increases with age. In a necropsy study, incidence was 5.9% in men aged 80 to 85 years and 4.5% in women who were older than 90 years of age. Based on U.S. studies, the prevalence for AAA 2.9 to 4.9 cm is 1.3% for men aged 45 to 54 years and up to 12.5% for men aged 75 to 84 years. Comparable prevalence for women is 0% to 5.2%.

Common iliac artery aneurysms are usually also found in association with AAA. One-third to one-half are bilateral and 50% to 85% are asymptomatic when diagnosed. Rupture occurs when they are more than 5 cm.

For the diagnosis, a history of abdominal and back pain and presence of a pulsatile mass are important indicators of the presence of AAA. Plain X-ray film of the abdomen may show curvilinear aortic wall calcification as an incidental finding. US or nuclear scan of abdomen may show AAA as an incidental finding. Similarly, during unrelated arteriography, slow or turbulent flow in the aorta may suggest presence of AAA.

US has a specificity of nearly 100% and sensitivity of 92% to 99% for the diagnosis of infrarenal AAA. For suprarenal AAA, the accuracy is much less. CTA and MRA are the current gold standard for the diagnosis of AAA. Spiral contrast-enhanced CTA with 3D reconstruction is now the standard preop evaluation to look for vessel calcification, thrombus, and anatomy of the aneurysm for optimal stent graft placement (Figure 20-26). In addition to previously described limitations, CTA tends to overestimate the diameter of the neck and underestimate the length of the neck of the aneurysm. MRA is inferior to spiral contrast-enhanced CTA in spatial resolution and not very good for detecting vessel wall calcification. MRA is slower than CTA but not inferior in the diagnosis. It is considered superior to catheter angiography for defining the proximal extent of the AAA, venous anatomy, intraluminal thrombus and iliac aneurysms. Renal arteries can also be imaged accurately with the new scanners. Standard MRA protocols for AAA are not available everywhere.

Catheter angiography is always done at the time of endovascular aneurysm repair (EVAR). Pelvic angiography is also done at the same time to visualize iliac arteries, which are also frequently involved with abdominal aortic aneurysm. It also helps in the optimal visualization of collateral or variant arterial anatomy. Contrast angiography, however, is not accurate in estimating the diameter of the AAA due to presence of thrombus that is usually present in the aneurysms. CTA or MRA are thus needed...
in conjunction prior to EVAR (Figures 20-27 and 20-28). Prior to open or endovascular repair the maximum transverse diameter of the aneurysm, its relationship to the renal arteries, presence of iliac artery or hypogastric artery aneurysm, stenosis of renal or iliac arteries, and presence of horse-shoe kidneys, etc., must be defined. The diagnostic modality must provide measurement of the neck and body of the AAA and of the iliac arteries. CTA is also excellent in defining the type of endoleak after EVAR before angiography to repair the endoleak (Figure 20-29).

Femoral approach is most common using 4- to 6-F pigtail or Omniflush catheter. Radial, brachial, or axillary approaches are also used. As a last resort, translumbar puncture can be done. For AAA, the pigtail or Omniflush catheter is positioned such that the tip is at T12-L1 level so that the side holes are at L1-L2 level. Contrast of 30 to 50 cc is injected. For abdominal or thoracic aortic stenosis, a translesional gradient can be measured as previously described. A gradient greater than 10 mm Hg is considered significant (Figure 20-17).

Visceral Artery Aneurysms

Open or endovascular repair has a class I indication for aneurysms greater than 2 cm in women of child-bearing age or in men or women undergoing liver transplant. They have Class IIa indication in men or in women who are beyond the child-bearing age. Splenic and hepatic artery aneurysms are not very common. Most are found incidentally during imaging for other reasons. Most are asymptomatic but a rupture in pregnant women carries a very high mortality that may approach 70% for the mother and >90% for the fetus. In general population the rupture carries a mortality of 10% to 25%.

SMA has 6% to 7% of all visceral aneurysms. Lower extremity aneurysms generally do not rupture but pose a danger of thromboembolism or vessel thrombosis. PA carries up to 70% of all LE aneurysms. CTA and MRA are the tests of choice.

Renal Artery

Renal artery stenosis (RAS) is a very common and progressive disease in patients with PAD. It is a relatively uncommon cause of hypertension. A duplex US study of patients older than 65 years showed an incidence of 9.1% in men, 5.5% in women, 6.9% in white population, and 6.7% in black population. In another series of 395 patients with abdominal aortic and iliofemoral disease, the incidence of RAS greater than 50% was 33% to 50%. The incidence of significant RAS in patients who were undergoing coronary angiography who also underwent renal angiography was approximately 11% to 18%. Conversely, the incidence of clinically significant CAD was 58% in patients with atherosclerotic RAS. In 24% patients...
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FIGURE 20-29. CTA of an abdominal aortic endograft showing an endoleak via a collateral between internal iliac and inferior mesenteric arteries (arrow).Courtesy: Robert Falk MD, 3-DR Louisville, KY.

with end-stage renal disease (ESRD) and in need for dialysis, there was severe atherosclerotic RAS. AS is by far the most common pathophysiological mechanism approaching 90% in patients with RAS. Fibromuscular dysplasia is found in approximately 10% of patients with RAS. There is also significant progression of RAS. In patients with less than 60% RAS, progression was 20% per year and in those with greater than 60% stenosis, there was complete occlusion in 5% cases at 1 year and 11% at 2 years. Bilateral RAS is also common. In six different studies including 319 patients, it was found in 44% of cases. Renal arteries arise at L1–L2 level from the posterolateral aspect of the abdominal aorta. Right RA typically originates slightly higher than the left. Accessory renal arteries are also quite common and found in 25% to 35% of the general population. These usually supply the lower poles of the kidneys. They can arise anywhere from suprarenal aorta down to the iliac and are generally smaller in caliber. Main renal artery further branch into segmental, interlobar, arcuate, interlobular, and arterioles.

Angiography

MRA has an ACC/AHA Class I indication as a screening tool for RAS (Figure 20-30). Similarly, CTA has Class I indication in patients with normal renal function. When the clinical suspicion is high and when the noninvasive tests are inconclusive, catheter angiography has Class 1 indication for the diagnosis of RAS (Figure 20-18).

MRA with gadolinium compared to catheter angiography has a sensitivity 90% to 100% and specificity of 76% to 94% in atherosclerotic RAS. For patients who have FMD, the accuracy of MRA is less. MRA is the most expensive test diagnostic tool and other limitations are as discussed before: CTA has a sensitivity of 92% and specificity of 95% when compared to DSA. Use of CTA is limited because of a risk of CIN. CTA with the old scanners had a sensitivity of 59% to 96% and specificity of 82% to 99% when compared to catheter angiography. With the new scanners, they have improved to 91% to 92% and 99%, respectively.

Currently, catheter angiography is reserved for those patients whose diagnosis is not clear by noninvasive testing. It is also recommended in patients who are undergoing coronary or peripheral angiography in whom there is a high suspicion of RAS.

For contrast angiography, CFA approach is most common using 5- to 6-F short sheath. In severely tortuous iliofemoral vessels, a long 6 F sheath should be used. Brachial approach is used in patients with poor femoral approach or if the renal arteries are acutely downward angulated. Nonselective angiography is done first with a pigtail or
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FIGURE 20-31. Bilateral renal artery stenoses on flush angiography of abdominal aorta utilizing pigtail catheter.

Omniflush catheter positioned at L1-L2 level in AP view to look for ostia of the renal arteries and also to look for accessory renal arteries. DSA at 4 FPS with 30 mL non-ionic iso-osmolar contrast at the rate of 15 mL/s is usually injected (Figure 20-31). For selective renal angiography 4 to

FIGURE 20-32. Selective left renal artery angiography utilizing Judkin’s right coronary catheter showing significant stenosis.

FIGURE 20-33. Selective right renal artery angiography utilizing Cobra catheter.

5 F JR4, renal double curve, Cobra, IMA, SOS, or Hockey stick catheters can be used (Figures 20-32 to 20-34). For downward-angulated renals, reverse curve catheters, for example, Simmons or Omniselective can be utilized from the femoral approach or a straight MP catheter from the brachial approach. Contrast of 5 to 8 mL at 5 mL/s using DSA at 4 FPS will give excellent images. Usually an ipsilateral 15 to 30 degree oblique view will display the ostium and proximal renal artery. Another useful technique is to modify the LAO/RAO angulation under fluoroscopy while the catheter is engaged until the tip of the diagnostic

FIGURE 20-34. Selective right renal artery angiography showing in-stent restenosis utilizing Judkin’s right coronary catheter.
catheter is maximally opened. Cranial and caudal angulation can be used to open up the bifurcation lesions. Cineangiogram is prolonged until the nephrogram phase to assess the kidney size and regional perfusion of the kidney to optimize revascularization strategy.

**No Touch Technique**

Abdominal aorta frequently is severely atherosclerotic and there is risk of visceral or distal embolization of atheroma during manipulation of catheters. With this technique, a 0.14-inch wire is advanced through the catheter beyond the renal arteries. The catheter is manipulated toward the renal ostia without touching them, thus avoiding the scraping of the aortic intima.

In borderline lesions, a transluminal gradient should be measured. A 0.014-inch pressure wire is most accurate. Alternatively, a 4 F diagnostic catheter is advanced beyond the lesion and gradient measured between the catheter and a 6 F sheath in the aorta. A systolic gradient greater than or equal to 20 mm Hg or a mean gradient of 10 mm Hg is considered significant. Vasodilators, for example, nitroglycerin 100 to 300 mg or Papaverine 20 to 30 mg intravenously can be used to augment the gradient. Intravascular ultrasound (IVUS) is also a very useful imaging modality in renal arteries to accurately assess the artery size and disease involvement of the ostia.

CIN is a significant risk and can be as high as 20% to 50% in patients with both chronic kidney disease and diabetes mellitus.\(^{125,126}\) Iso-osmolar contrast agent Iodixanol showed less nephrotoxicity than low-osmolar agent Iohexol in one randomized trial.\(^{127}\) In patients with creatinine clearance less than 60 mL/min and serum creatinine greater than 1.2 mg/dL, Mucomyst 600 mg twice a day decreased the incidence of CIN in patients undergoing coronary angiography.\(^{128}\) In patients with renal insufficiency, CO\(_2\) angiography can be done injecting 40 to 50 mL of CO\(_2\) delivered by hand injection while the patient is holding breath using DSA. This will allow visualization of renal ostia to facilitate selective renal angiography. Gadolinium contrast or iodinated contrast in a 50:50 ratio with normal saline can also be used in patients with renal dysfunction.

**Mesenteric Arteries**

AS involvement of these arteries is common but mesenteric ischemia is uncommon. Mesenteric ischemia can also be caused by nonobstructive arterial disease in cases of low flow states. Two-thirds of the patients with intestinal ischemia are women with a mean age of 70 years and most have preexisting CAD.\(^{129-131}\) Postprandial abdominal pain is almost always present as a symptom.

Celiac artery arises from the anterior surface of the aorta at T12 level. It travels inferiorly for 1 to 3 cm before dividing into common hepatic, splenic, and left gastric arteries. SMA arises at the L1-L2 level and gives rise to middle colic and pancreatoduodenal arteries. IMA arises at L3-L4 level and gives rise to left colic and superior rectal arteries (Figure 20-35).

These vessels have rich collateral pathways. Meandering mesenteric artery allows communication between SMA and IMA. Pancreatoduodenal artery communicates between celiac artery and SMA while IMA has collateral communications with the EIA. Occlusion of one of these arteries generally does not cause intestinal ischemia. Classical teaching was that severe stenosis or occlusion of two of the three of these arteries has to be present to cause this syndrome, but this is not considered entirely true now.\(^{132,133}\) Single vessel disease, virtually always of the SMA, can cause intestinal ischemia (Figure 20-36). Patients in whom collateral circulation has been interrupted by prior surgery are especially prone to intestinal ischemia by single vessel involvement.

Duplex ultrasound, CTA, MRA with gadolinium enhancement, and catheter angiography with lateral abdominal aortography where noninvasive testing is not available or indeterminate, all have Class I indication in the diagnosis. In many cases, US is not very helpful because of the presence of bowel gas or patient body habitus. CTA and MRA are good for detecting proximal artery lesions. CTA, however, requires intravenous contrast. In case of acute intestinal ischemia, catheter angiography is the best test but it is limited by the time it may require in such emergencies. It can differentiate between occulsive versus nonocclusive disease. Sometimes the patient is not stable to undergo the procedure. Immediate laparotomy and surgical revascularization is the best approach in such cases.

Chronic intestinal ischemia is rare and almost always caused by AS.\(^{134}\) Buerger’s disease, FMD, and aortic dissection are very rare causes.
FIGURE 20–36. Angiogram in a lateral projection showing critical stenosis of (1) celiac trunk and (2) 100% occlusion of SMA in a patient with severe mesenteric angina. Courtesy: John Laird MD, Washington Hospital Center, Washington, DC.

Catheter angiography has ACC/AHA Class I indication in patients with suspected nonocclusive intestinal ischemia whose condition does not improve rapidly with the treatment of the underlying disease, e.g., circulatory shock. It can also confirm vasospasm and vasodilator agents can be administered. 135–137

The CFA approach is most commonly used. Arm approach can be used if femoral approach is not feasible. A 4 to 5 F pigtail or Omniflush catheter is placed at T12-L1 level and 30–40 cc of contrast injected via power injector using DSA at 15 cc/s at 4 to 6 FPS. Lateral view will best visualize these vessels (Figures 20-37 and 20-38). An AP view should also be done to visualize the mesenteric circulation and the presence of any collateral vessels. “Arc of Riolan” (an enlarged collateral vessel connecting the left colic branch of the IMA with SMA) is an angiographic sign of proximal mesenteric arterial obstruction that is visible on the AP view.

Pelvis and Lower Extremity

Infra renal aorta and iliofemoral vessels are amongst the most commonly involved in atherosclerotic PAD. Ileofemoral involvement is more common in patients that have history of hypertension and smoking while below the knee, disease is commoner in diabetic population. Surgical
revascularization in the iliofemoral region has a patency of >80%[138,139] but it is associated with significant mortality and morbidity. Endovascular revascularization is rapidly taking over as the first line of treatment in these cases.

AA bifurcates into common iliac arteries (CIA) at the L4-L5 level. CIA divides at L5-S1 junction into internal iliac artery (IIA) and external iliac artery (EIA). IIA courses posteromedially and EIA anterolaterally and exits the pelvis posterior to the inguinal ligament to become the CFA. The IMA takes off medially at the junction of EIA and CFA. The deep iliac circumflex artery takes off laterally and superiorly. CFA originates at the inguinal ligament and bifurcates at the lower part of the head of the femur into SFA anteromedially and DFA posterolaterally. DFA has two major branches, lateral and medial circumflex femoral arteries.

These arteries along with the first perforating branch connect with the IIA via the superior and inferior gluteal and obturator arteries. Distally, its branches provide collaterals to the network around the knee, thus communicating with the popliteal and tibial vessels. Therefore, in cases of occlusion of SFA, the DFA becomes a very important source of collateral circulation.

The SFA becomes the popliteal artery (PA) as it enters the adductor canal (Hunters canal). PA runs posterior to the femur and gives sural and geniculate branches. Below the knee, the PA divides into anterior tibial artery (AT) that runs anterior and lateral to the tibia and continues into the dorsum of the foot as the dorsalis pedis artery (DP). After the takeoff of the AT, the PA continues as the tibiopopliteal trunk (TPT) that divides into posterior tibial and peroneal arteries. The peroneal artery runs between the AT and PT. It joins the PT above the ankle via its posterior division and the AT via its anterior division. PT runs behind the medial malleolus and gives medial and lateral plantar branches. The lateral plantar and distal DP joins to form the plantar arch.

Angiography

CTA and MRA are very good tools to delineate the anatomy (Figures 20-39 to 20-41). Compared to DSA, the MRA has shown a sensitivity of 97% and specificity of 99.2%.[141] Interest in this technology is growing as the sole diagnostic tool prior to surgical revascularization.[142] MRA in fact can be a better imaging modality than CTA and catheter angiography for below the knee vasculature (Figure 20-42).

CTA is also excellent in the diagnosis but limited by CIN and radiation hazard.[143] Contrast angiography is considered to be the gold standard (Figures 20-43 to 20-45). It should be reserved for the patients being considered for revascularization and should not be done for diagnostic purposes only if CTA or MRA facility is available. Initially a nonselective angiogram should be done. CFA, brachial, or radial approaches are used. Sheaths and catheters of 4 to 6 F are used. A PT or OF catheter is positioned at L4–L5 and 30 mL of contrast at 15 mL/s is injected with a power injector. DSA at 4 to 6 FPS should be utilized. In cases of known iliac artery obstruction, the catheter should be placed just below the renal

![FIGURE 20–39. CTA of abdominal aorta and pelvic arteries showing severe calcification of distal aorta, common and internal iliac arteries. Celiac trunk, superior mesenteric, and renal and inferior mesenteric arteries are patent. Courtesy: Robert Falk MD, 3-DR Louisville, KY.](image-url)

![FIGURE 20–40. CTA showing aortobifemoral and left femoral-distal bypass graft.](image-url)
arteries to look for collaterals from the lumbar branches. Selective iliac angiogram is typically done from the contralateral side using 4 to 5 F IMA or JR4 catheter. Other catheters, e.g., Simmons, Omniflush, or SOS, can be used as needed. An exchange length of 200 to 360 cm angled glide wire is advanced under fluor into the CFA or more distally and the catheter exchanged for a straight 4 to 5 F glide or MP catheter. A selective stepwise angiogram of the leg is performed. A 10 to 15 cc contrast is used at each step. For optimal below the knee angiogram, the catheter should be advanced to the distal SFA and vasodilators used. Interactive bolus chase technique as described before can also be used for nonselective angiography of both the legs.
Another technique to engage the common iliac artery is to advance the angled glide wire in the catheter (usually pig tail) already in the abdominal aorta that was used for initial angiogram. The tip of the catheter is faced toward the contralateral iliac. The wire is advanced to “open up” the catheter and the catheter gently pulled down toward the aortic bifurcation. The glide wire will drop down into the common iliac artery as the catheter hooks the ostium of the common iliac. The catheter is then exchanged for the straight catheter as described above. This technique saves an extra step of engaging the contralateral iliac with another catheter first.

After the angiogram of the contra lateral leg is completed, the catheter is pulled just a few inches proximal to the tip of the insertion sheath in the ipsilateral leg and angiogram completed in a stepwise fashion. This can also be done with the sheath alone but a smaller catheter has less risk of causing dissection during angiography: Power injector, hand injection, or an “assist device” can be used. Contralateral angle of 30 to 40 degrees will open up the iliac artery bifurcation and 30 to 40 degrees ipsilateral angles will open up the vessels below the EIA. Lesions with greater the 50% diameter stenosis and translesional systolic gradient greater than 10 mm Hg are considered significant.

If femoral approach is not feasible, then a brachial or radial approach utilizing straight catheters can also be used for selective angiography of each leg. Vasodilators, for example, NTG 100 to 300 mg, Papavarin 30 to 60 mg, or Tolazoline 12.5 to 25 mg can be used to optimize below the knee imaging and also to augment translesional radiant.\textsuperscript{144}

High success rate with endovascular treatment has now encouraged most experienced operators to tackle below the knee PAD that was long thought to be only fit for surgical therapy. Patients with CLI who are being subjected to amputation should be given an option for peripheral vascular intervention even if it helps in the short-term healing of their infections and to prevent more proximal amputation.

**VENOUS CIRCULATION**

With improvement in technology, enthusiasm is gaining momentum in the endovascular treatment of venous occlusive disease (VOD). The most common causes of VOD are coagulopathies, extrinsic compression from tumors, and thrombosis from iatrogenic catheters and wires. Venous enhanced subtracted peak arterial (VESPA) magnetic resonance venography is comparable to conventional venography in the diagnosis of femoral and iliac deep venous thrombosis.\textsuperscript{145} CTA and MRA are both useful in the diagnosis of upper extremity and central VOD, stenoses, extrinsic masses, and pulmonary embolism.

Venous system parallels arterial system. The superficial veins in the infragingual region drain into the small saphe nous vein, which drains into the popliteal vein, and into the greater saphenous vein that drains into the common femoral vein (CFV). The deep veins converge on the CFV that continues as the external iliac vein and combines with...
the internal iliac vein to form the common iliac veins which drain into the IVC that further drains into the right atrium of the heart.

Superficial upper extremity veins drain into the lateral cephalic and medial basilic veins that run along the arm. Cephalic vein empties into the axillary vein and basilic vein drain into the brachial vein. Deep veins drain into the brachial vein that continues as the axillary and subclavian veins. Each subclavian vein unites with the internal jugular vein to form the right and left inominate veins. They join together on the right side to form the superior vena cava (SVC) that empties into the right atrium.

Venous drainage from the pelvic area flows to internal iliac vein that joins with external iliac vein to form the common iliac vein. Venous drainage from abdominal visera goes to IVC. The azygous and hemiazygous system of veins form an important link between IVC and SVC. The hemiazygous vein and accessory hemiazygous vein is located along the left side of thoracic vertebrae and receives blood from the left chest wall and lung and drain into the azygous vein. In two-thirds of cases, the hemiazygous vein communicates directly with the left renal vein. Azygous vein is located on the right side of the thoracic vertebrae and drains into the SVC at the level of T4. Distally, it connects to the IVC at the level of the renal vein.

Venogram
This is still considered the gold standard for VOD. Small amount of contrast through peripherally inserted catheters will provide visualization of the veins. Raising the arm improves central filling. For lower extremity angiography, venous access is obtained in the dorsum of the foot. DSA is used. For iliac veins 5 to 6F sheath is inserted in the CFV and angiogram is obtained by hand injection of the contrast. For IVC, a pigtail or Omniflush catheter is inserted in CIV and 40 mL of contrast is injected. For pulmonary angiogram a 6F angled pigtail or a Grollman catheter is advanced in the main pulmonary artery through a sheath in the CFV or IJ vein. Contrast at 30 mL at 15 mL/s is injected, and angiography acquired in AP and lateral views for each lung. If pulmonary artery pressure is high, then selective right and left pulmonary artery angiogram is obtained. Care should be taken in patients with preexisting LBBB because the catheter may cause RBBB, thus, causing complete heart block.

**INTRAVASCULAR IMAGING**

There are other intravascular imaging techniques that are less commonly used in routine catheter peripheral angiography. They can however be very useful in cases of ambiguous situations or where a decision to intervene is not clear cut.146

IVUS is the most widely available. IVUS catheter uses reflected sound waves to image vascular walls and structures in a two-dimensional tomographic format. Compared to cardiac echocardiogram, the catheters used in peripheral imaging have a much higher frequency, 20 to 40 MHz versus 2 to 5 MHz. Most new IVUS catheters are compatible with 6F sheaths and guiding catheters. Over the wire and rapid exchange systems are available. In our center we use Boston Scientific Corp. system (Natweik, MA), unfractionated heparin at 70 units/kg is given intravenously during IVUS procedures. Intracoronary nitroglycerin is given prior to delivering the catheter at the area of interest. Automated pullback is done at 0.5 to 1 mm/s. Interpretation is based on recognition of blood-intima and media-adventitia interface. Lumina and adventitia are much brighter than the media creating a bright–dark–bright image. Angioscopy is not FDA-approved in the United States for clinical use. It is probably the best technique for imaging intravascular thrombus. It provides real-time color images of vascular surfaces and also gives information about atherosclerotic plaque and dissection flaps. Optical coherence tomography (OCT) generates real-time tomographic images from back-scattered reflection of infrared light. It can be conceptualized as an optical analog of IVUS. It has 10 times higher resolution than conventional ultrasound. Imaging procedure is similar to IVUS; however, saline or contrast media must displace blood. There is only one system that is commercially available (Light bulb Imaging Inc., Westford, MA). A 0.014-inch imaging wire is inserted in the vessel distal to the occlusion balloon. The diagnostic accuracy of OCT for plaque characterization is confirmed by an ex vivo study of 3007 human AS specimens from aorta, carotid, and coronary arteries.144 The complications of this procedure appear to be comparable to IVUS and angioscopy. However, data are lacking.

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**REFERENCES**


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81. MRC European Carotid Surgery Trial. interin results for symptomatic patients with severe (70%-99%) or with mild (0%-29%) carotid stenosis. European Carotid Surgery Trialists’ Collaborative Group. Lancet. 1991;337:1235–1243.


