Vascular disease is increasing in prevalence, but remains under-diagnosed and under-treated. In the past few years, interest in peripheral vascular and cerebrovascular intervention has blossomed. Techniques adapted from interventional cardiology, radiology, and surgery have ushered in a new era of endovascular intervention. The Guide to Peripheral and Cerebrovascular Intervention brings together experts in the field of endovascular therapy to cover topics such as the basics of vascular anatomy, the pearls of appropriate case selection, and the fundamental equipment and pharmacotherapy for successful procedures.

Specific chapters discuss advanced techniques in lower and upper extremity arterial intervention, renal and mesenteric intervention, carotid and vertebral stenting, intracranial intervention for stenotic as well as aneurysmal disease, venous thrombolysis and intervention, aortic stent graft placement, dialysis access, and infrapopliteal intervention and limb salvage. The technical aspects of these various procedures are explained in a manner that will not only be useful to the novice, but also informative to the experienced practitioner. Additionally, relevant literature and data are discussed to provide a thorough understanding of the related medical and surgical concerns associated with treating vascular disease. Numerous figures are included to illustrate key anatomical concepts. This book will be of interest to physicians, nurses, and technicians who currently treat patients with vascular disease or who plan to do so in the future.

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Guide to Peripheral and Cerebrovascular Intervention

Deepak L Bhatt, Editor
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Peripheral and Cerebrovascular Intervention
By the same editor:

*Essential Concepts in Cardiovascular Intervention*

*Handbook of Acute Coronary Syndromes*
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Preface

We are at the dawn of a new era in the treatment of vascular disease. The time of the scalpel is fading and endovascular intervention is becoming the dominant mode of treatment for peripheral and cerebrovascular diseases.

In keeping with the rapid expansion of knowledge in the field of endovascular intervention, this book brings together experts from various backgrounds to provide the essential content for the reader to perform complex endovascular interventions.

I am grateful to the authors for providing such excellent technical treatises, describing intricate procedures that are in a state of evolution, while at the same time providing the scientific data to justify their positions. I am appreciative of the efforts by Remedica to provide the highest quality reproductions of angiographic images, a prerequisite for any truly useful book pertaining to vascular disease. It is my wish that readers of assorted backgrounds at various stages in their adoption of endovascular techniques will find this book informative, exciting, and also enjoyable, as we enter the brave new world of endovascular intervention.

Deepak L Bhatt
To my wife Shanthala, my sons Vinayak and Arjun, and my parents, for their unwavering love and support through this and many other of life’s endeavors
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1 Anatomical considerations

Christopher T Bajzer
Introduction

A detailed knowledge and understanding of normal vascular anatomy and the common variants are essential to perform quality angiography and plan endovascular intervention.

Thoracic aorta and the great vessels

The thoracic aorta includes the aortic root, ascending aorta, aortic arch, and a portion of the descending aorta. There is variability in the aortic arch and the origin of the vessels off the aortic arch, which are usually termed the great vessels. The variability in the anatomy of the great vessels is both congenital and acquired. After the origin of the coronary arteries, the great vessels arise off the aortic arch and include:

- the innominate artery (also known as the brachiocephalic artery)
- the left common carotid artery (CCA)
- the left subclavian artery

The angiographic appearance of the origin of the great vessels off the aortic arch is classified as to whether the great vessels arise more from the ascending or the descending portion of the aortic arch. A reference dimension is defined as the diameter of either the left or right CCA. An imaginary horizontal line is drawn tangentially to the top of the aortic arch. Parallel imaginary lines are drawn inferiorly to this index line, spaced by the reference dimension set by the diameter of the CCA (see Figure 1).

- If the origins of all the great vessels arise within the arc segment of the aortic arch subtended by the first parallel reference line, it is termed a type I arch.
- If the origins of all the great vessels are included in the arc segment of the aortic arch subtended by the second index line, it is termed a type II arch.
- If the origins of all of the great vessels are included in the arc segment of the aortic arch subtended by the third index line, it is termed a type III arch.

Different arch types occur due to congenital variations as well as acquired variations due to unfolding of the aorta related to various pathologic processes, including long-standing hypertension.

Variations in the origins of the great vessels are often encountered. The innominate artery usually gives rise to the right CCA and right subclavian artery. When the left CCA also originates off the innominate it is termed a “bovine origin” of the left CCA (see Figure 2). The term bovine is used because this is the most common anatomy encountered in the bovine species. This variation in the origin of the great vessels is encountered in approximately 7%–20% of individuals.

Another commonly encountered variation is a separate origin of the left vertebral artery off the aortic arch. In this instance, the left vertebral artery is usually identified between the origins of the left CCA and the left subclavian artery. This is encountered in approximately 0.5%–6%
of individuals. A less frequently encountered congenital anomaly is a separate origin of the right subclavian artery with a retroesophageal course (0.2%–0.4% of individuals). A further, uncommon, variation in arch anatomy is a persistent right aortic arch; this is sometimes termed the avian arch because it is the most commonly encountered anatomy in birds. A double aortic arch is extremely uncommon and has been termed an amphibian arch (not surprisingly, it is the most common anatomy encountered in amphibians).

**Optimal views**

Arch aortography is optimal with the patient's head turned towards the right and their chin elevated. The camera's field of view is centered so that it includes the top of the arch and the extent of the carotid arteries to the level of the mandible. Filters minimize areas of over-exposure. Digital subtraction acquisition is utilized with the patient instructed to "Hold your breath, don't
move, and don't swallow.” A total of 30 mL of contrast is utilized at a rate of 15 mL/min with no rate of rise.

**Arterial supply to the upper extremities**

The right subclavian arises from the innominate artery, while the left subclavian most commonly arises directly off the aortic arch. The subclavian artery gives rise to the internal mammary and vertebral arteries, as well as to the high thoracic artery and thyrocervical trunk (see Figure 3). The subclavian artery is terminally demarcated by the first rib. As the subclavian artery courses over the first rib it becomes the axillary artery. The first segment of the axillary artery gives rise to the thoracoacromial trunk and the highest thoracic artery. The distal segment of the axillary artery gives rise to the lateral thoracic artery and the subscapular artery, which in turn gives rise to the circumflex scapular and the thoracodorsal artery (see Figure 4). The axillary artery then gives rise to the posterior and anterior circumflex humeral arteries before becoming the brachial artery (see Figure 5), which courses over the anterior aspect of the shaft of the humerus. Before this anterior course, the brachial artery gives rise to a radial collateral branch that courses posteriorly and laterally to the humerus itself. The radial collateral then courses anteriorly to the lateral epicondyle and usually rejoins the radial artery at the level of the antecubital fossa. On occasion, the radial collateral will give rise to a branch termed the middle collateral artery, which courses posteriorly to the lateral epicondyle of the humerus and often rejoins the interosseus artery.
After giving rise to the radial collateral artery, the brachial artery will first give rise to the superior ulnar collateral and then to the inferior ulnar collateral. These arteries course posteriorly and anteriorly to the medial epicondyle of the humerus, respectively. They rejoin the ulnar artery as the posterior ulnar recurrent artery and the anterior recurrent artery. The brachial artery bifurcates just below the trochea of the humerus, dividing into the radial artery (which courses laterally) and the ulnar artery (which courses medially) (see Figure 6). The interosseous artery commonly arises from the ulnar artery, but has been observed to arise from the radial artery, or as a true trifurcation of the brachial artery. The interosseous artery often divides into an anterior and posterior interosseous artery, which either terminate at the level of the metacarpal bones or rejoin the ulnar or radial arteries via a carpal arch (see Figure 7).

At the level of the carpal bones, the radial artery divides into superficial and deep branches, which join the superficial and deep branches of the ulnar artery, forming the superficial and deep palmar arches. Commonly, a continuation of the ulnar artery forms a superficial palmar arch and a continuation of the radial artery forms a deep palmar arch, although there is considerable variability. Palmar mediocarpal branches then arise from both the superficial and deep palmar arch and join together at the base of the interdigital spaces. At this level, the proper digital arteries arise directly. The proper digital arteries for the thumb and second and fifth digits often arise from the deep and superficial palmar arches (see Figure 8).

Optimal views

An upper extremity angiogram is optimally obtained with piecemeal stepped static digital subtraction images. The patient’s arm is fixed in an anatomic position, palm upwards and fingers separated. At least six stepped views are obtained with the catheter sequentially moved from more proximal to more distal positioning for optimal opacification of the small vessels.
The initial image has a field of view from the origin of the subclavian to the axillary artery, with the catheter positioned at the beginning of the subclavian artery. With the catheter advanced into the axillary artery, two stepped views of the upper arm are performed: first to encompass the shoulder to the mid biceps and second the mid biceps to the antecubital fossa.

The catheter is then advanced to the distal brachial artery prior to its bifurcation. Two stepped views of the forearm are obtained. The first encompasses the antecubital fossa to the mid forearm, with careful visualization of the forearm vessel bifurcations. Some slight oblique angulation can be utilized to optimally view these bifurcations. The next stepped view is from the mid forearm to the base of the wrist or metacarpal bones. Finally, a magnified view of the hand is performed, including the distal phalanges of all five fingers. On occasion, over-exposure is encountered with magnified views of the hand. If filtering is inadequate to allow image acquisition, the automatic exposure software can be assisted by placing a bag of saline over the x-ray source.

**External carotid artery**

Both the right and left carotid arteries divide into the internal (ICA) and external (ECA) carotid arteries at the level of the angle of the mandible (see Figure 9). There is considerable variability in the branching of the ECA. From an inferior to anterior and posterior course, commonly encountered branches of the ECA include:

- superior thyroidal artery
- ascending pharyngeal artery
The variability in the branching of the ECA was demonstrated in one study in which 80% of ECAs had a separate origin of the superior thyroidal, lingual, and facial arteries. In 20% of ECAs, both the lingual and facial arteries arose from a common trunk originating low in the ECA.

**Optimal views**

Carotid angiography is optimal with the patient’s head immobilized in the anatomic position and the chin slightly elevated. The innominate bifurcation is optimally viewed with the camera in a right anterior oblique position. Again, the patient is instructed not to breathe, move, or swallow when digital acquisition images are obtained. Selective carotid angiography is performed with the field of view focused on the carotid bifurcation; this is optimally viewed with an ipsilateral oblique in addition to a cross-table 90° lateral. On occasion, the geometry and anatomy of the carotid bifurcation varies, and a contralateral oblique or posteroanterior (PA) projection will optimally “open” the bifurcation.
Internal carotid artery

The ICA can be divided into four or five anatomic segments. The first is the cervical segment, which originates at the common carotid bifurcation and terminates at the base of the skull (see Figure 10). There are usually no branches off the cervical segment of the ICA. The carotid bulb is in the most proximal portion of the ICA and ranges from 1.1 to 1.4 times the diameter of the distal cervical ICA. The second segment is the petrous portion of the ICA, which traverses the temporal bone and begins at the skull base to the foramen lacerum. Again, this segment of the ICA usually has no branches.

The third segment is the cavernous segment. This segment begins at the foramen lacerum, traverses the venous sinuses, and terminates at the anterior clinoid process. One or two branch vessels can be seen originating from the cavernous segment; these include the meningohypophyseal artery and the inferolateral trunk artery.

The final segment is the cerebral segment, which occurs within the cranial subarachnoid space. This segment is sometimes divided into clinoidal and supraclinoidal subsegments. The clinoidal portion is extremely short, and traverses the dural ring and then enters the subarachnoid space. The supraclinoidal ICA begins at the dural ring and terminates at the ICA bifurcation. Branches off the cerebral segment or supraclinoidal subsegment of the ICA include the ophthalmic and hypophyseal branches and the posterior communicating artery (see Figure 11).

Optimal views

Acquisition of intracranial images is performed with the field of view encompassing the entire skull. With the patient’s head fixed in the anatomic position (if necessary, using adhesive tape on the forehead or a soft foam head support), the camera is positioned as needed in a right
or left oblique angulation in order to have the camera’s line of sight parallel to the falx cerebri. Cranial or caudal angulation is then adjusted to align the petrous ridge in the inferior aspect of the orbits. Digital acquisition images are obtained with the patient instructed not to breathe, move, or swallow. Imaging is continued until venous drainage is complete. A cross-table 90º lateral view is also obtained. The field of view again encompasses the entire skull.

Oblique angulation is performed until the sella turcica is clearly in view and the petrous ridges (or tympanic membranes) are clearly aligned. Again, digital acquisition images are obtained with the patient instructed not to breathe, move, or swallow, and imaging continues until venous drainage is complete. To optimally view the anterior cerebral artery (ACA), the camera is positioned in an ipsilateral oblique with cranial or caudal angulation – this places the segment within a field of view with minimal bony density to avoid subtraction artifact. This is often performed with the intent to place the segment within the orbit. Likewise, focal views of the middle cerebral artery (MCA) can be performed with a slight contralateral oblique or ipsilateral oblique view with cranial or caudal angulation added in order to minimize overlapping bony densities and focus on the segment of interest.

Anterior cerebral artery

The ACA is anatomically divided into five segments. The first segment (A1) begins at the origin of the ACA (the carotid bifurcation) and is demarcated by where the artery turns superiorly between the frontal and temporal lobes. The A1 segment can give rise to the medial striate artery and the anterior communicating artery, which connects to the contralateral ACA (see Figure 12). As the ACA enters the interhemispheric fissure, it ascends superiorly on the medial surface of the hemisphere and then continues posteriorly on the superior surface of the corpus callosum.

The A2–A5 segments are demarcated as the ACA gives rise to side branches – such as the orbital artery, the frontal polar artery, and the callosal marginal artery – and then terminates as the pericallosal artery (see Figure 11). Variations or anomalies of the ACA occur in about 25% of brains. These include unpaired arteries and instances where branches are given off to the contralateral hemisphere.

Middle cerebral artery

The MCA often appears as a continuation of the ICA beyond the origin of the ACA. The MCA is angiographically subdivided into four segments. The M1 segment, also called the horizontal segment, originates at the carotid bifurcation and terminates as the middle cerebral artery, and its branches turn superiorly into the area between the temporal lobe and the insula. The M2 segment (the insular segment) originates as the artery enters between the temporal lobe and the insula and ascends along the insular cleft before making a hairpin turn at the sulcus of the insula. The M3 segment (the opercular segment) begins at the apex of the hairpin turn in the sulcus of the insula and terminates as the branches reach the lateral convexity of the hemisphere. The M4 segment (the cortical segment) is visible on the lateral convexity of the hemisphere as the artery arises between the frontal, parietal, and temporal lobes (see Figure 12).
The MCA is the most complex of the three cerebral arteries and divides into a number of large branches. In the insular region, anything from five to eight branches of the MCA lie within the Sylvian triangle. The apex of the Sylvian triangle is angiographically determined by the most posterior branch of the MCA to emerge onto the lateral convexity. The lowest branches of the MCA form the inferior margin of the Sylvian triangle. The superior margin is formed by the apices of the hairpin turns that define the M2 and M3 segments (see Figure 11). The Sylvian triangle is angiographically helpful in that mass lesions can be easily detected as a displacement or distortion of the triangle.

The terminal branches of the MCA fan out over the lateral convexity of each hemisphere. The branches to the frontal, anterior temporal, and anterior parietal regions are small in comparison with those to the posterior parietal, posterior temporal, and terminal occipital regions, but they are more numerous. Branches of the MCA include the lenticulostriate arteries and the anterior choroidal artery, which arise from the M1 segment. The posterior communicating artery can also arise from the M1 segment. The cortical branches of the MCA include the anterior temporal artery, pre-rolandic artery, rolandic artery, anterior parietal artery, posterior parietal artery, and posterior temporal artery.

**Vertebral artery**

The vertebral artery usually arises from the subclavian artery and is angiographically divided into five segments. The first segment (V1) begins at the origin of the subclavian artery and extends to the point where the artery enters the transverse foramen of the sixth cervical vertebra. The V2 segment begins where the artery enters the sixth cervical vertebra and ascends through all the
foramina transversaria of the cervical vertebrae to the second cervical vertebra or the Atlas (see Figure 13). The V3 segment traverses the transverse foramen of C2 and terminates as the artery pierces the posterior atlanto-occipital membrane. The V4 segment is demarcated by the atlanto-occipital membrane and where the artery finally enters the foramen magnum at the base of the skull. The V5 segment traverses the foramen magnum and courses along the anterior lateral surface of the medulla oblongata, before it finally unites with the opposite vertebral artery at the inferior border of the pons to form the basilar artery. V5 commonly gives rise to the ipsilateral posterior inferior cerebellar artery (PICA) (see Figure 14).

**Basilar artery**

The basilar artery is formed when the right and left vertebral arteries join at the inferior margin of the pons, and terminates as it divides into the right and left posterior cerebral arteries (PCAs). Branches of the basilar artery include the anterior inferior cerebellar arteries (AICAs) and the superior cerebellar artery (SCA). There are also smaller labyrinthine arteries, as well as numerous peri-median and pontine branches (see Figures 14 and 15).

The PCA is angiographically divided into three segments. The first segment begins at the origin of the PCA to the origin of the posterior communicating artery. The second segment begins at the origin of the posterior communicating artery and terminates at the posterior aspect of the midbrain. The third segment begins at the posterior segment of the brain and terminates in the main arteries of the posterior temporal, parietal, and occipital lobes. There is a great deal of variability in these named arteries (see Figures 14 and 15).
Anatomical considerations

**Optimal views**

With the patient’s head immobilized in the anatomic position, the field of view is centered on the inferior margin of the nasal passage or the superior margin of the maxilla. A steep cranial angulation in a PA projection optimally displays the branches of the distal vertebral and basilar arteries. A cross-table 90° lateral view is also performed. The field of view is centered on the posterior third of the skull in the area of the cerebellum. The occiput and sella turcica should be clearly in the field of view. Digital subtraction imaging is acquired with the patient instructed not to breathe, move, or swallow. Imaging continues until venous drainage is complete.

**Common congenital anomalies of the intracranial circulation**

A PCA that is predominately supplied by the ICA or an M1 segment that is smaller than the posterior communicating artery is termed a fetal PCA. On occasion, the PICA is absent and the territory that is usually perfused by this artery is instead perfused by a very large and wandering AICA. This is termed the AICA–PICA complex.

**Cerebral vascular venous drainage**

Delicate venous drainage from the cerebral hemispheres emerges from the brain to form small venous structures in the pia mater. These larger venous channels then form cerebral veins, which bridge the subarachnoid space and enter into endothelial-lined sinuses within the dura mater. Small veins from the scalp also communicate with the dural sinus via emissary veins that perforate the skull. The majority of the cerebral convexities ultimately drain into the mid-line structure in the dura mater (the superior sagittal sinus). The superior sagittal sinus courses posteriorly back towards the occiput, where it receives drainage from the straight sinus. The straight sinus itself receives drainage from the inferior sagittal sinus, which courses in the falx cerebri. The inferior margin of the superior sagittal sinus divides into a right and left transverse sinus in the tentorium cerebelli, which is again made up of dura mater. Each transverse sinus curves downward and backward as a sigmoid sinus, and is ultimately drained by each of the internal jugular veins. Venous drainage is often asymmetrical, with the superior sagittal sinus most commonly draining into the right transverse sinus, while the straight sinus usually drains into the left transverse sinus.

The cavernous sinus is an irregular network of venous channels on each side of the sphenoid sinus and sella turcica, extending from the superior orbital fissure to the petrous portion of the temporal bone. The cavernous sinus encloses a segment of the ICA. Each cavernous sinus is connected to the other by a basilar venous plexus. Each cavernous sinus drains posteriorly into the superior and inferior petrosal sinus, which enter the transverse sinus and the bulb of the internal jugular vein (see Figures 16 and 17).
There is considerable variability in the venous drainage of the brain and skull. There are also numerous interconnections between venous drainage systems. The superior anastomotic vein (vein of Trolard) connects to the superficial middle cerebral vein, which usually empties into the cavernous sinus common with the superior sagittal sinus. The inferior anastomotic vein (vein of Labbé) connects the superficial middle cerebral vein with the transverse sinus.

Abdominal aorta and mesenteric arteries

As the descending thoracic aorta crosses through the crus of the diaphragm it becomes the most proximal segment of the abdominal aorta (see Figure 18). The first and often largest visceral branch of the abdominal aorta is the celiac trunk. The celiac trunk quickly bifurcates or trifurcates into branches. The main branches are the common hepatic and splenic arteries, and, in the case of a trifurcation, the left gastric artery (see Figure 19). Otherwise, the left gastric artery will arise off the splenic artery. The splenic artery also gives rise to the left gastroepiploic artery, prior to terminating at the spleen. The common hepatic artery gives rise to the right gastric artery and then the gastroduodenal artery. The gastroduodenal artery divides into the superior pancreaticoduodenal artery and the right gastroepiploic artery. Each of the right and left gastroepiploic arteries may have anastomoses to the superior mesenteric artery (SMA) and often form the prime source for collateral circulation between these two main mesenteric arteries.

The SMA is immediately inferior to the origin of the celiac trunk (see Figure 20). One of the first several branches of the SMA can be a collateral connection to the right and/or left gastroepiploic arteries. The SMA gives rise to jejunal and ileo branches, which fan out towards the left side of the abdomen. At the level of the first jejunal branches, the SMA gives rise to the middle colic...
artery, followed by the right colic artery and the ileocolic artery. At their periphery, the middle colic, right colic, and ileocolic arteries can form an interconnection that courses to the junction of the transverse colon and descending colon; this is termed the wandering artery of Drummond. Cecal branches are seen to arise from the ileocolic branch. The wandering artery of Drummond will anastomose with the left colic artery, which is a branch of the inferior mesenteric artery (IMA) and provides the primary source of collaterals between these two mesenteric arteries.

There are usually one or two sets of paired lumbar branches off the abdominal aorta before the origin of the right renal artery (see Figure 21) and then the left renal artery (see Figure 22). Branches to the adrenal gland can originate from either the aorta or the renal arteries. Accessory renal arteries are commonly encountered. An accessory renal artery supplies a portion of the superior or inferior pole of the kidney and is termed a polar artery. Right and left gonadal arteries originate from the infrarenal abdominal aorta, as do paired and unpaired lumbar branches. Just before the distal aortic bifurcation is the origin of the IMA (see Figure 23). The IMA gives rise to the left colic artery, as well as several sigmoid and then superior and inferior rectal branches. The middle sacral branch is sometimes identified at the level of the aortic bifurcation, especially in diseased states, where the sacral branch can provide significant collateral circulation. The distal abdominal aorta then bifurcates into the right and left common iliac arteries; each common iliac artery bifurcates into an external and internal iliac artery (see Figure 24). As the external iliac artery approaches the pelvic brim and the inguinal ligament, it is termed the common femoral artery. The internal iliac artery gives rise to the superior and inferior gluteal arteries, as well as the lateral sacral arteries. It then gives rise to the middle rectal artery and
hemorrhoidal arteries, and then to internal pudendal and vesicular arteries as well as an obturator artery. The true terminus of the internal iliac artery is the obliterated umbilical artery.

**Optimal views**

Abdominal aortography is performed using PA and cross-table 90° lateral views. On the PA projection, the field of view is from the level of the diaphragm to the top of the iliac wings; on the lateral projection, the field of view is the top of the diaphragm to the iliac wings, with visualization of the vertebral bodies and the anterior surface of the abdomen. Patients are instructed to hold their breath, preferably in exhalation, and not to move while digital acquisition images are obtained. The first two views of the abdominal aorta are performed with a flush or pigtail catheter tip located at the first lumbar vertebra. The catheter is then withdrawn to a position just superior to the aortic bifurcation and two pelvic or iliac views are obtained in right and left anterior oblique projections. Power injection of contrast is utilized for the initial aortogram at a rate of 15–20 mL/s for a total of 30–40 mL of contrast. No rate of rise is necessary. For the pelvic aortogram, lower flow rates and volumes are used, usually in the order of 7 mL/s for a total of 14 mL or 2-second injection.

**Arterial supply of the lower extremities**

The arterial supply of the lower extremities begins with the iliofemoral system. The common iliac artery supplies the external iliac artery and then the common femoral artery. The common femoral artery gives rise to the superficial epigastric artery, the external pudendal artery, and the superficial circumflex artery, prior to bifurcating into the deep femoral artery (also known as the profunda femoris) and the superficial femoral artery (SFA) (see Figure 25). The profunda femoris
gives rise to the medial and lateral circumflex femoral arteries, as well as to perforating arteries that provide the blood supply to the muscles of the thigh. A descending branch of the profunda femoris supplies a lateral geniculate artery, which can supply collaterals to the above-knee popliteal artery in the setting of a diseased or obstructed SFA.

The SFA courses inferiorly with few, if any, side branches, and then enters the adductor canal and courses posteriorly to the femur to form the popliteal artery (see Figure 26). A descending medial geniculate branch originates from the distal SFA just prior to its entering the adductor canal. In the setting of obstructive atherosclerotic disease, this branch often provides additional collateral circulation around the knee. The popliteal artery courses along the posterior surface of the femur and tibia. It divides into two just below the proximal anastomosis of the fibula to the tibia, giving rise to an anterior tibial artery and a tibial peroneal trunk (see Figure 27). The anterior tibial artery pierces the interosseus membrane between the tibia and the fibula and courses along the anterior surface of the interosseous membrane close to the tibia, where it changes at the mortis joint of the ankle and becomes the dorsalis pedis artery. Lateral and medial malleolar branches can form interconnections between the anterior and posterior tibial arteries and the peroneal artery as a form of collateral circulation in diseased states.

The tibial peroneal trunk courses along the posterior surface of the interosseous membrane and divides into a posterior tibial artery and a peroneal artery (see Figure 28). The peroneal artery (also known as the fibular artery) courses along the posterior surface of the interosseus membrane close to the fibula and terminates at the ankle, usually with lateral and medial calcaneal branches. There is a distal communicating branch between the peroneal artery and the distal posterior tibial artery at the level just above the lateral malleolus. This also forms a source of collateral circulation in diseased states. The posterior tibial artery courses along the posterior aspect of the tibia and forms the medial and lateral plantar arches. The plantar arch gives rise to metatarsal and then plantar digital arteries. Perforating branches from the plantar
arch communicate with the superficial or dorsal arch, which is usually formed as a sweeping terminus of the dorsalis pedis artery, and also give rise to the dorsal metatarsal arteries and dorsal digital arteries coursing into the toes (see Figure 29).

Optimal views

Different strategies can be utilized to obtain a lower extremity run-off study. Both legs can potentially be run-off simultaneously with imaging equipment with a large field of view. With the pigtail catheter just above the aortic bifurcation, stepped digital subtraction views can be obtained with injection of 90–100 mL of contrast at a rate of 10–15 mL/s. The patient is instructed not to move their legs or feet. Alternatively, the aortic bifurcation can be crossed over with a diagnostic catheter and guidewire for placement of a straight-tip flush catheter with sideholes in the contralateral external iliac artery. This facilitates unilateral lower extremity run-off using stepped digital subtraction imaging acquisition. Half of the contrast, or 45–50 mL, is utilized at a flow rate of 7–10 mL/s, with a reasonable rate of rise ranging from 0.5 to 1.0 seconds to ramp up the injection to the set flow rate. The flush catheter is then withdrawn to the ipsilateral iliac artery and the same procedure is repeated for a run-off of the remaining limb.

To obtain high-quality images, it is imperative that the patient does not move and that there is adequate filtering of overexposed areas. On occasion, it is important to utilize a guidewire and a straight flush catheter to position the catheter more distally in the leg for high magnification and digital subtraction images of the lower leg and/or foot. A sidehole straight-tip flush catheter can be safely placed in the popliteal artery and hand injections can be used to obtain high-magnified views of the distal lower extremity and foot. Placing the patient’s leg in a “frog” position can facilitate a lateral view of the foot.
Venous drainage of the lower extremities

Venous drainage of the lower extremities is divided into the superficial and deep systems. There is significant variability in the venous drainage of the lower extremities, with more variability noted in the superficial as compared with the deep venous drainage. Perforating or anastomotic veins on the medial aspect of the foot form the greater saphenous vein, which courses somewhat anteriorly as it superiorly ascends the leg to the level of the groin. The lesser saphenous vein forms from a confluence of perforating or anastomotic veins from the lateral aspect of the foot and courses posteriorly in the calf, where it joins the popliteal vein in the popliteal fossa.

The deep venous system courses alongside the arterial system and includes the anterior tibial, posterior tibial, and the peroneal veins, which ultimately form the popliteal vein. It is joined by the lesser saphenous vein from the superficial system, ascends, and forms the superficial femoral vein and ultimately the common femoral vein. The common femoral vein is joined by the greater saphenous vein, which usually receives the external pudendal vein as well as the superficial epigastric vein, and the superficial circumflex iliac vein. The common femoral vein empties into the external iliac vein, which, when joined by the internal iliac vein, forms the common iliac vein. Both the right and left common iliac veins join to form the inferior vena cava. The lumbar veins, as well as the left and right renal veins, empty into the inferior vena cava. The hepatic veins empty into the inferior vena cava prior to entering the right atrium. The mesenteric veins follow...
their named mesenteric arteries, which ultimately join the portal artery that courses into the liver. This venous drainage is described as the portal system. There are connections or anastomoses between the portal and systemic venous drainage systems located in the rectum, esophagus, and the umbilicus; these can be points of manifestation of dilated venous structures in the setting of portal hypertension.

**Venous drainage of the upper extremities**

The venous drainage of the upper extremities is again divided into a superficial and deep system. The dorsal digital veins are highly interconnected and form an array of superficial dorsal veins. These form a dorsal venous arch at the base of the back of the hand before the wrist. There are numerous perforating veins with connections to deeper venous structures and drainage. The cephalic vein courses from the dorsal venous arch, from the dorsal radial aspect of the forearm to the anterior radial aspect of the forearm. The basilic vein arises from either the dorsal or the palmar aspect of the hand and courses towards the palmar or anterior aspect of the forearm along the ulnar aspect of the forearm. An array of veins along the palmar or anterior surface of the forearm ultimately forms the median vein of the forearm. This vein flows