Introduction

There are few complications or traumatic injuries that elicit more distress in even the most seasoned surgeon than the possibility of uncontrolled hemorrhage from a major blood vessel. The vascular-trained surgeon has one key tool to manage this problem: the understanding of vascular exposures to obtain proximal and distal control. Herein, we discuss the basic exposures that any general surgeon would benefit to have at hand, the tools of the trade that can be foreign to those not familiar, and some basic steps in performing endovascular diagnostic studies. Although some of these exposures are common (e.g., femoral and brachial artery exposures), many are not relevant to an elective general surgical practice. The information may however be helpful in emergent/urgent situations for damage control or stabilization especially for surgeons practicing in rural settings.

Exposures

Aorta

Abdominal aortic exposure can be obtained through two primary approaches: transperitoneal and retroperitoneal. The benefits to each exposure listed in Table 2.1 have been discussed at length by many groups. The importance of the surgeon’s comfort level with each exposure cannot be overstated in terms of minimizing injury to additional structures and optimizing the benefits of each approach.

Transperitoneal Abdominal Aortic Exposure

The abdomen is incised in the midline as for a standard laparotomy approach (Fig. 2.1). Adherence to the linea alba makes abdominal closure easier. To minimize the likelihood of bowel injury secondary to abdominal wall adhesions, select a site in the upper abdomen or away from any prior incision sites to enter the peritoneum sharply. Digital exploration ensures that no bowel is adherent to the abdominal wall prior to extending the laparotomy incision along the length of the abdomen from xiphoid to pubis. The falciform ligament should be divided between ties. Exposure of the infrarenal aorta begins with mobilization of the small bowel to the right of the midline (Fig. 2.2). When taking down the attachments at the ligament of Treitz and opening the retroperitoneum, care should be taken to incise slightly to the left of the midline. This technique leaves an adequate margin of tissue for suture closure of the retroperitoneum at the end of the case without risking inadvertent bowel injury.

Once the retroperitoneum has been opened, clamp sites for proximal and distal vascular control should be exposed as soon as possible. Distal control can be obtained at the level of the common iliac arteries or by isolating each external and internal iliac artery separately, if common iliac aneurysmal or occlusive disease is present. Circumferential control of the iliac arteries is not necessary and should be avoided to minimize the risk of iliac vein injury. Surgical dissection at the aortic bifurcation should also be avoided to prevent injury to the sympathetic nerve plexus at that location.

Proximal dissection in the retroperitoneum begins by exposing the left renal vein as it crosses anterior to the aorta. Failure to find the left renal vein indicates the presence of a retroaortic left renal vein which passes posterior to the abdominal aorta. This relatively common anomaly highlights the importance of avoiding unnecessary circumferential dissection of the abdominal aorta (Fig. 2.3). A slight cephalad retraction of the crossing renal vein usually exposes the bilateral renal arteries.

If suprarenal aortic clamping is required, exposure between the SMA and renal arteries is sometimes adequate.
Exposure between the SMA and celiac artery is rarely needed, and a clamp in this location leads to ongoing blood loss secondary to SMA backbleeding via collateral pathways fed by the celiac trunk. To avoid this problem, the next level of exposure obtained via a transperitoneal approach is the supraceliac aorta. Exposure in this location is facilitated by having a nasogastric or orogastric tube in place. In emergent situations, pulling the cardia of the stomach downward allows for manual palpation of the gastric tube. The aorta is then located where it crosses the diaphragmatic hiatus. The left anterior crus of the diaphragm should be sharply divided, and planes on each side of the aorta can be digitally developed enough to place a clamp in this location. Being able to palpate the spine on each side usually indicates that the aorta has been adequately cleared for clamping. Attempts to clamp the aorta before incising the periaortic tissues down to the spine will fail as the clamp slips off anteriorly. The most common error in this location is inadvertent clamping of the esophagus, typically caused by forgetting that the aorta is the

### Table 2.1 Comparative benefits of aortic approaches

<table>
<thead>
<tr>
<th>Transperitoneal (supine patient)</th>
<th>Retroperitoneal</th>
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<tbody>
<tr>
<td>Easy access to upper extremities for line placement</td>
<td>Centripetal obesity and fatty abdominal viscera displaced</td>
</tr>
<tr>
<td>Bilateral groin access</td>
<td>Easy access to thoracic aorta and suprarenal aorta</td>
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<tr>
<td>Extension to median sternotomy</td>
<td>Abdominal viscera not in field</td>
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<tr>
<td>Access to abdominal viscera</td>
<td>Decreased post-op ileus</td>
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<tr>
<td>Ability to prep and drape prior to induction</td>
<td>Diminished risk of aortoenteric fistula secondary to decreased exposure of the suture lines</td>
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Adapted from Cronnenwett and Johnston [1]

**Fig. 2.1** Midline incision extending from the xiphoid to symphysis for transperitoneal approach to abdominal aortic exposure

**Fig. 2.2** The transverse colon and omentum are lifted cephalad and the small bowel retracted to the right to expose the retroperitoneum. Incision in the retroperitoneum is made slightly to left of the midline to allow closure of the retroperitoneum over the aorta after repair

**Fig. 2.3** The aorta with the crossing left renal vein. The crossing vein marks the approximate location of the renal arteries as well
more posterior structure and the vertebral bodies are directly deep to it. Palpation of the gastric tube in the esophagus provides a constant reminder of its location and helps avoid esophageal injury and inadvertent clamping.

When exposure of the visceral segment of the aorta is needed, for example, in the setting of type IV thoracoabdominal aneurysm repair, we recommend a retroperitoneal approach to avoid obscuration by the overlying viscera.

**Retroperitoneal Aortic Exposure**

Retroperitoneal aortic exposure has the advantages discussed previously (Table 2.1). The key steps in positioning prior to this exposure are as follows:

1. Patient on a “sandbag” or “beanbag.”
2. Ensuring that the flexion point or adjustable “kidney rest” of the operating table is at the level of the space between the iliac crest and the costal margin.
3. The patient is turned into a lateral decubitus position with the right side down. An axillary roll minimizes the possibility of right brachial plexus injury.
4. The left arm is extended upward and across the body and supported on either a Mayo stand or arm sling that can be secured to the operating table.
5. The lower extremities are carefully padded.
6. The “reflex” position of the bed obtained by raising the kidney rest opens the space between the costal margin and iliac crest and increases the intercostal spaces as well.
7. In patients with abdominal obesity, the pannus is allowed to fall forward while being supported with the beanbag.

This position ensures that the benefits of retroperitoneal exposure are maximized (Fig. 2.4).

A curvilinear incision begins lateral to the rectus sheath, approximately 2 in. anterior to the anterior superior iliac spine (ASIS) and extends superiorly to the appropriate rib space as determined by the proximal extent of the aneurysm. For most abdominal aortic pathology, the incision is carried through the 10th interspace (the highest unattached rib) (Fig. 2.5).

Careful attention to the layers of the abdominal wall in this location can help avoid inadvertent entrance into the peritoneum (Fig. 2.6). The first layer encountered is the external oblique aponeurosis. Incising this layer with elec-
trocautery exposes the fibers of the internal oblique. Using a blunt-tipped instrument in this location allows for spreading and exposure of the transverse abdominal muscular fibers, behind which lays the fatty tissue of the retroperitoneum. Digital exploration confirms access into the retroperitoneum not the peritoneum and allows for manual separation of the peritoneum from the abdominal wall layers to allow the remainder of the incision to be opened. Beginning this manual dissection laterally and extending it superiorly to the diaphragm helps maximize exposure.

Once the retroperitoneal space has been developed, manual displacement of the left kidney anteriorly allows for identification of the left renal artery and exposes the left diaphragmatic crus if needed. A self-retaining retractor assists with the exposure and can also be positioned to keep the left ureter out of the operative field. Exposure of the left renal artery and dissection proximally to its origin from the aorta takes the surgeon across an accessory lumbar vein that drains into the left renal vein. This vein should be preemptively divided to avoid avulsing it (Fig. 2.7). The aortic bifurcation can be located by palpation, and the bilateral common iliac arteries are usually bluntly exposed to minimize iliac vein injury while creating isolated clamp locations. If additional proximal exposure above the renal arteries is required, the right renal artery is usually lower than the left, and exposing above the left renal artery with a combination of blunt and sharp dissection allows the SMA pulsation to be appreciated. If space to clamp in this location is not adequate, the left crus can be divided which quickly exposes the suprarenal aorta. In emergent situations, the initial incision through the 10th intercostal space allows manual palpation of and clamp placement on the thoracic aorta until further exposure can be obtained. Thoracic aortic clamping is a temporary, salvage maneuver, and the clamp should be moved distally as soon as possible.

When planned intervention requires a suprarenal aortic clamp, the incision is often through the 9th interspace which requires division of the costochondral cartilage. If planned intervention is on the descending thoracic aorta primarily, or in addition to abdominal aorta, incision through the 6th rib space, with or without division of the diaphragmatic fibers, allows for proximal thoracic aortic clamping (Fig. 2.8). These procedures are typically performed with sequential clamp techniques and left heart bypass if the situation demands.

Fig. 2.7 Retroperitoneal aortic exposure with the left kidney reflected anteriorly. The left renal artery is traced back to its origin at the aorta, and the superior mesenteric artery can be felt slightly above. Inset: The accessory lumbar vein draining to the left renal vein is divided before the aorta is opened.
Descriptions of exposures to gain access to the aortic arch and the origin of the great vessels can be found in any cardiac or thoracic surgical atlas. Exposure of the ascending aorta, aortic arch, innominate artery, and left common carotid artery origin is obtained by way of a median sternotomy. To expose the origin of the left subclavian artery, a left anterior thoracotomy is performed through the fourth intercostal space.

**Carotid, Subclavian, and Axillary Artery Exposures**

**Carotid Artery**

The most common means of exposing the carotid artery, for both traumatic exploration and elective intervention, requires neck extension with the patient’s head turned to the contralateral side whenever possible (Fig. 2.9a, b). The incision is placed along the anterior border of the sternocleidomastoid muscle. Care is taken to angle the incision posteriorly as it approaches to within 1–2 in. of the angle of the mandible as this minimizes the risk of injury to the marginal mandibular nerve. Injury to this nerve can manifest as unilateral downward drooping of the mouth and numbness.

After incising the skin, the platysma is divided in the same direction as the skin incision using the electrocautery. The external jugular vein is sometimes encountered and can be ligated and divided between ties. The anterior border of the sternocleidomastoid muscle should then be delineated and the muscle belly grasped and retracted posteriorly and laterally to allow for exposure of the internal jugular vein (Fig. 2.10a). Once the internal jugular vein is identified, mobilizing its anterior border leads to exposure of the facial vein. This crossing vein typically functions as a landmark for the level of the carotid bifurcation. The facial vein should be ligated and divided with care to avoid injury of the underlying hypoglossal nerve. The carotid artery is encased within its own sheath and lies deep and medial to the jugular vein. Before opening the carotid sheath, careful inspection sometimes reveals an anterior vagus nerve that should be protected. The vagus nerve is easily differentiated from the crossing branches of the ansa cervicalis by its larger size and its course which parallels the carotid artery. The inferior border of the dissection is typically the omohyoid muscle, while superiorly the dissection usually ends at the posterior belly of the digastric muscle (Fig. 2.10b).
Division of either the omohyoid or digastric muscle belly allows for some additional exposure with minimal disability. Superior exposure of the internal carotid artery usually exposes the hypoglossal nerve which is held in place by an arterial branch to the sternocleidomastoid muscle. The division of this artery allows the hypoglossal nerve to be swung cephalad and protected from harm. Multiple small veins in this location also must be carefully dissected and preemptively divided to avoid unnecessary bleeding and blind placement of clips or cauterizing that can lead to nerve damage.

In the case of a planned carotid-subclavian bypass or transposition procedure, exposure of both the carotid and subclavian arteries can be obtained via a transverse supraclavicular incision centered over the medial third of the clavicle.

**Supraclavicular Subclavian Artery Exposure**

Supraclavicular exposure allows access to the subclavian artery as well as the origin of the vertebral artery if needed. The surgeon must remember that left-sided supraclavicular dissection risks injury to the thoracic duct, which arises deep...
and inferior in the wound to enter the posterior aspect of the internal jugular and subclavian vein confluence.

The patient is positioned with both arms tucked at the sides, the neck turned toward the contralateral side. A shoulder roll can be used when additional extension is needed to widen the space between the shoulder and neck. The incision is made approximately 1.5 cm above the clavicle and typically extends across the lateral head of the sternocleidomastoid (SCM) and 2 cm to either side (Fig. 2.11). The platysma muscle and the lateral head of the SCM are both divided. The authors recommend the scalene fat pad be mobilized inferomedially and then retracted superolaterally. Care is taken to not injure the phrenic nerve, which courses lateral to medial on the anterior surface of the anterior scalene muscle. Exposure of the subclavian artery typically requires the anterior scalene muscle to be divided. This is most safely done near its insertion onto the 1st rib. The muscle fibers can be elevated from the deeper brachial plexus using a right angle or straight dissector. Again, awareness of the trajectory and course of the phrenic nerve cannot be overemphasized.

Once the anterior scalene muscle is divided and reflected upward, the fascia overlying the subclavian artery can be sharply incised to mobilize the artery. The subclavian artery branches including the internal mammary, thyrocervical trunk, and vertebral artery can be individually encircled with vessel loops for control. Once mobilized, the subclavian artery easily elevates into the wound.

**Infraclavicular Exposure of the Axillary Artery**
Exposure of the axillary artery is most often used for axillo-femoral bypass. The patient can be positioned supine with the arm tucked at the side or the arm abducted 90° on an arm board. The use of a shoulder roll to slightly elevate the side being exposed can also be helpful. Sterile skin preparation should include the neck and chest from the midline across to the shoulder. An incision is made 2–4 cm below the clavicle extending from the deltopectoral groove to the lateral aspect of the clavicular head (Fig. 2.12). The fibers of the pectoralis major are then separated in the direction of their axis to expose the clavipectoral fascia beneath. The pectoralis minor lies laterally in the exposed space and should be divided in addition to the clavipectoral fascia to optimally expose the fibrofatty tissue surrounding the axillary artery and vein. The vein lies slightly anterior and inferior to the artery in this location, and care should be taken to avoid injury during circumferential dissection and control. In this location the thoracoacromial trunk should be divided to allow the artery to be pulled up into the wound, which is best done using atraumatic silastic vessel loops.

**Exposure of the Lower Extremity Arteries**

**Femoral Artery**
Understanding femoral vascular anatomy is critical to open, endovascular, and percutaneous procedures in vascular surgery. The inguinal ligament should be first delineated by the bony landmarks of the anterior superior iliac spine and the pubic tubercle. The femoral artery bisects the inguinal ligament with a slight medial to lateral trajectory.

For exposure of the femoral artery and its bifurcation, a vertical incision overlying and paralleling the expected course of the femoral artery is planned (Fig. 2.13) and is the preferred approach for occlusive disease. The overlying subcutaneous tissue is divided. The superficial epigastric vein is typically encountered and divided between ties or clips. Once the fibrofatty lymph tissue overlying the femoral artery is encountered, we recommend ligating and dividing this
tissue between ties. This technique minimizes the risk of postoperative lymphatic leak, which is particularly troublesome when prosthetic graft material has been used in the groin.

The first step involves palpating for the femoral pulsation or the non-pulsatile but highly calcified femoral artery. Exposure of the inguinal ligament allows for proximal control as the common femoral artery passes beneath the ligament. The femoral circumflex and inferior epigastric arteries are small branches arising laterally and medially, respectively, from the proximal common femoral artery. These branches are usually located at the level of the inguinal ligament and mark the border of the distal external iliac artery from the proximal common femoral artery.

The common femoral artery bifurcates into the superficial femoral artery (SFA) and 1–2 profunda (or deep) femoral arteries. The SFA is a direct continuation of the common femoral artery which continues distally and passes deep to the sartorius muscle. The profunda femoral arteries follow a lateral course into the muscles of the thigh (Fig. 2.14).

Exposure for endovascular aortic procedures (which is generally an isolated common femoral artery dissection) can be via an oblique or transverse incision just below the expected location of the inguinal ligament. The incision is deepened until the inguinal ligament is seen, and then a vertically oriented dissection is performed on the fibrofatty tissue overlying the femoral artery. Again we recommend dividing this tissue between ties to decrease the risk of lymphatic leak.

**Above-Knee Popliteal Artery**

This may be one of the easiest exposures in vascular surgery once the basic anatomy is understood. The SFA becomes the popliteal artery when it exits the adductor canal, also known as “Hunter’s canal.” Hunter first described the pathology of popliteal aneurysms in stagecoach drivers, whom he postulated developed the aneurysms as a result of repeated trauma to the artery secondary to prolonged sitting. He also
demonstrated that ligation of the artery above and below would not result in limb loss if time was allowed for the development of collateral pathways.

The lower extremity should be prepped circumferentially and positioned with external rotation and abduction at the hip and flexion at the knee. A “bump” of rolled towels or sheets is useful to maintain this position and is positioned under the calf (Fig. 2.15). An incision is made in the natural skin crease that is present between the sartorius and the quadriceps muscle group (Fig. 2.16). After retracting the sartorius muscle downward, the fascia between the adductor tendon and the semimembranous muscles is incised with electrocautery, and the adductor canal is entered. The adductor canal is identified by a space filled with fibrofatty tissue. The vastus medialis is then retracted superiorly (Fig. 2.17).

Blunt manual dissection spreads the fibrofatty tissue until the popliteal artery is easily felt by palpating along the posterior aspect of the femur. The popliteal artery is typically medial to the vein in this location (Fig. 2.18). The anterior tibial nerve, an in-line branch of the sciatic nerve, also courses posterior to the vascular structures in this location and should be protected from harm.

**Behind-the-Knee Popliteal Artery**

The prone position provides the best exposure of the popliteal artery directly behind the knee and may be useful for addressing selected popliteal artery aneurysms, popliteal entrapment syndrome, and adventitial cystic disease. The patient should be supported under the torso, waist, and ankles. A “lazy-S” incision decreases the risk of skin contracture and typically extends from the medial aspect of biceps femoris to the lateral head of the gastrocnemius at the calf (Fig. 2.19). The small saphenous vein is the first structure encountered and is at risk for an incidental injury. Depending on its caliber, the small saphenous vein can be mobilized and harvested for use as an interpositional bypass.

Running lateral to the small saphenous vein is the medial sural nerve, which can be traced back to the tibial nerve in the popliteal fossa. An incision in the fascia medial to the small saphenous vein allows access to the popliteal fossa. The apex of the fossa is formed by the semimembranous muscle medially and the biceps femoris laterally. The popliteal artery and vein typically lie deep and slightly medial to the tibial nerve in this location, so care is taken to protect the nerve injury during surgical exposure. A small silastic vessel loop can be used to gently retract the nerve laterally. The vein and artery take a parallel course at the apex of the popliteal fossa before the vein moves deep to the artery as the...
dissection progresses distally. Proximal and distal arterial control in this location is obtained in the standard fashion as described elsewhere within this chapter.

Below-Knee Popliteal Artery and Proximal Anterior and Posterior Tibial Artery, Tibioperoneal Trunk, and Peroneal Arteries
Preparation is similar to the above-knee exposure with circumferential leg prep and external rotation/flexion/abduction positioning. For optimal exposure, a bump should be placed above the knee (Fig. 2.20a).

A medial calf begins at the level of the medial condyle approximately 2 in. posterior to and parallel to the tibial bor-

Fig. 2.17 Incision through the subcutaneous fat to the level of the fascia. Inset: the fascia is incised to allow entry to the space between the sartorius muscle, which will be retracted posteriorly, and the vastus medialis and adductor muscle group, which will be retracted anteriorly.

Fig. 2.18 After blunt digital dissection in the fibrofatty space. The popliteal artery and vein are exposed. Note that the artery is medial to the vein in this location and, thus, encountered first.

Fig. 2.19 “Lazy-s” incision for the posterior approach to the popliteal artery behind the knee.

der. The fascia overlying the gastrocnemius medial head is incised and the muscle belly retracted inferiorly and posteriorly. We recommend dividing the tendinous insertions of the semitendinous, gracilis, and sartorius muscles to improve exposure and minimize extrinsic compression of anatomically tunneled grafts. This maneuver results in minimal, if any, morbidity.
The below-knee popliteal artery is easily palpable by compressing the neurovascular bundle against the posterior aspect of the tibia. The nerve and popliteal vein are typically anterior to the artery so these structures need to be carefully dissected and retracted with the assistance of vessel loops and self-retaining retractors in order to expose the popliteal artery (Fig. 2.20b).

If exposure of the tibioperoneal trunk and anterior tibial artery origin is needed, these vessels can also be exposed through this approach. Taking down the soleus muscle from its insertion on the tibia exposes the remainder of the below-knee popliteal artery and the tibioperoneal trunk (Fig. 2.21a). The dissection can be carried as far distal as necessary to expose the bifurcation of the tibioperoneal trunk into the peroneal artery and posterior tibial artery origins (Fig. 2.21b). Crossing veins and the small, deep anatomic space mandate a careful and meticulous dissection.

The anterior tibial artery is identified as it originates laterally on the popliteal artery, deep to the crossing anterior tibial vein which is typically divided to facilitate exposure. From this exposure the artery travels “away” from the operating surgeon on its way to the anterior compartment. At this point, an anatomic tunnel can be created behind the knee. The index finger of each hand should be positioned just medial to the above- and below-knee neurovascular bundles (Fig. 2.22). Progressive sweeping maneuvers between the fingers will clear the minimal tissue that is in the popliteal fossa allowing for the fingers to touch. A large clamp, umbilical tape, or bypass graft can then be passed through the tunnel.
Distal Posterior Tibial Artery
The distal third of the posterior tibial artery, above the ankle, is best approached from a medial calf incision just posterior to the bony edge of the tibia (Fig. 2.23). The initial skin incision should expose the soleus fascia (Fig. 2.24a). The fascia is incised and muscle fibers spread in the direction of their travel. Just deep to the soleus muscle, the tendon of the flexor digitorum longus (Fig. 2.24b) is retracted anteriorly, and the posterior tibial neurovascular bundle lies immediately deep to it (Fig. 2.24c).

Mid to Distal Anterior Tibial Artery
As previously described, the origin of the anterior tibial artery is exposed as an extension of the below-knee popliteal artery exposure. Because the anterior tibial artery quickly passes through the interosseous membrane, more distal exposure is not pursued from the medial approach.

An anterolateral exposure begins with the hip and knee flexed approximately 30° and internally rotated. An incision is made midway between the tibia and the fibula at the desired exposure level. The fascia separating the tibialis anterior muscle and the extensor digitorum longus is incised using electrocautery. Manual exploration or a self-retaining retractor will expose the anterior tibial artery, veins, and peroneal nerve. The bundle rests on the interosseus membrane with one of the paired veins typically lying anteriorly making it the first structure encountered. Careful dissection will reveal the plane between the anterior tibial vein and artery. A constant theme of any tibial artery dissection is bridging veins between the venae comitantes which should be intentionally ligated and divided before they are avulsed. Anatomic tunneling of a bypass graft in this location requires enlarging the native canal in the interosseus membrane to accommodate two fingers. The bypass graft can then be tunneled from the deep posterior to the anterior compartment in a standard fashion.

Distal to the lower third of the tibia, the extensor hallucis longus (EHL) muscle originates from the medial tibia border. The anterior tibial neurovascular bundle follows a course between the EHL and the tibialis anterior muscle. The anterior tibial vein remains anterior, and the peroneal nerve remains posterior to the anterior tibial artery in this location as well.

Mid to Distal Peroneal Artery
Although the distal peroneal artery can be exposed via a medial approach, we prefer the lateral approach as described below. The lower extremity is circumferentially prepped and draped and positioned with the lower leg slightly flexed and internally rotated. An assistant is often needed to maintain this position for exposure. A longitudinal incision is made over the fibula extending above and below the level of planned peroneal artery exposure for a total length of approximately 15 cm. The common peroneal nerve should be protected as it wraps around the proximal fibular head. The
peroneus longus and peroneus brevis muscles are stripped from their attachments to the fibula using a periosteal elevator. Confirm that the muscle has been stripped medially from the fibula before division to avoid inadvertent injury to the underlying peroneal vessels with fibular resection. The fibula is then resected using a bone cutter. Once this segment of fibula has been removed, the peroneal artery and paired veins can be seen in the underlying muscle bed.

For the medial approach to the peroneal artery, the patient is supine, the knee flexed, and the leg rotated laterally [2]. A medial vertical incision is made posterior to the tibia. The soleus muscle is detached from the tibia and retracted posteriorly. The fascia covering the flexor digitorum longus tendon is incised and the plane entered to expose the vessels in the deep compartment. The posterior tibial vessels are encountered first, and the peroneal vessels are exposed by extending the dissection in this plane farther laterally (toward the fibula).

**Upper Extremity Exposures**

**Brachial Artery**

Exposure of the brachial artery can be achieved using a transverse incision a finger breadth above or below the antecubital fossa or a longitudinal upper arm incision directly over the brachial pulse. The “lazy-S” incision begins on the medial, distal upper arm and traverses the antecubital fossa before terminating on the proximal, lateral forearm [3]. The choice of incision depends on the reason for exposure. The transverse incision is typically used for arteriovenous access, while the “lazy-S” incision is used in the setting of upper extremity arterial thrombosis requiring an embolectomy or thrombectomy (Fig. 2.25).

Exposure of the brachial artery at above or below the antecubital fossa requires partial division of the biceps aponeurosis fibers that fan from the biceps tendon to the ulnar head. There are typically multiple superficial veins in this

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*Fig. 2.24* Distal posterior tibial artery exposure. (a) Skin incision exposes underlying soleus fascia. (b) Incising the fascia exposes the flexor digitorum longus tendon anteriorly and the fascia overlying the neurovascular bundle. (c) Incising the fascia exposes the posterior tibial artery and its paired veins.
location, including the cephalic vein and medial antecubital vein which should be dissected free and protected from injury, particularly if the planned procedure is for creation of autogenous dialysis access (Fig. 2.26a, b).

The brachial artery typically runs between two venae comitantes, which must be sharply dissected free at the proximal and distal control sites. Crossing veins may be ligated between fine silk ties. The median nerve is medial to the brachial artery at this location and the proximal forearm, so careful sharp dissection also decreases the risk of nerve injury.

**Proximal Radial Artery**

Exposure of the proximal radial artery usually involves distal extension of the “lazy S” until the brachial artery bifurcation is encountered. This exposure is most often used during thrombectomy, when the ability to selectively guide a thrombectomy catheter down the radial and ulnar arteries is required. In the setting of trauma, proximal exposure for ligation of the radial artery can also be used to remotely decrease hemorrhage in the more distal and often traumatized surgical field.

**Distal Radial Artery**

Distal radial artery exposure is via a longitudinal forearm incision which parallels the course of the artery (Fig. 2.27). Care is taken to ensure the incision does not extend on to the mobile part of the wrist to minimize the risk of postoperative joint dysfunction. The fascia of the forearm is thin in this location and overlies the brachioradialis tendon. At the wrist,

**Distal Ulnar Artery**

Like the distal radial artery, distal ulnar exposure is via a longitudinal forearm incision paralleling the course of the artery. Similarly, care is taken to ensure the incision does not extend onto the mobile part of the wrist to prevent contracture (Fig. 2.27).
Surgical Techniques

Methods of Obtaining Proximal and Distal Control

Adequate exposure is the prelude to the core principle of vascular surgery: proximal and distal vascular control. After anticoagulating the patient with heparin, one of the techniques described below can be used to gain vascular control.

Vessel Loop Control

Vessel loop control is ideal for thrombectomy or embolectomy procedures and when branch vessels need to be controlled. Silastic loops that come in varying thickness and strength can be passed around small- and medium-sized vessels. They are often single looped for venous control and double looped for arterial control. Tension can be placed on the loops to occlude the vessel lumen. Heavily calcified arteries often fail to occlude when a loop is tightened and may be difficult to control. Pulling on the loop for hemostasis can also distort the vessel wall. To avoid this situation, loops are often exchanged for clamps when an arteriotomy closure or anastomosis is required.

Clamp Control

Although hundreds of vascular clamps are commercially available, each operating room’s selection varies. We recommend a variety of large aortic clamps, side-biting clamps, small peripheral vascular clamps, and bulldog-style clamps that are relatively atraumatic for smaller arteries and veins (Fig. 2.28a, b).

Balloon Occlusion

Although balloon occlusion is often overlooked by the non-vascular surgeon, this technique can be lifesaving when dealing with highly diseased, calcified vessels or previously placed stents (see Table 2.2). An appropriately sized Fogarty balloon with a three-way stopcock can obtain intraluminal vascular control when vessels are too diseased to clamp without risking significant injury. Occlusion balloons specifically designed for this purpose come in a range of sizes.
Using an open approach, the balloon catheter is placed through the arteriotomy and advanced proximally before inflating the balloon. Endovascular balloon control usually involves percutaneous access through the contralateral femoral artery and fluoroscopic guidance to place the balloon in the appropriate location.

**Tourniquet**

Placing a sterile tourniquet on the upper arm or thigh can be a valuable adjunctive maneuver when exploring an extremity for possible vascular injury or anticipating difficulty obtaining vascular control. Padding to protect the underlying skin should be placed before the tourniquet is applied. To minimize backbleeding, the extremity is wrapped with an Esmarch bandage to empty the veins immediately before inflating the tourniquet to above systolic pressure.

**Arteriotomies**

Adequate exposure and proximal and distal control are the critical first steps that allow surgeons to operate safely on the vasculature. An arteriotomy is typically then made by using an 11-blade or 15-blade to make an initial entrance into the vessel lumen. The arteriotomy is then extended using Potts or Metzenbaum scissors (Fig. 2.29a, b).

A transverse arteriotomy allows for primary closure of the artery without the risk of narrowing the vessel lumen. Embolectomy/thrombectomy procedures and arterial access for endograft delivery typically use a transverse arteriotomy. A longitudinal arteriotomy, paralleling the course of the vessel, is used for endarterectomy, proximal and distal bypass anastomoses, and AV fistulas and grafts or whenever extension of the arteriotomy is anticipated. In these circumstances, the vessel is generally not at risk for narrowing. In most cases, closing an endarterectomy with a patch angioplasty reduces the risk of restenosis.

**Anastomotic Techniques**

**Instruments and Suture Material**

Although each surgeon has a “preferred” anastomosis, a facility with several anastomotic techniques ensures flexibility to adjust to the exposure and vessel depth which can vary for each individual patient. Castroveijo needle drivers are ideal for most suture 5-0 or smaller in size, while Ryder or regular needle drivers can be used for larger sutures (Fig. 2.30). Several options for needle sizes and shapes exist depending on the site of the anastomosis. The following list describes the “rules of thumb” regarding suture size and material (Fig. 2.31):

- **Aortic anastomosis**: 3-0 nonabsorbable monofilament
  - Needle options: MH or SH (Ethicon)
- **Iliac anastomosis**: 4-0 nonabsorbable monofilament
  - Needle options: MH, SH, or BB
- **Femoral and carotid anastomoses**: 5-0 or 6-0 nonabsorbable monofilament
  - Needle options: C-1, BV1, or RB-2
- **Popliteal, brachial, and radial**: 6-0 nonabsorbable monofilament
  - Needle options: BV-1 or RB-2
- **Tibial vessels**: 6-0 versus 7-0 nonabsorbable monofilament
  - Needle options: BV-1 or CC
Techniques for Anastomosis

Parachute
This technique is ideally used when the site of the anastomosis is in a deep space. This style allows the back wall of the anastomosis to be visualized until the graft is pulled or “parachuted” into place. It is easiest to start on the side of the anastomosis farthest from the sewing surgeon (Fig. 2.32a–c).

End to End
This technique is used when the ends of two vessels are being brought together. To avoid narrowing, both vessel ends are cut at oblique angles or “spatulated” prior to beginning the anastomosis. Spatulation can correct size discrepancies between the vessels by creating an equal circumference for sewing and by spreading the distance of the sutures along the length of the vessels which prevents narrowing (Fig. 2.33).

End to Side
This common method involves suturing the cut and spatulated end of one vessel to a longitudinal arteriotomy in the sidewall of the second vessel (Fig. 2.34).

Thrombectomy
Choosing an appropriately sized thrombectomy catheter requires knowledge of the typical luminal size for various blood vessels. Table 2.2 provides a reference for the luminal size and corresponding recommended balloon catheter size. Thrombectomy catheters are used for clearing thromboembolism but can also provide “balloon control” of bleeding. To perform a thrombectomy, the catheter is passed beyond the level of the thrombus. While slowly pulling the catheter back, the balloon is inflated until the surgeon senses that the balloon has engaged the sidewalls of the vessel. The catheter is then withdrawn taking care to keep just enough inflation pressure on the balloon to engage the vessel sidewalls thereby dragging the thrombus out of the vessel through the arteriotomy. Overinflation of the thrombectomy balloon or inattention during catheter withdrawal can denude the arterial endothelium causing a significant injury.

Basics of Angiography
Like surgery, endovascular skills accumulate with time and experience. Percutaneous arterial punctures usually use ultrasound guidance to ensure that the suitability of the access vessel enhances safety. The choice of access vessel
depends on the target for intervention. For most lower extremity interventions, contralateral femoral access is recommended; planned common iliac interventions are usually performed from ipsilateral femoral access. Renal and carotid interventions frequently use femoral access with the laterality determined by anatomy and surgeon handedness. Subclavian interventions can be performed with femoral or ipsilateral brachial access, and interventions for the celiac access or superior mesenteric artery can be performed through femoral or left brachial arterial access.

Fig. 2.32 Parachute anastomotic technique: (a) start throws from “out-to-in” on graft at about midpoint of the back wall. Carry around the “heel” to approximate the midpoint of the front wall before “parachuting” the graft into place. (b) The back wall suture is then carried around the toe in a standard running fashion. (c) The two suture ends come together at the midpoint of the front wall.

Fig. 2.33 End-to-end anastomosis. Both vessel ends are typically slightly spatulated in opposite directions to facilitate this anastomosis and accommodate any size mismatch.

Fig. 2.34 End-to-side anastomosis. The initial bite is taken at the heel and a knot tied to the outside then run out of both corners to meet at the midpoint of the front or back wall.

Femoral Access

The access needle should ideally enter the common femoral artery between the femoral bifurcation and the inguinal ligament. Punctures that stray too far distally into the SFA or too far proximally into the external iliac artery can result in bleeding complications. The SFA is too distal to be compressed against the head of the femur when holding pressure for hemostasis. In
the case of accidental percutaneous iliac access (“high stick”), manual pressure is usually held distal to the actual needle hole allowing unabated bleeding into the potential space of the retro-peritoneum. It is difficult if not impossible to manually apply hemostatic pressure to a puncture site above the inguinal ligament. Use of a closure device is recommended in the event of a high puncture. Ultrasound guidance for percutaneous needle punctures helps to confirm vessel patency, identify the bifurcation, and assess the extent of calcification.

The femoral artery is best accessed using a micropuncture kit of some variety. This typically contains a 21Ga needle and a mandrel or micropuncture wire of 0.018 in. diameter (Fig. 2.35). After puncturing the artery, the wire should pass without resistance through the femoral and iliac arteries to the abdominal aorta. The position of the wire should be confirmed by fluoroscopy.

We recommend making a small skin nick using an 11-blade with the micropuncture needle still in place as a guide. The needle is then exchanged for the micropuncture sheath, using the standard Seldinger technique. The inner cannula of the microsheath as well as the .018” guidewire is removed and the .035” wire of the surgeon’s choosing is then advanced, again under fluoroscopic guidance. Passing the larger caliber wire allows the micropuncture sheath to be exchanged for a working sheath of the required diameter, typically 4 Fr or 5 Fr for initial diagnostic angiography.

Any type of flush (side-hole containing) catheter (Fig. 2.36) can then be advanced into position for digital subtraction angiography. While vascular interventions are beyond the scope of this text, they can be found in textbooks of endovascular surgery or angiography.

Radiation Safety

All angiographic procedures involve radiation exposure, and the interventionist must make a concerted effort to ensure the safety of the patient and health care team. When performing fluoroscopy there are three potential sources of radiation exposure [4]:

1. Primary radiation comes directly from the x-ray tube to the patient. The proceduralist is only exposed to this when a hand, or other body parts, comes between the patient and the primary beam.
2. Scatter radiation is the primary exposure source of radiation for the proceduralist and is emitted in all directions from the patient after the imaging beam comes into contact with him or her.
3. Leakage radiation is emitted from the imaging system and accounts for minimal exposure when using modern imaging equipment.

Radiation safety begins with education and the use of appropriate personal protective equipment. A lead attire including a thyroid shield and lead safety glasses ensures maximum operator protection. Lead aprons should be checked for cracks and flaws biannually by the hospital’s radiation safety officer. Appropriate lead aprons block more than 90 % of potential leakage radiation and 95–99 % of scatter radiation.

Some basic intra-procedural maneuvers to decrease radiation exposure include minimizing time spent on continuous fluoroscopy in favor of intermittent spot or pulse fluoroscopy. Collimating the imaging field also focuses the radiation beam so that the patient receives less radiation thereby decreasing the amount of scatter radiation that can reach the proceduralist. Minimizing the use of magnification also decreases the total radiation dose to the patient and the amount of radiation available for scatter. Decreasing the space between the patient and the image intensifier decreases the amount of scatter radiation, widens the imaging field, and improves image quality. With the patient
closer to the image intensifier, the space between the patient and the x-ray emitter increases which minimizes the effect of leakage radiation. Finally, simply stepping back from the patient whenever possible during digital subtraction angiography exponentially decreases the radiation exposure. In other words, 3 ft of extra distance decreases radiation exposure by a factor of 9. All regular users of fluoroscopy should undergo appropriate radiation safety training and exposure monitoring.

References

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