Injury to the major peripheral arteries or veins is often life-threatening but invariably poses a threat to the viability of the affected limb. Historically, because of rapid blood loss, injury to major vessels was often quickly fatal in the field. Most patients who survived to reach a hospital had relatively minor vascular injuries. However, with the advent of modern emergency medical services systems with advanced extrication methods and rapid transport, more patients with major vascular injury reach the hospital alive. In addition, the incidence of penetrating civilian injuries from interpersonal violence and blunt injuries from motor vehicle–related trauma in the United States has increased dramatically during the past 50 years. Consequently, emergency physicians are frequently confronted with critically ill patients harboring overt or occult vascular injuries. Management of vascular injuries has evolved with advances in diagnostic methods and surgical techniques. Treatment of vascular injuries before and during World War II was simple ligation of the peripheral artery or vein involved. This approach resulted in limb amputation rates ranging from 40% for axillary artery injuries to 72% for popliteal artery injuries. During the Korean War, routine attempts to repair injured arteries decreased the amputation rate for popliteal injuries to 32%. During the Vietnam War, repair of penetrating axillary and popliteal artery injuries with routine angiography and improved surgical techniques resulted in decreases in the amputation rate to as low as 5% and 15%, respectively, which approach the current rates of amputation for civilian injuries. Owing to the nature of the munitions and the extensive use of body armor in the Iraq and Afghanistan wars, the proportion of severe wounds of the extremities has increased. The amputation rates thus far are 5% for upper extremity and 21% for lower extremity vascular injuries. However, extrapolation of high-velocity military wound data to low-velocity civilian gunshot wounds may not be valid, and even lower rates might be expected with civilian wounds.

Tremendous progress has been achieved in diagnostic and therapeutic techniques for dealing with peripheral vascular injuries, and several noninvasive diagnostic modalities have emerged as accurate alternatives to surgical exploration or angiography. These techniques are easily used in the emergency department, and the goal of timely detection and repair of serious vascular injuries is achievable in the vast majority of cases.

**Epidemiology**

Throughout the world, the causes of peripheral vascular injuries are divided almost equally between blunt and penetrating mechanisms. In the United States, 56 to 90% of these injuries are a result of penetrating wounds, mainly because of the high rate of penetrating trauma in inner-city urban areas. Although the incidence of low-velocity gunshot wounds has decreased during the past decade, gunshot wounds remain the second leading cause of death in the 15- to 34-year-old age group in the United States. Major venous injuries are present in 13 to 51% of all cases, but more than 80% of these are associated with arterial injury as well. Approximately 90% of patients with vascular injury are male, and most are younger than age 40 years. Because of the increased use of percutaneous endovascular diagnostic and therapeutic procedures, the incidence of iatrogenic vascular injuries has increased and accounts for up to one third of all cases in some series.
massive destruction of soft tissue and bone, depending primarily on the range from which the shotgun was fired. The presence of multiple missiles ranging from 9 or 10 (buckshot) to dozens (birdshot) also complicates the evaluation of these injuries because of the many potential sites for vascular injury to occur. In addition, close-range shotgun wounds (<3 yards) can cause significant blunt trauma to blood vessels as well as a higher rate of bone and nerve injury than occurs with gunshot wounds. Migration of pellets or bullets proximally through the venous system to the heart or injury than occurs with gunshot wounds. Migration of pellets or bullets proximally through the venous system to the heart or through an artery with subsequent distal occlusion has been reported frequently as a delayed complication.

**Blunt Trauma**

Blunt injury involves avulsion forces that can stretch vessels beyond their capacity or direct crushing injury that disrupts the vessel wall. Fracture fragments resulting from blunt extremity trauma can lacerate or entrap vessels. Vascular injury can range from small intimal tears to complete avulsion of arteries and nerves. Open avulsion injury of a limb is particularly severe because the skin is the final structure to tear, and once such tearing has occurred, it is inevitable that vessels and nerves will be torn as well. Vascular injury also should be suspected in patients with massive soft tissue avulsion or crush injury, displaced long bone fractures, electrical or lightning injuries, and severe burns, as well as in those with compartment syndrome from trauma or prolonged immobilization as a result of stroke, coma, drug overdose, or other causes. Bites that are inflicted by large animals, such as dogs used by law enforcement, are particularly prone to arterial injury and wound complications. Collateral circulation may continue to perfuse the limb adequately, but injuries that occur proximal to the collateral branch point or that involve both the main trunk and collateral branches will preclude adequate flow.

Distal ischemia results from the inability of tissues to continue aerobic metabolism. Eventually, anaerobic metabolism consumes all substrate, thereby resulting in the accumulation of lactic acid. As ischemia progresses, cellular integrity is lost and irreversible cell death occurs. A vicious cycle of tissue edema and further impairment of the blood supply occurs.

When no specific measures are taken to cool the limb, it is said that the limb is undergoing “warm ischemia” at room temperature. Although the time in individuals may vary, 6 hours of complete warm ischemia is generally considered the point at which irreversible nerve and muscle damage begins to occur. After 6 hours of warm ischemia, 10% of patients will have irreversible damage; by 12 hours, 90% will have irreversible damage. Artificially cooling the limb to just higher than freezing temperature (cold ischemia) will reduce the metabolic demands of unperfused tissues and greatly prolong the tissue’s tolerance of ischemia to 24 hours or more. Animal studies suggest that hyperbaric therapy may be useful in repaired limbs that have undergone prolonged warm ischemia.

Two main types of vascular injury can result from trauma: occlusive injury (transsection, thrombosis, and reversible spasm), in which all effective perfusion distal to the occlusion is lost, and nonocclusive injury (intimal flap, dissection, arteriovenous fistula [AVF], and pseudoaneurysm), in which some arterial flow continues past the injury.

**Complete Occlusive Injury**

**Transsection.** The most common vascular injury is complete transsection in which distal flow is effectively eliminated. Cleanly transected arteries will often retract and undergo spasm so that blood loss is minimized. With longitudinal arterial lacerations and venous injuries, blood loss cannot be limited by this means, and such injuries tend to result in greater blood loss. Pulsatile bleeding may lead to exsanguinating hemorrhage and shock.

**Thrombosis.** Intraluminal thrombosis (Fig. 48-1) may occur in an injured artery acutely (within 24 hours) or may be delayed for many months. Acute thrombosis is initiated by stasis resulting from compression of the artery or from a disruption in the intima of an artery that becomes a nidus for thrombus formation. As the thrombus propagates, complete occlusion of the vessel can occur. Delayed thrombosis can occur months to years after injury if the injured vessel heals with stricture formation and decreased blood flow distally, followed by stasis and clot formation.

**Reversible Arterial Spasm.** The precise cause and incidence of significant reversible arterial spasm after trauma are unknown. In the case of arterial transection, arterial spasm is beneficial and limits hemorrhage. In other cases, however, the segmental arterial spasm occurs at some distance from the site of traumatic injury and can produce severe distal ischemia. Arterial spasm is particularly common in children. The spasm usually reverses with conservative treatment (topical warm saline or topical nitroglycerin paste), but prolonged spasm may require infusion of vasodilators such as nitroglycerin, calcium channel blockers, alpha-blockers, nitroprusside, specific prostaglandin inhibitors, or warm saline. In many series, segmental arterial spasm is the most common arteriographic finding. However, it should never be assumed on clinical grounds that symptoms of ischemia are a result of arterial spasm; that diagnosis is based on arteriographic results only.

**Nonocclusive Injuries**

**Intimal Flap.** An intimal flap occurs when there is a break in the intima of a vessel, generally from excessive stretch or concussive forces. Although flow is not altered by small flaps and the associated soft tissue wounds often appear benign initially, these intimal flaps may become a nidus for thrombosis that can occur hours to months after the initial injury. However, most intimal flaps heal spontaneously, and asymptomatic injuries that do not disrupt perfusion of the limb can be treated conservatively with antiplatelet agents such as clopidogrel.
Pseudoaneurysm. A true aneurysm contains all three layers of the vessel wall (intima, media, and adventitia) and rarely is caused by trauma. A pseudoaneurysm is formed following a tear in a vessel wherein the hemorrhage is contained by surrounding fascia and the resulting hematoma is gradually encased by a capsule of fibrous tissue, analogous in consistency to the adventitia of a normal vessel (Fig. 48-2). Because it is relatively thin walled, rupture of a pseudoaneurysm is a distinct possibility. In addition, because its diameter inevitably expands under arterial pressure over days to months, compression of adjacent tissue may result in neuropathy, venous obstruction with resultant peripheral edema and venous thrombosis, and even erosion into adjacent bone. The cavity of a pseudoaneurysm is in direct communication with the lumen of the vessel, so embolization of mural clots may produce distal arterial occlusion. Patients with pseudoaneurysm are commonly seen months to years later with symptoms of compression neuropathy or peripheral arterial embolism or for investigation of a soft tissue “tumor” that represents the growing aneurysm.

Arteriovenous Fistula. An AVF is formed when both the artery and an adjacent vein are injured. Higher-pressure arterial flow is directed into the lower-pressure vein, thereby diverting the blood supply to distal tissues and engorging the distal veins. Because the aperture of the fistula is often relatively narrow and thus results in turbulent flow, a bruit and palpable thrill are common diagnostic findings. Symptoms are primarily those of distal ischemia, but rarely, high-output congestive heart failure may occur when large central vessels are involved. Symptoms are often delayed for months because it takes time for the fistula to mature.

Compartment Syndrome. Compartment syndrome is most common after crush injury or a long bone fracture but may also be seen after reperfusion of an ischemic limb. Initially, blood flow is diminished and the injury can be considered nonocclusive. Progressive edema elevates tissue pressure above capillary pressure, thus ending arterial perfusion and initiating a cascade of events that results in compartment syndrome. The risk for this complication is increased when ischemia time is prolonged; in the presence of combined arterial and venous injury; after ligation or repair of a major artery or vein; or in the presence of significant soft tissue injury, frequently concomitant with a long bone fracture. Smaller caliber vessels are compressed first, whereas larger vessels remain relatively patent and compartment pressure rarely exceeds arterial pressure, so pulses may be palpable until very late in the course. If the condition is allowed to progress, however, all blood flow may end and the injury is then an occlusive one. After restoration of arterial flow to a previously ischemic limb, a cascade of reperfusion injury has been identified that results from release of oxygen free radicals, lipid peroxidation, and influx of intracellular calcium. These mediators give rise to progressive cellular damage, edema, and necrosis, thereby propagating the vicious cycle that increases compartment pressure. Consequently, frequent reexamination of the limb is indicated to assess compartment pressure after arterial repair or in the high-risk circumstances listed earlier.

CLINICAL FEATURES

Detection and treatment of vascular injuries takes place within the context of the overall resuscitation of the patient according to established principles of trauma care. If the source of bleeding is readily identifiable, it is compressed with digital pressure. While control of active bleeding is being achieved in this manner, detection and treatment of other life-threatening injuries proceed concurrently. Peripheral vascular injury can occur coincident with other life-threatening trauma, which may take higher priority in resuscitating the patient. In other cases, peripheral vascular injury may be the most serious or only injury, and evaluation and management of this type of injury can proceed directly. Despite rapid transport to a hospital through a modern emergency medical service, injury to large central arteries and veins is still often fatal, and many of these deaths occur before medical contact. Patients who survive to reach the hospital may have obvious exsanguinating hemorrhage or only very subtle signs of vascular injury. Many patients have no evidence of injury but are considered at risk for vascular injury because of penetrating wounds that traverse the course of major neurovascular bundles or because they have sustained high-risk injuries such as posterior knee dislocation. Patients who remain hypotensive after an initial fluid challenge may harbor an occult vascular injury if no other cause is found. In addition, patients with symptoms of intermittent claudication or with unexplained peripheral embolization and a history of previous trauma to the limb should be suspected of having occult arterial injury.

Peripheral vascular injury can be divided into three categories by physical examination: hard findings, soft findings, and asymptomatic high-risk wounds based on the mechanism of injury.

Hard Findings of Vascular Injury

Many patients have the classic “hard” findings of arterial injury, including pulsatile bleeding, loss of distal pulses, an audible bruit or palpable thrill indicative of an AVF, or an expanding or pulsatile hematoma. In addition, pallor or cyanosis and decreased temperature are common in a poorly perfused extremity, and massive distention of distal superficial veins may indicate an AVF as arterial flow is directed into distensible veins. The incidence of arterial injury in patients with any hard finding is consistently greater than 90%, and the presence of these findings requires further investigation by emergency angiography or, more commonly, immediate surgical intervention, depending on the duration of warm ischemia and the overall status of the patient.

Soft Findings of Vascular Injury

An additional group of patients have “soft findings” of vascular injury, including a palpable but diminished pulse in comparison
with the uninjured extremity, isolated peripheral nerve injury, history of severe hemorrhage in the field, unexplained hypotension, or a large nonpulsatile hematoma.²¹⁻²⁴ The significance of prolonged capillary refill is controversial; some experts find it to be a reliable sign of vascular injury (when combined with a pulse deficit) and consider delayed capillary refill to be a valid “soft sign” of vascular injury. Others have found this sign to be a nonspecific and unreliable predictor of arterial injury.²¹ Delayed capillary refill by itself is insufficient to diagnose arterial injury, but in combination with other physical signs it supports the diagnosis.

Isolated penetrating injury to a peripheral nerve is commonly associated with vascular injury because of the close proximity of these structures within the neurovascular bundles. Vascular injury occurs in 8 to 45% of cases of penetrating peripheral nerve injury.²⁵,²⁶ Conversely, vascular injuries have associated peripheral nerve injury in almost half of cases. It is sometimes difficult to distinguish whether the pain, paresthesias, or paralysis is caused by a primary nerve injury, an associated vascular injury causing compression of the nerve, or compartment syndrome. In general, primary nerve injury occurs immediately at the time of injury, whereas vascular neuropathy occurs over minutes to hours after the injury. Up to 35% of patients with “soft” findings of vascular injury have positive angiographic studies, although only a small proportion of these injuries require emergency repair.²¹,²⁶,²⁷

High-Risk Injuries

The proximity of a penetrating wound to a neurovascular bundle is defined imprecisely. Various definitions include 1 cm, 1 inch, or 5 cm as constituting “proximity.” Certainly, penetrating wounds that occur within 1 cm of a major neurovascular bundle or whose presumed trajectory has crossed such a bundle (“proximity wounds”) are more likely to result in an occult vascular injury. Major neurovascular bundles include large limb arteries proximal to critical branch points, such as the axillary, brachial, common femoral, and popliteal arteries (Figs. 48-3 and 48-4).²⁸ In addition, a small minority of patients with high-risk injuries, such as bites from large dogs or other animals, shotgun wounds, severely displaced fractures, crush injuries, or major joint dislocations (especially knee dislocation), will initially have occult vascular injury that may not be detected on physical examination.²⁹ The risk of missing such injuries is that the traditional 6-hour window of warm ischemia time will be exceeded or the patient will experience delayed complications resulting in loss of the limb. For example, patients with intimal flaps may be completely asymptomatic initially but can subsequently develop arterial thrombosis. Similarly, pseudoaneurysms progressively enlarge to produce compression of adjacent structures but may be very small and undetectable on initial physical examination. Consequently, some centers routinely perform radiographic confirmation of arterial patency in these cases, although in most large-volume trauma centers current practice does not consider proximity alone as an indication for imaging.

History

In patients who achieve and maintain hemodynamic stability, a more comprehensive history can be obtained. Important historical points to note include the exact time and mechanism of the injury. The time of injury is important because of the significant morbidity that results from prolonged warm ischemia time. The mechanism is of clinical and often forensic importance in that the injury is frequently inflicted during an assault or other violent crime, in the context of domestic violence or physical abuse, or in association with work. Various mechanisms of injury may mandate special reporting and may alter the patient’s ultimate disposition. Certain types of injuries, such as crush or bite wounds, are
particularly prone to complications. The occupation, avocation, and hand dominance of the patient are pertinent because a more aggressive strategy may be indicated in certain cases. Medical conditions that pose a risk of complications are important to note. Patients who are immunocompromised because of diabetes, acquired immunodeficiency syndrome, asplenia, cancer, or steroid use are at increased risk for infection and impaired wound healing. Patients with previous vascular insufficiency have more tenuous perfusion, are more susceptible to ischemia from elevated compartment pressure, and have a higher incidence of complications. As with most aspects of trauma care, patients whose sensorium is altered by head injury or intoxication, patients with spinal cord injury who cannot perceive pain, and those with significant painful distracting injuries will not reliably be able to report pain or paresthesias suggesting vascular insufficiency, so extra caution is exercised in these cases.

Physical Examination

Surprisingly, in this era of increased reliance on technology, meticulous physical examination in combination with comparison of blood pressures in the affected and unaffected limbs has reemerged as the mainstay of diagnosis of vascular injury.22 Physical examination is directed at discovering evidence of local wound complications and distal ischemia suggestive of vascular injury. Palpation of pulses in the affected extremities is the initial step. A comparison of the strength and quality of the pulses between the injured limb and its uninjured counterpart is then made. Isolated detection of a diminished pulse distal to the site of injury is a finding that merits further investigation rather than immediate surgery because palpation of pulses is a relatively inaccurate means of predicting arterial injury. False-positive findings of a pulse deficit may occur because of shock, in which all pulses are diminished; congenital absence of a pulse in one extremity; preexisting vascular disease; or arterial spasm or compression. A false-positive finding of a pulse deficit occurs in 10 to 27% of cases.5,22,23 False-negative findings can occur with transmission of the pulse through a “soft clot,” past an intimal flap, or through collateral circulation. Distal pulses can persist in 6 to 42% of patients despite significant arterial injury.30 Compression of an artery by casts, splints, or dressings may produce a pulseless extremity, and these should be removed if evidence of ischemia occurs. Finally, although the pulse may be absent, the limb may be well perfused by collateral arterial supply, thus making immediate repair of the arterial injury less compelling. Simultaneous palpation of the injured and unaffected limbs can detect relatively small differences in skin temperature that may suggest hypoperfusion. Testing two-point discrimination on the injured and unaffected limbs is similarly an effective means of detecting sensory deficits. Auscultation over the site of injury is an often-ignored examination that may reveal a bruit suggestive of an AVF. A bruit is audible in more than half of patients with an AVF.31 Repeated examination of the hematoma adjacent to the wound is indicated during the first 24 hours to determine whether it is expanding or pulsatile.

Despite the limitations just noted, reliance on the history and physical examination to triage patients into immediate surgery, imaging studies, and observation groups has been found to be relatively dependable, with a sensitivity of 92% and a specificity of 95%.22 However, studies of military casualties injured by blast injury or high-velocity gunshot wounds have found physical examination to be less reliable than in studies of civilian casualties.22

**DIAGNOSTIC STRATEGIES**

The diagnostic strategy for detection of peripheral vascular injury is tailored to the clinical situation. Patients with clearly evident major arterial injury (e.g., pulsatile hemorrhage from a penetrating wound with a cold, pulseless distal end of the extremity) may require emergency operative intervention without the potential benefit of any ancillary confirmation of their injury. Occasionally the use of an intraoperative angiogram may be helpful in delineating the exact location and nature of the injury in patients taken directly to the operating room, especially if there are multiple potential sites of injury. However, delaying definitive treatment of an obvious arterial injury that is approaching the 6-hour limit of warm ischemia time to obtain an angiogram is ill advised.

**Plain Radiography**

Plain radiographs of the affected extremity are indicated to detect fractures, joint penetration, and foreign bodies. With gunshot wounds, the sum of the number of intact bullets seen on radiographs and the number of entrance and exit wounds in the body should be an even number. Failure to locate a bullet can result in unexpected complications. Rarely, bullets or shotgun pellets can migrate distally and produce vascular occlusion or migrate proximally through the venous system to the heart. These emboli are readily detected on plain radiographs if the search is vigilant.33,34 Lead bullets retained within a synovial joint can result in systemic absorption and elevated lead levels and should be removed electively.35-41

**Pulse Oximetry**

Several relatively simple noninvasive maneuvers can be performed at the bedside to elicit evidence of arterial injury. The use of pulse oximetry has been suggested as a means of identifying limb ischemia after trauma, but it has been found to be relatively insensitive for this purpose. Clearly, in the absence of a pulse, no reading can be obtained. As the technology of transcutaneous measurement of physiologic indices advances, measurement of tissue oxygenation by near-infrared spectroscopy (NIRS) to quantify muscle oxyhemoglobin may prove more useful in detecting vascular injury because these devices are portable, noninvasive, and simple to use and appear to provide more accurate information than pulse oximetry.42-47 Thus far, however, small clinical studies have found contradictory results in use of NIRS for this indication.48-49

**Hand-held Doppler**

An inability to palpate pulses in an injured extremity should be verified by auscultation with a hand-held Doppler unit. Apart from the absence of any signal, arterial injury may be suggested by a change in the usual triphasic quality of the Doppler pulse to a biphasic or monophasic waveform as the pulse is “damped” by partial occlusion. Although Doppler is more sensitive, auscultation of the pulse by this method is subject to the same types of limitations as is palpation of the pulse.

**Ankle-Brachial Index and Arterial Pressure Index**

In an effort to improve on the accuracy of physical examination without relying on expensive and invasive tests such as arteriography, the use of blood pressure in the injured versus the uninjured extremity (arterial pressure index [API]) or the blood pressure in an injured leg at the ankle compared with brachial artery pressure (ankle-brachial index [ABI]) was developed and validated in numerous studies as an accurate means of detecting vascular injury. Systolic pressure is measured by inflating a standard blood pressure cuff proximal to the injury and recording hand-held Doppler systolic pressure distal to the injury. The
process is repeated on the uninjured limb, and a ratio of injured to uninjured systolic pressure is calculated (API). In general, a ratio less than 0.90 is considered abnormal and is an indication for further investigation. In several studies, an API less than 0.90 yielded a sensitivity of 95%, specificity of 97%, positive predictive value of 100%, and negative predictive value of 95%. However, a few studies have found API to be less accurate, including one in which a cutoff of 0.90 resulted in a false-negative rate of nearly 40%; nevertheless, the use of an API ratio less than 0.90 can eliminate a large number of unnecessary angiograms for proximity wounds and increase the diagnostic efficiency of angiography or computed tomographic angiography (CTA) by limiting its use to high-yield cases.

Patients with an API of 0.90 to 0.99 merit observation for 12 to 24 hours for repeated physical examination and API measurements to detect evolving injury. Patients with normal physical examination findings and a completely normal (≥0.99) ABI can be safely discharged from the emergency department provided there are no other injuries requiring admission.

Exclusive reliance on API to screen for arterial injury has significant limitations. Comparisons cannot be made when both limbs are injured or when severe soft tissue mangling precludes placement of a blood pressure tourniquet or location of the artery to be measured with the Doppler unit. As with physical examination, the sensitivity of API is limited when an intimal flap allows near-normal flow or when collateral circulation is sufficient to produce near-normal systolic pressure, as in proximal injuries to the subclavian or iliac vessels. Certain arteries (e.g., the profunda femoris, profunda brachii, and peroneal arteries) normally do not produce palpable pulses, and API is of limited usefulness in these injuries. Shotgun wounds often are associated with normal APIs despite multiple small arterial wounds; catheter-based angiography is the preferred diagnostic modality in this group. As with formal angiography, API cannot detect venous injuries.

Despite the limitations previously noted, API has proved effective in screening patients with proximity wounds. The vast majority of injuries missed by API heal spontaneously. Those that do not heal are generally seen within 3 months with signs of arterial injury and can be repaired electively.

### Ultrasound

The development of relatively small portable ultrasound (US) units has made possible direct visualization of both arterial and venous flow in major vessels. There are several different types of US that can detect vascular injury, and newer, more accurate techniques are being developed rapidly. B-mode (real-time) US is the most readily available form of US in portable units. It can easily visualize arterial pulsation in major vessels. Loss of pulsation distal to an obstruction or thrombosis is readily apparent. However, B-mode US cannot visualize certain anatomic areas accurately (subclavian and iliac vessels) because of overlying pulmonary tissue, and it is unreliable in detecting a fresh, relatively nonechoic thrombosis or hematoma. As blood liquefies within a hematoma, it becomes echoluent and more readily distinguishable from surrounding tissues.

Doppler US interprets sound moving toward or away from the transducer as flow. Venous flow is heard as a low-pitched hum, whereas arterial flow has a higher-pitched triphasic quality. The combination of B-mode and Doppler US is called duplex US and has enhanced accuracy in examining blood vessels. Duplex scans showing a focal increase in peak systolic velocity suggest partial obstruction of the vessel. However, duplex scanning is slightly less accurate in detecting injuries that do not decrease flow, such as small pseudoaneurysms, AVF, and intimal flaps. Also, it is technically limited in examining certain anatomic areas, such as the profund femoris and profunda brachii arteries and the iliac and subclavian vessels. Duplex US findings may be subtle, and as with other applications of US, its accuracy is highly operator dependent. Despite these limitations, the sensitivity of duplex US in comparison with standard angiography ranges from 83 to 100%, with a specificity of 99 to 100% and an accuracy of 96 to 100%.

Color flow Doppler converts Doppler echoes into quantitated visual signals. Flow toward the transducer is seen as red, and flow away from the transducer is seen as blue. The intensity of the color (the number of pixels on the screen) is proportional to flow through the vessel. Small prospective studies have indicated a high rate of accuracy in detecting arterial injury. However, a few studies have found API to be less accurate, including one in which a cutoff of 0.90 resulted in a false-negative rate of nearly 40%; nevertheless, the use of an API ratio less than 0.90 can eliminate a large number of unnecessary angiograms for proximity wounds and increase the diagnostic efficiency of angiography or computed tomographic angiography (CTA) by limiting its use to high-yield cases.

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### Computed Tomography and Magnetic Resonance Imaging

With a few important exceptions, computed tomography (CT) with contrast enhancement (CTA) has largely replaced catheter-based angiography for the detection of peripheral vascular injury in most trauma centers. Multidetector helical CT (MDCT) scanners have proven very accurate for diagnosis of peripheral vascular injury in multiple series with a sensitivity of 93 to 100% and specificity of 87 to 100% compared with catheter-based angiography. The advantages of CTA over catheter-based angiography are that it is noninvasive, readily available, and less costly and provides information on other injuries in the region being studied. However, there are several pitfalls to the use of MDCT angiography. Metallic artifact from bullets, orthopedic hardware, or other penetrating objects may obscure visualization of parts of a vessel, although with image reconstruction techniques, this problem can be largely overcome. Venous injuries may be missed depending on the phase of the contrast. The rapid image acquisition of current CT scanners makes timing of the contrast bolus more critical, and out-of-phase images may miss arterial injury. In practical terms, though, CTA is very useful in that it can be integrated into an overall plan for diagnostic imaging, including CT of the head and trunk, all of which can be accomplished rapidly. Because of the enhanced detail, accuracy, and speed of image acquisition with 64- to 256-slice CT scanners and the ability to perform three-dimensional reconstructions, this modality has become the standard imaging technique for suspected vascular injury. Magnetic resonance angiography (MRA) has been described and accurately detects vascular injuries but has yet to prove clinically useful. MRI is also contraindicated in the presence of iron-containing metallic foreign bodies.

### Arteriography

The policy of routinely exploring proximity wounds greatly improved the preservation of injured limbs in World War II. With the advent of arteriography and digital subtraction angiography (DSA), it became apparent that many negative wound explorations could be avoided with routine arteriography. In a study using routine arteriography, the negative surgical exploration rate
in patients with soft signs of arterial injury or with proximity wounds decreased from 84 to 2%. As a result, until recently, catheter-based contrast angiography has been the gold standard for diagnosing peripheral arterial injury, with a sensitivity of 99% and specificity of 97%.

Beginning in the 1980s, the number of civilian penetrating wounds increased dramatically. Because of high cost, limited availability at all hours, and poor reimbursement rates, the policy of routine arteriography for proximity wounds has been questioned. From a practical perspective, the time required to mobilize the angiography team and perform the study may be several hours, thus making this option less desirable when dealing with the time limitations posed by arterial injury. In addition, arteriography has a small but measurable complication rate, including allergic reactions to contrast media, renal complications, hematoma formation, and false aneurysm formation at the site of cannulation. Finally, the clinical usefulness of the information provided by arteriography has become increasingly suspect in recent years as more of these injuries have been managed expectantly. Routine “exclusion” arteriography for proximity wounds detects unsuspected arterial injury in 0 to 21% of cases. However, relatively few of these patients require emergency surgery. In a series of 284 patients who underwent routine angiography for proximity wounds, 17% had unsuspected arterial injury detected, but only 1.8% (five patients) required emergency surgical repair. In other series reporting on a total of 483 patients who underwent angiography for proximity wounds, only one arterial injury that required emergency repair was discovered.

In the presence of soft signs of injury other than proximity, the yield for angiograms increases to 29 to 35%, but many of these injuries do not require emergency repair and can be detected by noninvasive means. In addition, angiography results in an approximately 5% false-positive and false-negative rate compared with surgical exploration. Many of the injuries detected on angiography are caused by reversible vasospasm or very small intimal defects that generally heal spontaneously. Consequently, angiography for proximity wounds can detect injury in up to 21% of cases but results in acute surgical intervention in only 0 to 4.4% of cases. Many centers now successfully manage proximity wounds by repeated physical examination over a 24-hour period and reserve CTA for those with abnormal physical findings or an ABI less than 0.9. Angiography is also limited in that it cannot detect major venous injuries, which are increasingly being repaired surgically. The use of angiography is difficult in children because of the small caliber of their vessels and a propensity for vasospasm induced by angiography. Consequently, physical examination and noninvasive methods are preferred for detection of vascular injury in young children.

DSA has been used for detecting vascular injuries as well. DSA has been found to be more accurate than standard angiography for detection of extravasation and has the advantage of requiring the administration of a smaller load of contrast material. However, the field of view is much smaller with DSA than with standard angiography, thus making it technically difficult to study the entire course of a limb artery with DSA. Standard angiography is also more accurate than DSA in detecting intimal flaps and dissection. Traditional catheter-based angiography has the advantage over other diagnostic techniques in that it can also be used to treat many lesions. Embolization of pseudoaneurysms, endovascular stent insertion to bypass a dissection or AVF, and injection of thrombolytic agents to dissolve thrombus are routinely performed via intra-arterial catheter. Because of increased reliance on endovascular treatment, many of the lesions detected by other means ultimately still require angiography. Intraoperative angiography is often used as a primary study in patients with hard findings of vascular injury to delineate the extent of the damage to the vessel and plan operative repair.

**TREATMENT**

Initial treatment is directed at ensuring a patent airway and adequate air exchange before assessing the circulation. Once this has been accomplished, active hemorrhage is controlled by direct digital pressure. Blind clamping of a bleeding vessel is not recommended because of the risk of crushing adjacent nerves; however, clamping a clearly visible vessel can be effective. The use of tourniquets has been generally discouraged because of compression nerve palsies, occlusion of veins resulting in increased compartment pressure, and an increased risk of venous thrombosis. However, recent reports in the military literature state that the use of tourniquets for up to 6 hours is safe, effective, and lifesaving in some cases. Tourniquets should be applied if direct pressure is insufficient to control bleeding and left in place until definitive surgical control can be achieved. In the military studies, there were few complications associated with the use of tourniquets, and almost all of these were transient. In cases in which proximal and distal control of large-vessel injuries cannot be readily achieved in the emergency department, insertion of a Foley catheter into the wound and inflation of the balloon with sterile water can temporarily tamponade the bleeding. Intravenous lines should not be started in the injured extremity because they may be ineffective in delivering resuscitation fluid or medication and because extravasation from an injured vein may increase compartment pressure. Serial hemoglobin determinations may indicate unexpected blood loss from occult vascular injury. Patients with significant blood loss should have blood typed and crossmatched and may require immediate transfusion for stabilization. Patients with significant vascular injury often remain hypotensive despite such infusion and require further volume infusion or blood transfusion. Moribund patients with multiple severe injuries may require urgent amputation as part of their overall stabilization or extraction from wrecked automobiles or collapsed buildings. Between 50 and 70% of patients with severely mangled limbs require urgent amputation, especially if they have multisystem trauma.

The issue of “hypotensive resuscitation” is controversial with regard to major vascular injuries. A tenuous clot can form in injured arteries and prevent further blood loss as long as the patient remains hypotensive. Once arterial pressure reaches a critical but variable point, the clot may be expelled and massive blood loss can ensue. Therefore when the arterial injury is inaccessible for occlusion by direct pressure, the target blood pressure for resuscitation should be lowered to a systolic pressure of approximately 90 mm Hg. Overly aggressive and rapid fluid administration in the field or in the emergency department can produce transient intravascular hypervolemia and may ultimately increase the rate of blood loss. Close monitoring of vital signs and the total volume of fluid infused is indicated in these situations.

Once a vascular injury has been identified, a specific diagnostic and therapeutic strategy can be developed that is consistent with the severity of the injury, the presence of other injuries, and the resources available. In hospitals without the ability to perform vascular repair, transfer to a trauma center should be initiated early. In cases in which the transfer will involve a delay of several hours, cooling the ischemic limb will avoid exceeding the critical 6-hour cutoff for warm ischemia. For this to be accomplished, the limb is wrapped in towels, and ice in plastic bags is applied around the limb, avoiding direct contact of the ice to the limb, which can result in frostbite.

**Major Vascular Injuries**

Major vascular injuries that compromise the viability of a limb should be repaired within 6 hours to avoid irreversible ischemic neuropathy and myonecrosis. Treatment of vascular injury has changed dramatically in the past 10 years. Endovascular treatment
with self-expanding stents is currently the preferred technique for repair of these injuries in stable patients, and the majority of arterial repairs in the United States are now done with this technique.\textsuperscript{86-88} In hemodynamically unstable patients, open surgical repair is still preferred. If other life-threatening injuries must be repaired first, a temporary polytetrafluoroethylene (PTFE) vascular shunt can be placed in the operating room to restore perfusion to a limb.\textsuperscript{89} These temporary PTFE shunts can be left in place for up to 24 hours before thrombosis begins to occur within the shunt. Major arterial transection or thrombosis is ideally repaired by end-to-end reanastomosis, if possible, without placing undue tension on the suture line. If a larger segment of the artery is destroyed, interposition of a reverse saphenous vein graft is the preferred technique. PTFE grafts are suitable for grafting larger arteries if necessary, but they tend to occlude when used in smaller arteries (e.g., distal to the femoral or brachial arteries). Before completion of the reanastomosis, a Fogarty catheter is passed through both ends of the repair to extract any thrombi that may have formed. The distal circulation is flushed with a dilute 1:10 solution of heparin or enoxaparin to prevent early clot formation. Systemic administration of heparin is usually contraindicated in patients with major trauma. Assessment of distal perfusion and, in particular, compartment pressures is indicated frequently after repair and reperfusion of the limb. The use of broad-spectrum antibiotics is recommended before commencement of vascular repair.

Apart from excision of the affected arterial segment and repair of the vessel, less invasive techniques have been developed to manage pseudoaneurysms. Percutaneous embolization with Silastic beads, gel clot emboli, or thrombogenic coils is often successful in excluding the pseudoaneurysm.\textsuperscript{90} Placement of an endovascular stent can exclude the aneurysm and is also a successful alternative to open repair.\textsuperscript{91} Similarly, repair of an AVF can be undertaken through open surgical ligature of the fistulous connection, by endovascular placement of a stent to exclude the fistula, or by percutaneous embolization of the fistulous tract.\textsuperscript{90}

Late Complications

Despite timely optimal repair of arterial injuries, approximately 21\% of patients experience delayed complications requiring further surgical intervention, including delayed amputation. The most common of such complications is delayed thrombosis, which often occurs after many months as stenosis at the repair site progresses. Other complications include intermittent claudication, chronic pain or edema of the limb, and aneurysm formation in the graft.\textsuperscript{92}

Venous Injuries

Venous injuries may be primarily ligated if the condition of the patient cannot tolerate prolongation of surgery. However, the current trend is to repair major venous injuries if possible, particularly in the lower extremity, because wound healing is improved and the incidence of compartment syndrome, venous thrombosis, pulmonary embolism, and chronic edema is decreased.\textsuperscript{92-93} Extensive venous collaterals in the upper extremity make surgical repair less compelling.

The timing of repair of a vascular injury when associated with complex fractures requiring fixation is controversial. Historically, the fracture was repaired first to give a more accurate measurement of limb length and the length of graft required for vascular repair and because of fear that manipulation of long bones during reduction might damage the vascular repair. However, the need for postoperative fasciotomy is higher in these patients than in those who undergo vascular repair first (80\% vs. 36\%), and vascular repair is limited by warm ischemic time.\textsuperscript{96} Currently in most centers, vascular repair is prioritized over orthopedic repair, although temporizing PTFE shunts may be used to restore perfusion during fracture repair.

Minor Vascular Injuries

Increasingly, minor nonocclusive vascular injuries are being treated expectantly. Criteria for observation of vascular injuries include low-velocity missile wounds, intact distal circulation, absence of active hemorrhage, and minimal arterial wall disruption on angiography if performed. Angiographic or CTA findings meeting these criteria include intimal flaps extending less than 5 mm and pseudoaneurysms smaller than 5 mm in diameter.\textsuperscript{95} Follow-up of these injuries with repeat angiography or US reveals that approximately 85\% resolve spontaneously.\textsuperscript{95} Patients meeting these criteria can be monitored as outpatients for 3 months, with repeat physical examination and US to detect delayed complications.\textsuperscript{96,97} However, almost all pseudoaneurysms ultimately require repair and, once discovered, should be repaired electively rather than undergoing continued observation. Failure to detect and repair occult arterial injuries in children often results in severe edema or pain of the limb, and thus a more aggressive policy of repairing any arterial injury that causes even a relatively minor decrease in blood flow to a child’s growing limb may be justified.

### SPECIFIC INJURIES

#### Upper Extremity

##### Subclavian Artery and Vein

Subclavian artery injuries are uncommon and represent 1\% or 2\% of all vascular trauma.\textsuperscript{98} Isolated injury to the subclavian vein is more common than isolated arterial injury, but in almost half the cases both the vein and the artery are injured.\textsuperscript{99} The vast majority (95-99\%) of penetrative wounds, and because of massive hemorrhage, these injuries are often lethal before arrival at a hospital. Mortality in those who reach the hospital alive averages 15\%, but overall mortality as high as 75\% has been reported.\textsuperscript{100-104} It is interesting to note that morbidity is higher with a blunt mechanism, whereas mortality is higher with penetrating wounds.\textsuperscript{101} The right subclavian artery arises from the brachiocephalic artery, and the left arises from the arch of the aorta. From their origin, they course posterior and inferior to the clavicles to the outer margins of the first ribs, where they become the axillary artery and vein. The left subclavian artery rises higher than the right and extends into the root of the neck.\textsuperscript{28}

The clinical manifestation is that of hemorrhagic shock in 77\% of cases. Occasionally, unsuspected subclavian vascular injury is discovered at thoracotomy performed for excessive blood loss from a chest tube.\textsuperscript{28} Approximately 60\% have an associated pneumothorax or hemothorax, and additional injury to mediastinal and spinal structures is relatively common.\textsuperscript{96} Symptoms of limb ischemia may be apparent with absent radial and brachial pulses. However, pulses are completely absent in only 33\% of cases because collateral flow from the thyrocervical trunk may provide sufficient perfusion to avoid the symptoms and signs of ischemia.\textsuperscript{79} Neurologic deficits in the upper extremity occur in more than half of patients. The most severe of these injuries is damage to the brachial plexus, which occurs in almost 50\% of patients with blunt injury.\textsuperscript{59}

In a series of 100 cases of subclavian artery injury, the combination of physical examination and chest x-ray findings suggestive of subclavian injury (hemothorax, pneumothorax, apical pleural cap, or wide mediastinum) was 100\% sensitive and could have eliminated the need for 69\% of the arteriograms obtained.\textsuperscript{101} If the patient’s clinical condition permits, however, angiography can
provide an accurate diagnosis and can locate the injury precisely. APIs are relatively inaccurate with proximal thoracic outlet injuries because of collateral arterial flow. US techniques are also relatively inaccurate in detecting subclavian injuries because of interference by overlying gas-filled lung tissue. Therefore in cases in which the clinical diagnosis is equivocal (soft signs of injury or proximity wounds), arteriography (CTA or catheter based) is required to detect the injury. Immediate proximal and distal control of the subclavian artery is very difficult. An incision along the course of the clavicle is recommended but often needs to be extended to a sternotomy. If primary reassnastomosis is not possible, synthetic grafts are usually successful but have a tendency to fracture over time owing to the wide range of motion at the shoulder and resultant compression of the graft by the first rib and clavicle.

Blunt subclavian injuries are often associated with clavicular fracture or dislocation. Isolated first rib fracture is rarely combined with vascular injury unless posterior displacement occurs. However, first rib fracture in association with other major injuries, such as a wide mediastinum on the chest radiograph, an expanding hematoma, an upper extremity pulse deficit, or a brachial plexus injury, is accompanied by arterial injury in 24% of cases and merits investigation by arteriography or CTA. Several cases of shear injury of the subclavian artery have been reported to result from a loose shoulder restraint of a seat belt during a motor vehicle collision (MVC). Overall, blunt subclavian artery injuries have a higher morbidity than penetrating injuries because of higher rates of limb amputation and associated brachial plexus injury.

Subclavian vein injuries are even more lethal than those to the artery. In addition to massive blood loss, there is a relatively high risk of massive air embolism, which is frequently fatal in association with penetrating subclavian vein injuries. Patients with known or suspected subclavian vein injury should be placed in Trendelenburg’s and left lateral decubitus position to reduce the incidence of this complication.

**Axillary Artery and Vein**

Injury to the axillary vessels constitutes 3 to 9% of all vascular injuries, with penetrating mechanisms predominant. Blunt injuries are associated with proximal humerus fracture or forceful reduction of a dislocated shoulder, particularly if chronically dislocated. The axillary artery courses from the lateral border of the first rib to the inferior border of the teres major muscle, where it becomes the brachial artery. The axillary vein runs medial to the artery. The extensive anastomotic arterial connections around the shoulder joint usually permit good collateral flow and up to half of these patients will have palpable pulses as a result of collateral circulation. Because of the close proximity of the brachial plexus and the axillary vessels, significant denervation of the upper extremity can occur. Near-avulsion injuries resulting in scapulothoracic dissociation invariably produce severe disruption of the brachial plexus and often ultimately result in amputation despite successful vascular repair. There is a high rate of amputation for the combination of axillary vascular and brachial plexus injury, mainly because the presence of a flail limb results in amputation for placement of a prosthesis.

**Brachial Artery**

The brachial artery continues from the lower border of the teres major muscle and divides into the radial and ulnar arteries at the level of the proximal aspect of the radial head. The median and ulnar nerves and the basilic vein are in close proximity to the brachial artery. The profunda brachii artery is a major branch that arises slightly after the origin of the brachial artery and often contributes good collateral flow if the brachial artery is injured distal to this branch point. Brachial artery injuries occur as a result of penetrating trauma, humeral shaft fracture, elbow dislocation, or animal bites. They are the most common major vascular injuries in the upper extremity. In 75% of cases the radial pulse is absent. Studies have shown that limb salvage rates have improved to nearly 100% owing to efficient out-of-hospital transport, improved surgical techniques, and shorter time to first antibiotic dose. Repair is indicated in all cases because the amputation rate is high with ligation.

**Forearm Arteries**

The radial artery begins in the cubital fossa and runs superficially to the distal end of the radius, where it ultimately joins the deep branch of the ulnar artery to form the deep palmar arch of the hand. The ulnar artery begins in the cubital fossa and runs with the ulnar nerve anterior to the flexor retinaculum, at which point it joins the radial artery to form the superficial palmar arch of the hand.

Injuries detected by arteriography or US that are below the bifurcation of the arterial supply in the upper extremity do not need to be repaired unless there are signs of ischemia in the hand; “hard signs” of arterial injury such as an expanding hematoma, pseudoaneurysm, or AVF; or injury to both radial and ulnar arteries. However, some authors recommend repairing all these injuries because of the risk of intermittent claudication or cold intolerance in patients who have one artery ligated. Certain patients are almost exclusively dependent on the ulnar arterial supply to the hand because of an underdeveloped deep palmar arch. Clearly, ulnar artery injuries should be repaired in these patients. Compartment syndrome in the forearm is common after repair of proximal arteries and veins and may require fasciotomy.

**Lower Extremity**

**Iliac Artery and Vein**

Given the intra-abdominal course of the iliac vessels, virtually all iliac artery and vein injuries have associated trauma to the small or large intestine, bladder, solid viscera, or bony pelvis. The common and external iliac arteries are injured with equal frequency and more often than the internal iliac vessels. Approximately 80% of iliac vessel injuries are caused by penetrating trauma, and the remainder are mainly associated with pelvic fracture. Trauma to the iliac veins is responsible for massive bleeding in displaced pelvic fractures and often requires angiographic embolization for control (see Chapter 55). In moribund patients, an initial “damage control” laparotomy with temporary vascular shunting of the iliac vessels is often necessary as resuscitation continues. After the patient has overcome lactic acidosis, hypothermia, and coagulopathy, a second definitive repair can be undertaken. It is surprising to note that the incidence of infection of synthetic or autologous grafts is rather low despite the high degree of bacterial contamination associated with perforation of a hollow viscus. Distal ischemic complications occur with approximately one third of repaired iliac arteries, and subsequent amputations are required in up to 18%.

**Femoral Artery and Vein**

The external iliac vessels become the common femoral vessels at the inguinal ligament. After giving off the profunda femoris artery in the femoral triangle, the femoral artery continues as the superficial femoral artery almost vertically to the adductor tubercle of the femur and enters the popliteal fossa as the popliteal artery. There are extensive proximal collaterals around the hip joint,
including the gluteal, obturator, and pudendal branches of the iliac artery.10

Femoral artery and vein injuries are the most common vascular injuries seen in major trauma centers. Common femoral artery injury occurs as a result of intertrochanteric hip fracture, hip dislocation, and iatrogenic injury from the placement of arterial catheters or from hip replacement surgery, although 86% of femoral artery injuries are caused by penetrating wounds.11 Ligament of the common femoral artery culminates in amputation of the lower extremity in 80% of cases, so repair should be attempted in all cases. Penetrating wounds of the thigh result in femoral artery injury in 6.2% of cases, and up to 40% of these injuries are clinically occult. A medial or anteromedial wound track is present in virtually all these cases, and CTA has proven highly accurate in diagnosing these injuries and has largely replaced other imaging techniques.114-116

Popliteal Artery and Vein

The popliteal artery gives off the genicular branches in the popliteal fossa and then divides into the anterior and posterior tibial arteries at the lower border of the popliteus muscle. The peroneal artery arises from the posterior tibial artery slightly after its origin. The anterior and posterior tibial arteries and the peroneal artery form the trifurcation of the popliteal artery, and each runs with a corresponding vein and nerve in different compartments of the leg.28

The most common cause of popliteal artery injury is posterior knee dislocation in which bony elements directly lacerate or cause thrombosis of the artery. Displaced fractures of the knee, particularly tibial plateau fractures, may also result in popliteal artery injury. Anterior knee dislocations may cause excessive stretch on the popliteal vessels that can culminate in arterial thrombosis, but this injury is relatively rare. Overall, knee dislocation results in popliteal artery injury in 25 to 33% of cases.117 Up to 40% of these injuries may be clinically occult, and diagnosis is delayed in up to 40% of cases,7 although other series note that more than two hard signs of ischemia occur immediately in 71 to 94%.4,5 Twenty-five percent of cases have an associated injury to the peroneal and posterior tibial nerves. In half the cases, the knee dislocation may reduce spontaneously, leaving little evidence of the original trauma, particularly in obtunded patients.101 Patients showing complete ligamentous disruption of the knee on physical examination should be suspected of having a spontaneously reduced knee dislocation. Hemarthrosis may also be absent if the joint capsule is torn because blood can track into the fascial planes of the leg.

No consensus has been reached on the diagnostic approach to detect popliteal artery injury resulting from documented or suspected knee dislocation. There are three possible strategies, and each has proponents and detractors. The first option is to perform routine arteriography on every case of knee dislocation.118,119 The second is to perform CTA or arteriography on selected cases in which vascular injury is not certain despite the combination of physical signs, abnormal ABI measurement, or findings on noninvasive tests such as color flow Doppler or duplex scan.121 The third option is to rely completely on these physical findings and ABI to exclude arterial injury. If both these findings are normal, advocates of this approach claim 100% negative predictive value for vascular injury that requires surgery.51,80,82,122,125 The choice of these options is institution specific, but most centers continue to use angiography in selected cases. Abnormal ABI and US (duplex and color flow Doppler) have been found to be very accurate in detecting popliteal injuries, and many centers reserve angiography or CTA for cases in which noninvasive tests result in equivocal findings. As a general rule, high-energy mechanisms of trauma (e.g., auto vs. pedestrian and MVC) and posterior knee dislocations are more likely to produce popliteal artery injury than are low-energy mechanisms (e.g., sports injuries), and a more aggressive diagnostic approach (i.e., angiography or CTA) may be warranted in such cases. However, patients with penetrating trauma and more than one hard sign of popliteal artery injury can be taken directly to the operating room for repair because delaying these cases to obtain an angiogram is “superfluous, unnecessary, costly, and potentially dangerous.”106 Patients with blunt trauma can have false-positive hard findings generated by soft tissue swelling and external arterial compression, and these patients should undergo diagnostic testing first to confirm arterial injury. The amputation rate for popliteal injuries was as high as 40% in the past, but current rates are lower. In one large series, the amputation rate was 20%, but a high rate of permanent disability was found at 2-year follow-up.124 Another series reported no amputations with modern diagnostic and repair techniques.5,106 Factors that place patients at higher risk of amputation include severe mangling of the extremity, the presence of multiple fractures, major venous repair, or delay in repair exceeding 6 hours of warm ischemia time.119 Because of the high incidence of compartment syndrome with lower leg injuries, fasciotomy is required in 49% of cases, and some centers routinely perform fasciotomy in all such cases.125 Approximately two thirds of patients with popliteal artery injury will have persistent deficits caused by peripheral nerve injury, chronic ischemia, or amputation.

Lower Leg Arteries

The popliteal artery divides into three branches—the anterior and posterior tibial and the peroneal arteries at the inferior margin of the popliteal fossa. Injuries below the trifurcation at the knee may need repair if hard signs of arterial injury are apparent in the foot or if two of the three arteries are occluded on angiography.27 However, vascular injuries in the lower part of the leg are notorious for causing compartment syndrome and need to be monitored closely. Amputation is usually a result of a combination of soft tissue, nerve, and bone injuries. If significant injury to all three of these tissues is present, the amputation rate may reach 54%.27,126 The combination of orthopedic and vascular injury, particularly as a result of crush injury, and shock on initial evaluation culminates in amputation in 35% of cases and should be considered a poor prognostic sign for limb viability.110

DISPOSITION

Patients with confirmed injury to major vessels, equivocal findings on diagnostic tests, or symptoms of limb ischemia are admitted to the hospital for further investigation or observation. Consultation with a vascular surgeon is indicated as soon as vascular injury is strongly suspected or the need for emergency operative repair established. Patients who are unstable because of vascular or other injuries may undergo further investigation or exploration in the operating room. If the treating hospital is incapable of performing vascular surgery or appropriate investigations, transfer to a trauma center should be initiated. Delaying transfer for angiograms of proximity wounds in centers that are incapable of acting on positive results is unwise because it often delays definitive care beyond the safe limits of warm ischemia time.
The overall condition of the patient determines the extent of diagnostic study and stabilization in the emergency department. Critically injured patients may require immediate surgery, which should not be delayed for confirmatory study of obvious vascular injury.

Arterial injury may be readily apparent or clinically occult. Up to 21% of proximity wounds show arterial injury only on angiography, although few of these require emergent surgery. Similarly, various US modalities and abnormal APIs frequently detect clinically unapparent vascular injuries.

Symptoms of arterial injury may be delayed by hours to months after the initial injury. Late onset of symptoms suggests delayed thrombosis, pseudoaneurysm or AVF formation, compartment syndrome, or intermittent claudication resulting from stenosis or reliance on small-caliber collateral vessels for arterial perfusion.

Reperfusion injury can occur after restoration of arterial flow and result in compartment syndrome. Frequent reexamination of the reperfused limb is indicated in the postoperative period.

Compartment syndrome frequently develops in limbs with arterial injury, and fasciotomy is often required.

CT angiography is playing an increasing role in the diagnosis of vascular injury and essentially replaced catheter-based angiography for all but a few indications.

Many vascular injuries are amenable to endovascular treatment with self-expanding stents. This results in fewer complications, lower cost, and earlier discharge from the hospital.
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