11 Vascular Trauma to the Limbs

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11.1 Incidence of Vascular Trauma in Armed Conflicts

The reported incidence of combat vascular trauma has been low in the past with a range of only 0.2–4% [1, 2]. This was probably due to excessive mortality during prolonged evacuation time. In more recent reports from the wars in Afghanistan and Iraq, this incidence increased to 6.8% [3, 4] probably due to better immediate resuscitation and evacuation from the battleground. Even more so in our recent experience of the Lebanon 2006 war in which the rate of vascular injuries increased to 7.6% of all casualties and to 10.8% in the subgroup of soldiers only [5]. Vascular injuries are mostly caused by penetrating trauma due to small arms used in direct combat, high-velocity bullets, and pellets (Fig. 11.1).

Less frequently, blunt trauma is the cause of acute vascular occlusion. In modern wars, better torso protection of soldiers by advanced ceramic armored vests caused a new injury pattern, so vascular injuries of the limbs are now the main cause of severe bleeding, ischemia, amputations, and death (Fig. 11.2).

Almost half (46%) of all combat vascular injuries are affecting the lower limbs, and almost a quarter the upper limb [5].

Fig. 11.1 Pellets and fragments of missiles aimed at both civilian and military targets during the 2006 Second Lebanon War

Fig. 11.2 Typical CTA of a complex combat injury causing skeletal and soft tissue destruction and vascular thrombosis

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11.2 Methods of Hemorrhage Control

In vascular trauma, the goal of treatment is twofold: First to stop continued bleeding, and then to revascularize ischemic limbs. Injured patients with limb vascular trauma are frequently saved from exsanguinations by liberal use of rubber tourniquets that are available to almost every soldier in the battlefield nowadays. Improvised tourniquets are seldom used (Fig. 11.3).

Local prolonged hand pressure to stop bleeding is used only temporarily until a tourniquet is applied. Prolonged pressure during evacuation has been used in one case only in the 2006 Lebanon War where bleeding was from the inaccessible subclavian artery. On the other hand, mortality was reported in cases where an injured artery bleeding could not be stopped before evacuation, as may happen with iliac artery injury. This liberal use of tourniquets and prompt removal upon arrival to the hospital seem to save lives without serious side effects of secondary ischemia or nerve injury.

11.3 Tourniquets

Extremity vascular injuries are associated with approximately 9–10% mortality rate due to exsanguinations. Tourniquets (Fig. 11.3) are the basic equipment of every medical team to control battlefield hemorrhage. On the other hand, unnecessary abuse may result in limb ischemia and paralysis leading to amputation and improper use does not stop the bleeding. Tourniquets were utilized in 3–8% of extremity injuries in Iraq. In the Israeli Defense Force, every soldier has a tourniquet that can be used when deemed necessary, even without the presence of a medical team. In our 2006 Lebanon War experience, tourniquets were liberally used in 39% of all extremity vascular injuries and were removed only in the operating room [5]. Tourniquets were beneficial in 11 patients and overused (abused) in 2 additional patients without adverse effects. In a recent publication [6], eight tourniquets were used at Kandahar Airfield Base: five saved life, one was misused and one overused. Prehospital tourniquet use in Operation Iraqi Freedom was associated with improved hemorrhage control without adverse outcomes related to its use [7]. These findings support liberal use of tourniquets and refute the policy of their utilization as a last resort option.

11.4 Evacuation Methods of Casualties with Vascular Injuries

Rapid evacuation from the arena of injury to the nearest vascular facility is of utmost importance in vascular trauma. The time factor is important both in reducing continued uncontrolled bleeding and for reducing tissue ischemic time of the injured limb when tourniquets are applied. Emergency evacuation should be ordered otherwise mortality may ensue. Evacuation by helicopter is the most rapid method when the vascular facility is remote (Fig. 11.4). However, ground vehicles may prove to be faster when the arena is close [8].

Fig. 11.3 A combination of dressings and tourniquet used in the battlefield in an attempt to stop arterial bleeding

Fig. 11.4 Evacuation by a dedicated helicopter from the battlefield to a vascular facility

11.5 Triage in Emergency Room

Vascular injuries assume a first priority in treatment paradigms since shortening of the time of bleeding and the time of ischemia are of paramount importance in saving lives and limbs of the injured. When a vascular injury is identified clearly, the patient is rushed to the operating room without further delay. Classical hard physical signs of vascular injury include active hemorrhage, pulsatile or expanding hematoma, bruit or thrill and clear signs of ischemia: pain, pallor, paralysis, paresthesias, pulselessness, and poikilothermy (The 6 P's). Some of these signs may mislead in complex injuries and cause both false negative and false positive diagnoses.

When such injuries are suspected by physical examination but not certain, then vascular imaging is required. A simple handheld Doppler apparatus is very helpful in identifying arterial flow in the Dorsalis Pedis or the Tibialis posterior arteries, especially in patients with severe vasospasm (Fig. 11.5). Sophisticated Duplex ultrasound machines have yet to prove efficacy in the treatment algorithm of the suspected vascular injury.

Fig. 11.5 CTA demonstrating severe vasospasm of arteries in the area of severe limb injury

11.6 Vascular Injury Imaging

Precise identification of injured blood vessels is of utmost importance for the success of treatment. However, in complex modern war limb injuries, with multiple penetrating wounds, the exact extent, severity and location of the vascular injury is not always straightforward. High-quality vascular imaging helps to identify such injuries (Figs. 11.6 and 11.7).

In other cases, imaging may exclude significant injuries, especially in patients with shock, large

Fig. 11.6 Multiple penetrating wounds of the limbs causing limited vascular injury

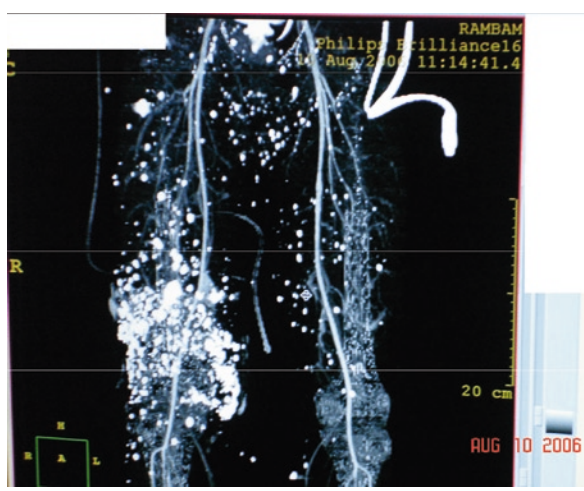


Fig. 11.7 CTA of the patient in Fig. 11.6. Accurate diagnosis of a single arterial injury is possible

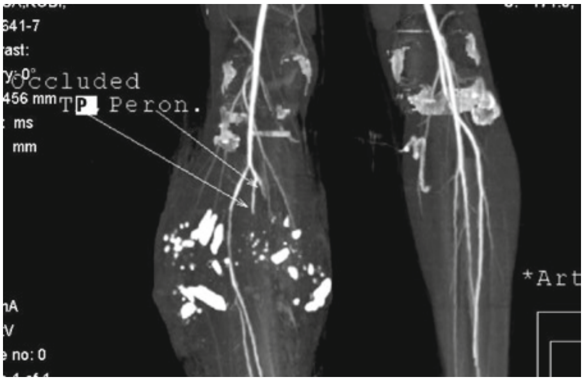


Fig. 11.8 CTA performed preoperatively to identify injured and uninjured vessels. This enables well-planned access and repair strategy

hematomas, and large bone fractures. In these cases, an unnecessary vascular exploration may be avoided.

The routine use of old "gold standard" angiography is no longer indicated because of its time consumption which spans hours, and its inherent inaccuracies including 15% false negative rate [9, 10]. Instead, multislice CT Angiography with rapid reconstruction became our preferred method of imaging in war trauma. CTA is rapid, accurate, and provides additional information such as size of hematoma, periarterial hematoma, bony fragment compression, unexpected injuries, proximity of shrapnel, and more details (Fig. 11.8). See Chap. 6 for a more detailed discussion.

11.7 Priority in the Operating Room

First priority in the OR is for rapid blood-loss control. If tourniquets are still applied, they should be released as soon as possible under controlled conditions. If bleeding resumes, direct pressure is applied on the point of bleeding and proximal control of the artery is gained. Distal control is also required to reduce bleeding. Then the injured segment of the blood vessel is approached and repair is started by standard vascular methods. If the patient is successfully stabilized with no more overt or occult bleeding, we use intravenous Heparin to avoid secondary thrombosis of injured blood vessels. Only after bleeding is stopped and revascularization is secured other necessary fixations and repairs are undertaken. Intensive care unit is recommended for 24 h following surgery due to hypovolemic shock, reperfusion injury, hypothermia, and bleeding diathesis. In addition, frequently multiple wound debridement or skin grafts are necessary to clean devitalized tissues in order to prevent infection or graft exposure.

11.8 Mechanisms of Vascular Injury

The large physical forces and thermal effects applied to the vascular wall during the traumatic event may cause a spectrum of injuries. These may range from a mild contusion of the adventitia or a minor intimal damage to a complete transaction of the vessel. Sometimes a small intimal flap may develop over time to an occluding dissection with distal ischemia (Fig. 11.9), especially in the popliteal artery.

A lateral laceration of the vessel wall is sometimes causing unstoppable continuous bleeding because the blood vessel is unable to use the inherent protective mechanism of contraction and spasm (Fig. 11.10).

Spontaneous thrombosis is frequently seen in the injured segment, usually on both sides of the injury up to the nearest uninvolved branch. A pseudoaneurysm or a pulsating hematoma may develop if the arterial bleeding is partially contained by adjacent tissues and fasciae. An arteriovenous fistula may develop when both an artery and an adjacent vein are lacerated simultaneously (Fig. 11.11).

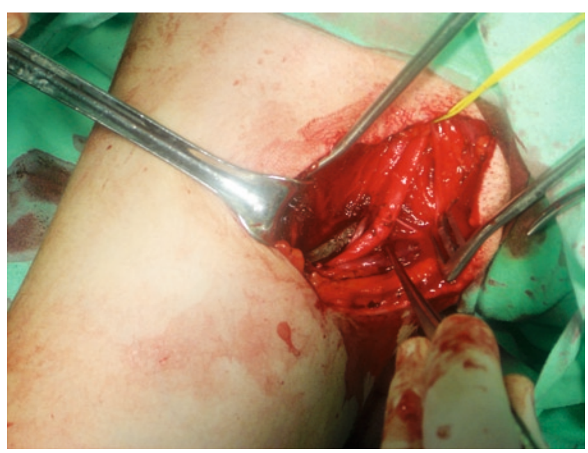


Fig. 11.9 Intimal flap and thrombosis of the brachial artery caused by a large penetrating fragment

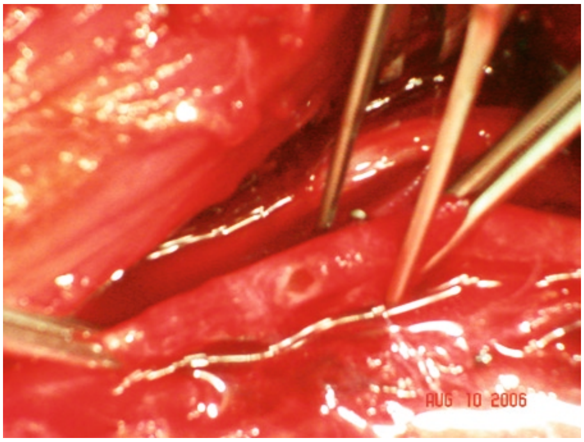


Fig. 11.10 Lateral laceration of an artery causing continuous bleeding

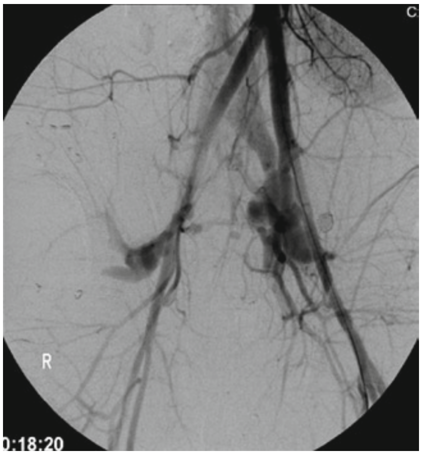


Fig. 11.11 Bilateral iliac arteriovenous fistulas caused by multiple penetrating fragments

11.9 Methods of Vascular Repair

After control of bleeding, the vessel is inspected and the best method of repair is decided. Simple repairs of injured blood vessels are preferred (Fig. 11.12).

A segment of the injured vessel is resected if required (Fig. 11.13).

Lateral suture of lacerations and debridement of short segments with end-to-end anastomosis when possible are rapid and effective with few complications (Fig. 11.14).

Reversed venous bypasses are used when required, usually if the gap is of more than 3 cm long (Fig. 11.15).

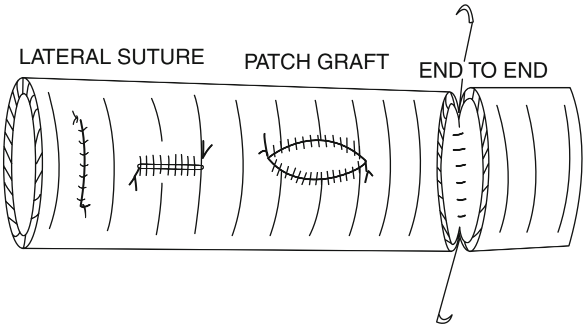


Fig. 11.12 The various methods of simple vascular repairs

Fig. 11.13 Debridement of an injured arterial segment is necessary to achieve healthy endothelialized edges for repair

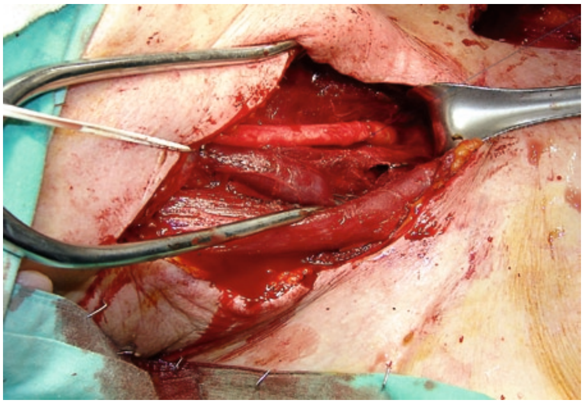


Fig. 11.14 End-to-end repair after resection of a short arterial segment

Multiple segments of injured vessels may be repaired by short venous segments. Synthetic grafts should be avoided if possible because of a higher risk of thrombosis and infection.

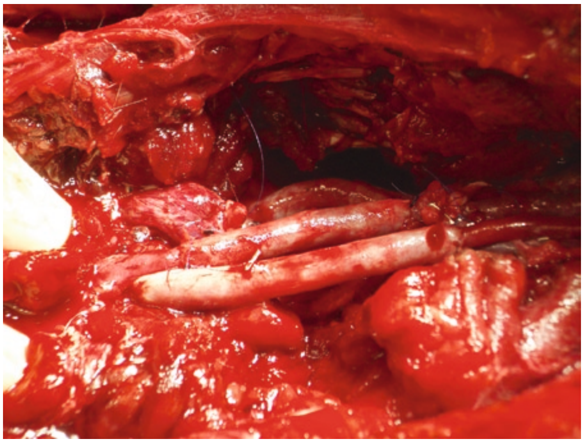


Fig. 11.15 Multiple-reversed venous interposition grafts of two arterial segments and one venous segment

Fig. 11.17 Large soft tissue defect after external fixation and vascular repair. Every vascular structure must be covered by viable myocutaneous flaps

Fig. 11.16 Large soft tissue defect after external fixation and vascular repair. Every vascular structure must be covered by viable myocutaneous flaps

Ligation of a major vessel should be used only in dying patients. All vascular repairs should be well covered by viable clean tissues to prevent late infection and bleeding (Figs. 11.16 and 11.17).

In our recent experience, interposition reversed venous grafts were used in 38.5% of cases, end-to-end anastomosis in 23%, lateral repair or patch in 15.5%, whereas primary ligation was reserved for small arteries and for veins (7.5%). In 13% of recent cases, we used endovascular methods of embolization or vascular occlusions. Covered stents are seldom used, mainly in relatively inaccessible segments like the subclavian or iliac artery (Fig. 11.18). Extra-anatomic bypasses are rarely required.

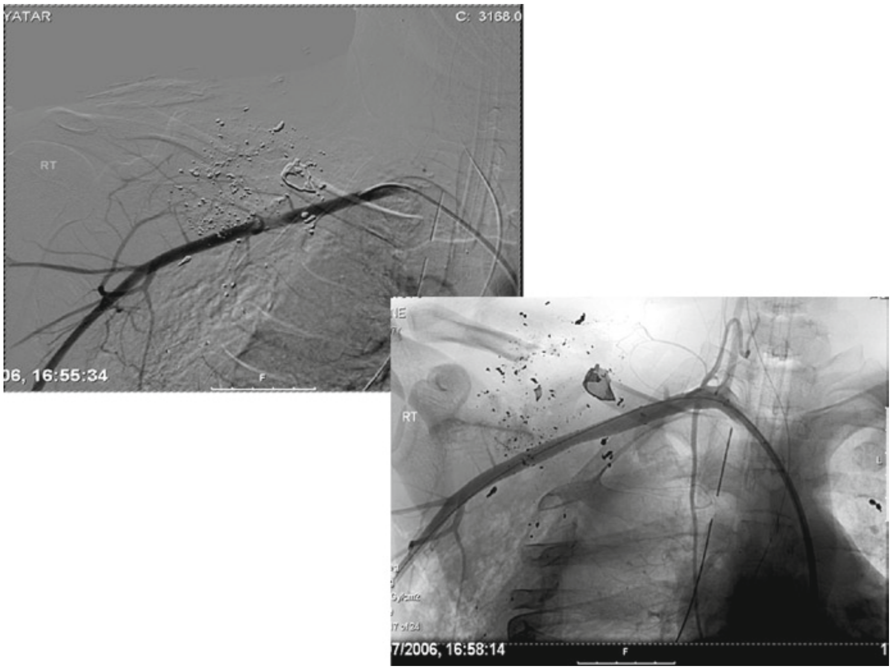
11.10 Endovascular Methods

Although potentially easier, the use of endovascular techniques in combat injuries is still rare, though more cases were treated in recent combat events. In our experience, open repair is more expeditious in the limbs than endovascular techniques, except in trunk vascular injuries. In the recent 2006 conflict, we used covered stents for limb vascular injury only in the subclavian artery injury (Fig. 11.18). We used other endovascular methods of embolizations and occlusions in vessels like iliac arteries and veins (see more details in Chap. 6).

11.11 Temporary Shunt

The use of temporary shunts is still controversial in the literature. Eger et al. from Israel were among the first authors reporting on the use of temporary vascular shunts in the modern era [11]. Although ischemia to an extremity has a lower treatment priority than massive hemorrhage, a temporary shunt may be inserted very quickly. The shunt serves for temporary revascularization by restoring blood flow to the leg, thereby reducing the ischemic time until the definitive vascular procedure is performed. Recent studies in animal model have confirmed a physiologic beneficial effect of temporary vascular shunts [12]. Early shunting protects the extremity from further ischemic insult and reduces circulating markers of tissue injury (Fig. 11.19).

Fig. 11.18 Endovascular repair of a lacerated subclavian artery with a covered stent



Temporary shunt utilization for a major extremity vascular injury is recommended when other injuries assume first treatment priority or when prolonged evacuation/transportation times to a trauma center are expected. When dealing with a combined vascular, skeletal and soft tissue trauma, treatment priorities are dictated by limb ischemia. These injuries, especially when involving the popliteal artery, are associated with high limb loss rates. With a stable fracture, the vascular surgeon can perform the definitive repair followed by external or rigid internal fixation of the fracture. If, however, the fracture is unstable or the orthopedic surgeon needs to shorten the limb, a temporary vascular shunt is needed and the definitive vascular repair will be performed after the orthopedic treatment. Temporary vascular shunts in wartime casualties were used with beneficial effects by us and by others [5, 13–16].

Technique: Injuries are exposed, proximal and distal control are achieved, vessel edges are debrided, thrombectomy is performed, and heparinized saline is administered, and then a temporary shunt is inserted and secured in place. Shunts may be made of improvised plastic lines of different diameters or specialized shunts like the Javid Shunt for Carotid repair (Fig. 11.19).

Possible problems include dislodgment and especially thrombosis in the range of 2–22% in both military and civilian patients, and especially for shunts used in distal or very small arteries [13–16].

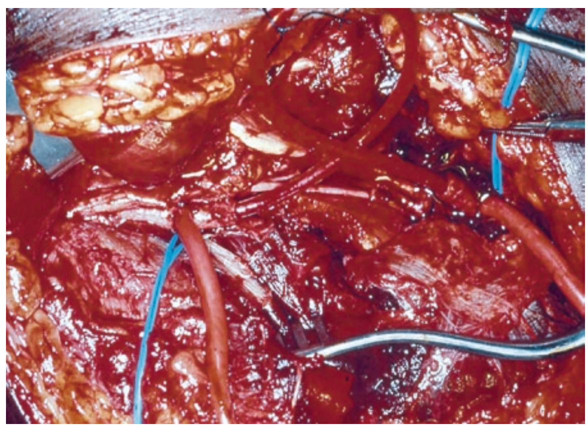


Fig. 11.19 A Javid shunt is used for temporary revascularization of ischemic limb tissues

11.12 Compartment Syndrome and Fasciotomy

Prophylactic fasciotomy should be performed every time the question "should it be done?" in a trauma patient is raised. Four compartment fasciotomy (Fig. 11.20) of the leg proved to be effective in limb salvage after ischemia-reperfusion.

Exact measurement of the compartment pressure is seldom helpful. Classical indications for prophylactic fasciotomy are prolonged limb ischemic time (more than 6 h),

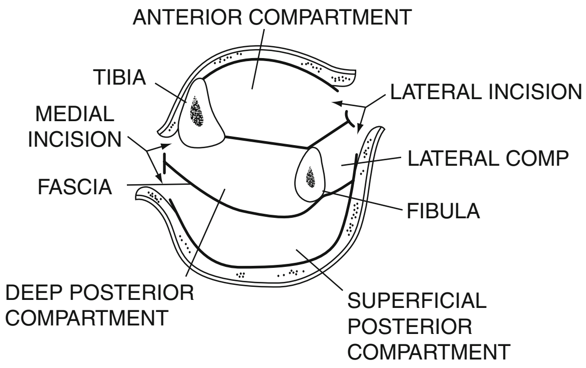


Fig. 11.20 The four compartments of the leg and method of fasciotomy by one lateral and one medial long incisions

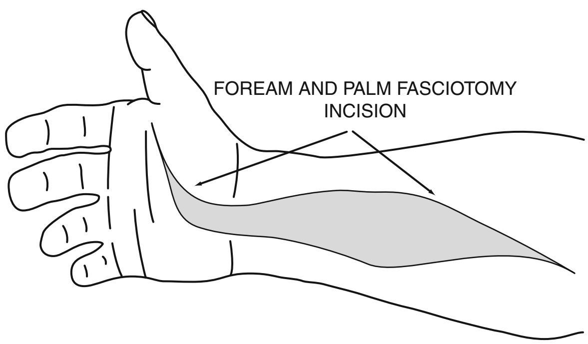


Fig. 11.21 Method of fasciotomy of the forearm and palm of the hand

a combined arterial and venous injury, and a massive soft tissue injury [17–19]. However, compartment syndrome may develop even after short periods of ischemia.

Clinical judgment is preferred and there is no real need to use sophisticated instruments to measure compartment pressure. The aim is to prevent compartment syndrome from happening rather than to treat it once it is diagnosed resulting in an irreversible neuronal damage [17]. If fasciotomy is not done immediately, then treatment with intravenous hypertonic 20% Mannitol solution should be considered in an attempt to prevent the later development of a compartment syndrome [20].

Fasciotomy of the forearm and palm should be considered if prolonged hand ischemia occurred or a large hematoma is threatening hand function (Fig. 11.21).

Fasciotomy as a treatment for compartment syndrome should be performed on clinical grounds: pain, paralysis, swelling, edema, and paresthesia. Once compartment syndrome is diagnosed, fasciotomy is an urgent procedure for limb salvage [17–19]. Seventy-eight percent of our patients with combat-sustained extremity vascular trauma underwent fasciotomy, similar to the results in Iraq (Fig. 11.22).

11.13 Arterial Versus Venous Injury

Arterial injuries of the extremities are manifested by life-threatening hemorrhage or by ischemia resulting in limb loss. Hard signs for vascular injuries are active arterial bleeding, expanding or pulsating hematoma, ischemia (pallor, pulselessness, paresis, or paralysis), and a thrill/bruit. Presence of a hard sign with a single entry and/or exit wound lead to surgery after the primary assessment in the emergency room. Soft signs which call upon further investigation of a possible vascular injury include a history of a moderate hemorrhage, hypovolemic shock, decreased but present peripheral pulses, peripheral neurologic deficit, or proximity to a named large artery. With multiple injuries or the presence of soft signs for a possible vascular injury, imaging is necessary for both the correct diagnosis and the choice of the preferred treatment. A high index of suspicion in high-energy trauma is mandatory especially in periarticular knee and elbow injuries or a gross displacement fracture.

In sharp contrast, severe venous trauma is manifested by hemorrhage, not ischemia. Bleeding may be internal or external and rarely may lead to hypovolemic shock. Unlike arterial injury, repair of major extremity veins has been a subject of controversy [21–23], and the current teaching is to avoid venous repair in an unstable or multi-trauma patient. Our experience in the 2006 Lebanon War leads to preference of venous repair over ligation, even when an interposition graft, rather than simple repair is needed [24]. Repair of a vein is of special importance when this vein is the only venous drainage route, as in the popliteal vein (Fig. 11.23).

11.14 Amputation

Among the vascular risk factors for limb amputation are ischemias of longer than 6 h, which may reach 50% with ischemia of more than 12 h, a combined injury of both the popliteal artery and vein, and a failed vascular

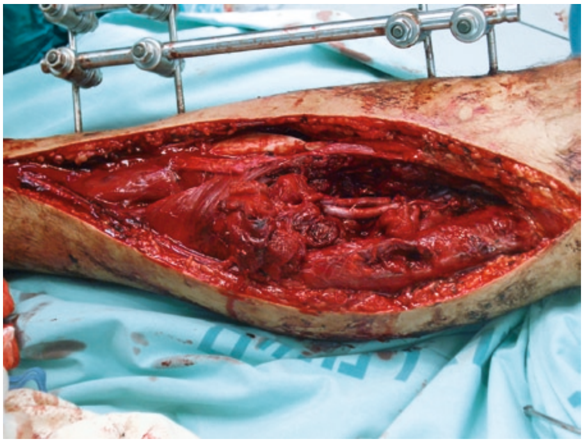


Fig. 11.22 Full-length incision of skin and fasciae are required for effective decompression of compartments

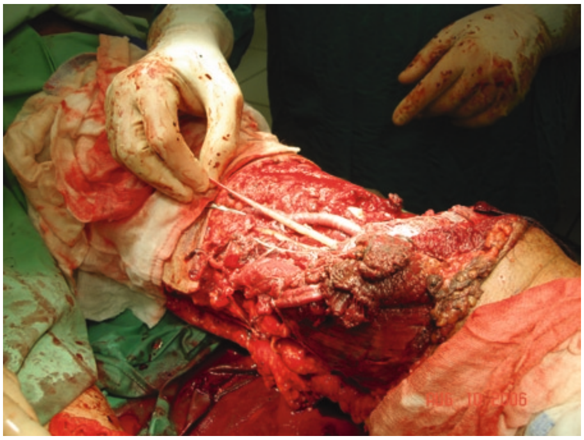


Fig. 11.23 Repair of a major vein after completion of the arterial repair

reconstruction. Amputation rates due to vascular injuries are decreasing over time from 60% in World War II, to 12% in Vietnam, 9% in Iraq, 5% in Ireland, 2% in the 1982 Lebanon War, and 0% in the recent 2006 Second Lebanon War [5, 24]. The continued improvement of results seem to be due to multiple factors like a high index of suspicion for vascular injury, better imaging techniques, coupled with a quick and meticulous intervention, performed by experienced vascular specialists, in a multidisciplinary team [25, 26]. Primary amputation should be considered in a severely mangled limb [27] with irreversible ischemia. However, the new technical possibility to initially shorten limbs and repair all neurovascular elements with later elongation (Fig. 11.24) may save many limbs from unnecessary amputations [28].

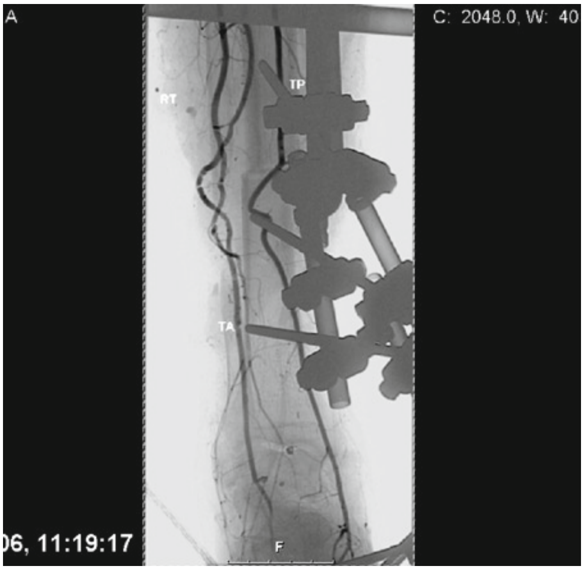


Fig. 11.24 Changes in arterial shape with tortuosity of the tibial vessels after intentional shortening of the leg

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