Management of lower extremity arterial injuries

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Past and current military experience has contributed considerably to the advances made in the treatment of extremity vascular injuries. However, the management of arterial injuries of the lower extremity is still associated with significant rates of limb loss and functional deficits. The incidence of civilian arterial limb injuries, including those related to iatrogenic vessel catheterization, has increased over time, but remains fortunately uncommon. Several related issues, such as the initial order of intervention for associated bony injuries, use of temporary intravascular shunt, repair of concomitant venous injuries, and prophylactic fasciotomy, have been debated extensively and remain controversial. The current treatment of extremity arterial injuries continues to evolve with the availability of superior imaging modalities and emerging endovascular technology. Additionally, the multi-disciplinary approach to the injured patients has produced improved limb-salvage and patient survival. In this review, we discuss the diagnostic evaluation, surgical and endovascular treatment of arterial injuries in the lower extremity.

KEY WORDS: Extremities - Trauma - Vascular diseases - Wounds and injuries - Endovascular surgical procedures - Transplants - Stents.

Our basic understanding of vascular trauma has derived largely from our past military experience during the war era. The limb salvage rates for extremity arterial injuries dramatically improved when the treatment rationale changed from simple vessel ligation during World Wars I and II, to direct arterial reconstruction during the Korean and Vietnam Wars.1-3 In general, extremity arterial injuries represent 70-80% of all vascular trauma in both the civilian and military experience. The limb amputation rates for lower extremity arterial trauma have continued to decrease with the advances made in the surgical techniques and the overall care of the trauma patients, but still ranges from 6% to 54% in reported series from various parts of the world.4-10 The basic principles in treating acute traumatic arterial injury to the lower extremity are to limit hemorrhage and to avoid prolonged warm limb ischemia. Clearly, prompt diagnosis and treatment is imperative for limb-salvage and patient survival. Although limb-salvage is predicated on the successful arterial reconstruction, other factors including associated long bone trauma, soft tissue loss, concomitant vein and nerve injury can greatly influence the outcome.5-10

A multi-disciplinary approach to the management of complex extremity trauma is essential to optimize limb-salvage and function. In addition to the usual nursing and ancillary care, the medical team should consist of at least a vascular surgeon, trauma surgeon, plastic reconstructive surgeon, orthopedic surgeon, rehabilitation specialist, physical and occupational therapists working in concert toward achieving a functional limb-salvage. In this review, we discuss the diagnostic work-up and the management of arterial injuries of the lower extremity, based on the literature and our experience. In addition, we review several related controversial issues, such as the initial order of intervention for associated bony injuries, use of temporary intravascular shunt, repair of concomitant...
Table I.—Physical signs of extremity arterial injury.17, 18

<table>
<thead>
<tr>
<th>Hard signs</th>
<th>Soft signs</th>
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<tbody>
<tr>
<td>Cold ischemic extremity</td>
<td>Unexplained hypotension</td>
</tr>
<tr>
<td>Absent distal pulses</td>
<td>Weak distal pulses</td>
</tr>
<tr>
<td>Expanding or pulsatile hematoma</td>
<td>Non-expanding hematoma</td>
</tr>
<tr>
<td>Pulsatile active bleeding</td>
<td>Significant bleeding at the scene</td>
</tr>
<tr>
<td>Associated paresthesia and paralysis</td>
<td>Isolated neurologic deficits</td>
</tr>
<tr>
<td>Bruit or thrill</td>
<td>Proximity of wound to vessel</td>
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**Mechanism and location of arterial injuries**

In a recent report from Serbia in Belgrade, 413 patients were treated for extremity arterial injuries from 1992 to 2001 (34% were war casualties and the remaining were civilian injuries).9 The mechanisms of injury included: gunshot (40%), blunt (24%), explosive (20%), and stabbing (16%). In this large series, the most frequently injured vessels were femoral (37.3%), popliteal (27.8%), axillary and brachial (23.5%), and crural arteries (6.5%). In the current US expanded military operations in Iraq, lower extremity injuries represent 52.5% of all vascular injuries recorded in the Balad Vascular Registry and reported in several successive publications.10, 11 From September 1, 2004 through August 31, 2006, the incidence of lower extremity arterial trauma was 4.4% (n=301) of all battle-related injuries. The majority of injuries resulted from improvised explosive devices (55%), and gunshot wounds (39%). Similar to the Serbia experience, of the 301 arterial injuries in the lower extremities, the anatomic distribution of the injured vessels involved the superficial femoral artery in 17.6%, popliteal artery in 13.3%, and tibial arteries in 14.6%.9-11

The mechanism of injury has been shown to be an important risk factor for limb loss. Generally, explosive injuries are associated with the worse prognosis followed by blunt trauma. The damage to the surrounding tissues and adjacent structures is most severe in explosive injuries. For the same reason, high-velocity gunshot wounds tend to cause worse injuries compared to low-velocity gunshot wounds. Stab wounds typically have the best limb-salvage rates. Blunt trauma severe enough to cause vessel injury is typically associated with high incidence of soft tissue devitalization, bony fracture/dislocation and nerve injury. In particular, blunt popliteal artery injury is associated with a high incidence of skeletal trauma.8, 12, 13 Conversely, the incidence of popliteal artery injury in patients with knee dislocation (anterior and posterior) has been reported varying from 7.5% to 23%.14-15 In assessing patients with fracture or dislocation of the knee, one should have a high index of suspicion for a popliteal artery injury.

**Diagnosis**

The initial management of the trauma patient, regardless of type and location of injury, should always follow the "ABCDs" of Advanced Trauma Life Support (ATLS) protocol. The diagnosis of lower extremity arterial injury can be made based on the history and physical examination alone, or confirmed with diagnostic imaging. "Hard" and "soft" physical signs of arterial injury have been described17, 18 (Table I). It is widely accepted that patients showing hard physical signs of extremity arterial injuries can be taken immediately to surgery for exploration and definitive repair without further studies. Recently, we treated 20 out of 57 (35%) patients with distal superficial femoral and popliteal arteries, based solely the clinical history and physical examination.9 In patients with soft signs suspicious for extremity arterial injury, further evaluation is warranted. A decreased ankle-brachial index in the involved extremity further raises the index of suspicion for an arterial injury. In the stable and cooperative patient, an ultrasound duplex examination can demonstrate a pseudoaneurysm, arteriovenous fistula, or arterial occlusion. However, duplex examination of the affected extremity is frequently difficult because of severe pain in the wound, for instance, related to adjacent bony fractures.

Catheter-based selective contrast arteriography has been the gold standard diagnostic imaging modality to delineate the location and extent of the arterial injury and the distal run-off vessels. However, multislice helical computed tomographic angiography (CTA) is increasingly used to image vascular injuries in major trauma centers (Figures 1A-D).19-21 In a recent study, CTA achieved 100% sensitivity and 100% specificity in detecting clinically significant arterial injury in
63 injured lower extremities. There were 22 positive and 40 negative studies for arterial injury. There were no missed injuries. CTA was non-diagnostic in 1 patient (1.6%), secondary to artifact from retained missile fragments. CTA is non-invasive and can be rapidly acquired and does not require the involvement of an additional special procedure team. Three-dimensional (3-D) reconstruction of CTA images is helpful although not essential. CTA will likely replace invasive catheter-based angiography as the diagnostic modality of
of patients in whom the injured limb is either nearly amputated by the force of the trauma or associated with irreversible neurological damage, the treatment of choice is primary amputation. Debate exists in the management of the patient with a mangled extremity in whom limb-salvage is usually first attempted, but such efforts are thought to be doomed. In this substantial group of patients, although the injured limb appears viable initially, it remains neurologically impaired or develops overwhelming infection within days or weeks after revascularization, and requires subsequent amputation. Several severity injury scoring systems have been tested to predict the risk of limb loss and guide the clinical decision.22, 23 The Mangled Extremity Severity Score (MESS) is widely used (Table II). In a retrospective study of 25 patients with severe lower extremity arterial injuries, from Harborview Medical Center in Seattle, Washington, the authors reported that those patients in whom limbs were saved all had MESS scores of 6 or less, and those whose limbs were amputated had scores of 7 or greater.23 We advocate the use of MESS scores for reporting and stratifying severity of injury, but do not apply it to predict for limb loss because of its lack of accuracy.5

**Order of intervention and intravascular shunting**

An ongoing controversy pertains to the order of intervention for patients with combined orthopedic and arterial injuries. We and others have proposed that expeditious arterial reconstruction take place before skeletal fixation.5,24-26 In a retrospective review of trauma victims at Ben Taub General Hospital, in Houston, Texas, the length of hospitalization was shorter and the fasciotomy rate was lower in patients who had revascularization before fracture fixation, compared to patients who had the reverse order of intervention.24 Other authors have argued that vascular repair should follow skeletal stabilization, quoting an increased risk of vascular complications with the reverse order of intervention. Generally, external fixation of bony instability requires shorter operative time compared to open reduction internal fixation.27 We favor the use of external fixators for critically ill patients with multiple injuries and for the mangled extremity (Figures 2A-C).

In the case of a patient with an isolated knee dislocation causing distal ischemia, it is generally agreed that reduction should take place first. Dislocation of

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**Table II: Mangled Extremity Severity Score (MESS) variables**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Points</th>
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<tbody>
<tr>
<td>A) Skeletal and soft tissue injury</td>
<td></td>
</tr>
<tr>
<td>Low energy (stab; simple fracture; “civilians” gunshot)</td>
<td>1</td>
</tr>
<tr>
<td>Medium energy (open or multiple fractures, dislocation)</td>
<td>2</td>
</tr>
<tr>
<td>High energy (close range shotgun, “military” gunshot, crush injury)</td>
<td>3</td>
</tr>
<tr>
<td>B) Limb ischemia*</td>
<td></td>
</tr>
<tr>
<td>Pulse reduced or absent, but normal distal perfusion</td>
<td>1*</td>
</tr>
<tr>
<td>Pulseless, parasthesia, diminished capillary refill</td>
<td>2*</td>
</tr>
<tr>
<td>Cool, paralyzed, insensate</td>
<td>3*</td>
</tr>
<tr>
<td>C) Shock</td>
<td></td>
</tr>
<tr>
<td>Systolic blood pressure always &gt;90 mmHg</td>
<td>0</td>
</tr>
<tr>
<td>Transient hypotension</td>
<td>1</td>
</tr>
<tr>
<td>Persistent hypotension</td>
<td>2</td>
</tr>
<tr>
<td>D) Age (years)</td>
<td></td>
</tr>
<tr>
<td>&lt;30</td>
<td>0</td>
</tr>
<tr>
<td>30-50</td>
<td>1</td>
</tr>
<tr>
<td>&gt;50</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>13</td>
</tr>
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</table>

*: score doubled for ischemia >6 h.
the knee produces stretch and contusion forces to the proximal (adductor hiatus) and distal (interosseous membrane and fibrous arch over the soleus) attachment sites of the popliteal artery that can cause injury to the vessel.\textsuperscript{14,} For years it has been debated whether all patients with knee dislocation should have contrast arteriography, even in the presence of normal foot perfusion and distal pedal pulses. Based on the current literature, patients with normal pedal pulses and ankle-brachial index can be safely monitored, and arteriography is selectively reserved for those with associated physical signs of distal leg ischemia.\textsuperscript{14-16,} 28-30

Intravascular shunting is often used when skeletal stabilization is carried out before revascularization to limit the period of ischemia. The use of an intravascular shunt remains controversial in the management of civilian trauma.\textsuperscript{31-34} It is generally accepted that intravascular shunting is beneficial for patients who cannot undergo immediate arterial reconstruction, such as in a war zone, or part of a "damage control" strategy for patients who are too "unstable" because of other life-threatening injuries.\textsuperscript{10,} 11, 35 Temporary intravascular shunting was used in approximately 50% of the victims with extremity arterial injuries in the report on the experience thus far in the Iraq conflict.\textsuperscript{10,} 11 Eighty-six percent of the shunts were patent when placed in the proximal arteries.\textsuperscript{10} However, the patency rate was much worse for shunts inserted distal to the brachial or popliteal arteries (18%).\textsuperscript{10} Recently, we studied the outcome of trauma victims treated for trauma to the distal superficial femoral and popliteal arteries at Memorial Hermann Hospital in Houston, Texas.\textsuperscript{5} We compared patients who had revascularization prior to orthopedic fixation to those who had the reverse order of intervention.\textsuperscript{5} We found no significant differences in limb-salvage between the two groups. Our results showed that there is no increased risk of arterial disruption during orthopedic manipulation, and that arterial reconstruction before orthopedic fixation would obviate the use of intravascular shunting.\textsuperscript{5}

**Operative reconstruction**

Surgical repair of lower extremity vascular trauma is undertaken in the operating room. General anesthesia is usually administered with the patient in the supine position. We prefer to use the supine position for all cases as it is more versatile and allows easy access to the vessels at all locations (femoral, popliteal and tibial arteries). Intravenous large-bore catheters are placed for rapid fluid and blood infusion. We routinely give preoperative antibiotic (cefazolin or vancomycin for penicillin allergy). An indwelling catheter is inserted to drain the bladder and monitor urine output. We clean and sterilize the skin using an aseptic solution. If the patient has an isolated lower extremity trauma, we prepared both the injured extremity and the contralateral extremity, in case we need to harvest the contralateral greater saphenous vein conduit. In the presence of associated truncal injuries, we include a wide operative field and prepare the neck, chest, and abdomen in addition to the legs. Hypothermia is a common consequence of major trauma, and appropriate measures are taken to circumvent decreasing body temperature in the operating theater.

The technical aspects of arterial reconstruction are straightforward. We routinely administer intravenous heparin (1 mg/kg) just before stopping pulsatile flow to the injured artery. We omit systemic heparin in patients with concomitant intracranial hematoma or disseminated coagulopathy. The segment of the damaged artery should be debrided to grossly normal ends (Figures 3A, B). Insufficient debridement of the damaged artery can lead to acute postoperative throm-
It is generally agreed that a technically perfect primary repair of the artery has the best long-term outcome. However, several commonly recognized factors regarding this issue are noteworthy. To achieve a tension-free anastomosis, mobilization of the injured artery is necessary (which may require sacrifice of branches). When the artery is partly severed and a significant part of its wall is injured, a lateral repair with a patch (vein preferably or synthetic) is recommended to prevent arterial narrowing.

An interposition bypass graft is usually necessary when 2 cm or more of the injured artery is excised to ensure a tension-free anastomosis. In reviewing the literature, we found that primary repair of the injured artery was more commonplace in the earlier period compared to the more frequent usage of interposition bypass graft in contemporary series. As much as 40-50% of blunt popliteal artery injuries were repaired primarily at the Los Angeles County hospital from 1967 to 1987. In contrast, in the recent report on the casualties from Iraq, primary repair of injured arteries were possible in <20% of the cases, and 56% required arterial bypass or patch. Arterial injuries due to stab wounds tend to be most amenable to primary repair whereas those caused by high-velocity gunshot wounds and blunt trauma typically require interposition bypass. In our recent series, we were able to repair the injured artery in only 2 of 57 patients, and the remaining patients had vein graft interposition or vein patch (Figure 4). One of the two patients who had primary repair developed immediate postoperative thrombosis that was subsequently successfully revascularized using an interposition vein graft. The repair failed because the ends of the artery had not been adequately debrided with injured arterial walls still present.

The return of normal pulses beyond the repaired artery is typically a good indicator of good revascularization. However, if there is doubt regarding the repair, a completion study should be obtained to demonstrate its adequacy. A completion arteriogram can show the satisfactoriness of the repair and the distal run-off vessels. Alternatively, an intraoperative duplex ultrasound can also be used to image the repaired segment of artery or bypass graft. There is no universal agreement with regard to the routine use of a completion imaging study. Its use remains a surgeon's preference.

Choice of conduit

The autogenous greater saphenous vein graft is widely accepted as the conduit of choice for the reconstruction of the superficial femoral and popliteal
arteries. This conduit is associated with the highest patency rate and the least risk of graft infection. To replace a larger common femoral artery (diameter: >6 mm), a synthetic graft, made of polyester or expanded polytetrafluoroethylene (PTFE) (Dacron or PTFE), may be preferred for better vessel size match. In general, the greater saphenous vein from the uninjured leg is harvested, preserving the ipsilateral saphenous vein for venous drainage of the injured leg. This is particularly important when the injured extremity is mangled and in the presence of concomitant venous injuries. We have found no increase in morbidity of the affected leg when using the ipsilateral saphenous vein conduit. In our series of patients with distal femoral and popliteal artery injuries, the ipsilateral greater saphenous vein graft was used in 13 patients and the contralateral saphenous vein graft in 42. It has been proposed that a synthetic graft may be more resistant to local enzymatic degradation than an autogenous conduit in a contaminated wound, insofar as the graft is not exposed. However, this concept has not been proven and synthetic grafts remain inferior to autogenous saphenous vein grafts. PTFE grafts should be reserved for above-knee arterial reconstruction when there is no available autogenous conduit, or when the patient is critically ill with acidosis, hypothermia, coagulopathy, or had received massive blood transfusion. In the latter situations, the longer harvest of time for the autogenous saphenous vein can increase systemic complications.

Common femoral, superficial femoral and popliteal arteries

Injury to the common femoral, superficial femoral and popliteal arteries accounts for the majority of lower extremity arterial injury in civilian and military trauma. Every attempt should be made to repair or reconstruct these arteries, because vessel ligation alone results in high risk of limb loss. Isolated injury to the common femoral artery is least frequently seen among this group. Operative exposure for injury to the common femoral artery can be problematic in the face of active bleeding or distorted anatomical planes due to a large hematoma. Getting proximal control of the injured vessel is of paramount importance. If proximal control appears tenuous in the groin, the common or external iliac artery can be controlled through a retroperitoneal approach via a flank incision. An alternative option is to get percutaneous access from the contralateral femoral artery, pass a wire up and over and inflate an occlusion balloon positioned across the ipsilateral iliac artery. The advantage of the latter procedure is the avoidance of a flank wound. Hybrid procedures with combined endovascular techniques and operative repair are emerging. Proximal control using the balloon occlusion technique can be applied in most of the large vascular beds.

The superficial femoral artery can be exposed directly with a medial longitudinal incision at or adjacent to the site of injury. Exposure of the popliteal artery can be obtained either by a medial longitudinal or a posterior S-shaped incision. We have favored the medial approach along the anterior border of the sartorius muscle for its versatility. The S-shaped incision behind the knee has been advocated by others for popliteal artery injuries, but this requires placing the injured patient in a prone position.

Profunda artery

The profunda artery is the least commonly injured vessel in the lower extremity with reported incidence from 3.7% to 6% of the cases, and mostly it is due to penetrating trauma. Surgical treatment can be vessel ligation, direct repair, and interposition bypass. Surgical approach to the profunda can be difficult in the presence of a large hematoma and active bleeding. Either a standard anterior groin incision or a lateral approach can be used to expose the profunda. We prefer the anterior medial approach for ease of extension. Endovascular embolization has been used effectively to stop bleeding from branches of the profunda and to close pseudoaneurysms of the profunda.

Tibial artery

The incidence of isolated tibial artery injury is reported between 10% to 15%. In general, limb ischemia is not evident unless two or more tibial arteries are disrupted, because of the good collateral network. In the Balad registry, the injured tibial artery was primarily ligated in 43% of the cases without increase risk of amputation. Reconstruction was achieved using predominantly an autogenous vein graft or patch angioplasty, and less frequently by primary repair. Similar results were noted in the series from South
Africa for traumatic tibial artery injuries. Open approach to the injured tibial vessels varies depending on the vessel to be repaired. The anterior tibial artery is approached via an anterior incision. The posterior artery is exposed via a medial incision. A lateral calf incision with resection of a segment of the fibula provides a quick access to the peroneal artery, or alternatively, a medial approach can be used. Frequently, exposure to the injured artery may have been created already by the path of the trauma. Catheter-based embolization are used increasingly to treat pseudoaneurysms of the tibial arteries. Endovascular therapy is discussed in more details later in this chapter.

Extra-anatomical bypass and muscle coverage

In severely contaminated wounds, the injured artery can be ligated and an extra-anatomical bypass is undertaken with routing of the conduit through a clean tissue plane. Alternatively, an interposition bypass graft that is placed anatomically in a contaminated wound can be covered with a local muscle flap. This is particularly critical in the presence of a synthetic graft. The local sartorius muscle, gracilis muscle, rectus femoris muscle and fascia lata have all been used successfully in this setting.

Concomitant venous injury

Venous repair remains one of the most controversial issues in the management of traumatic lower extremity injury. Proponents of venous repair have reported that impaired venous drainage can result in severe limb edema, increased compartment pressure and eventual limb loss. Others have found no significant clinical sequelae from venous ligation. Preservation of the femoral and popliteal veins should be attempted, particularly, in the presence of concomitant arterial injury. Venous ligation in this situation can lead to severe limb edema and compartment syndrome. Venous reconstruction has been associated with high rate of postoperative thrombosis. Thrombosis of the repaired vein has been linked to pulmonary embolism. It is our practice to attempt repair of the femoral and popliteal veins, in the form of primary lateral repair, or using an autogenous vein interposition graft or patch in stable patients. In unstable or critically ill patients, the injured veins are expeditiously ligated. In general, we repair the injured vein first to establish venous drainage before reconstructing the injured artery. In view of the high incidence of venous thrombosis, prophylactic or therapeutic anticoagulation should be considered for patients with venous injuries, unless contra-indications exist.

Non-operative management

Non-operative management of arterial injuries in the lower extremity has been used in selected patients. This selection can be based on the clinical exam, duplex ultrasound, or angiography. In one series from the Los Angeles County-University of Southern California Medical Center, 61 non-occlusive arterial injuries were treated non-operatively. Various arteriographic findings included intimal defect/flap, pseudoaneurysm, arterial stenosis, and arteriovenous fistula. Criteria for non-operative therapy included low-velocity injury, minimal arterial wall disruption (<5 mm for intimal defect and pseudoaneurysm), intact distal circulation, and no active bleeding. Repeated arteriography showed resolution, improvement or stabilization of these injuries in 87% of the cases. The authors concluded that non-operative management of non-occlusive arterial injuries is safe and recommended serial arteriography to document healing. Similarly, a low rate of long-term complications has been shown in a group of patients treated expectantly for clinically occult penetrating extremity vascular injuries at the University of Florida Health Science Center in Jacksonville. In this study, only 1.3% of 287 patients with asymptomatic (based on the physical exam alone) penetrating extremity injury required delayed surgical arterial repair. The authors concluded that clinically occult arterial injuries can be managed non-operatively. With the increasing use of CT angiography, it is expected that clinically occult arterial injuries will be diagnosed more frequently. Nevertheless, the same criteria can be applied for non-operative therapy.

The role of fasciotomy

Increased compartment pressure leads to tissue ischemia, giving rise to classic symptoms and signs of
severe pain out of proportion to injury that is exacerbated with passive stretch, paresthesia, motor weakness, and swelling of the calf (or thigh). Compartment pressure over 25-30 mmHg is generally regarded as diagnostic for compartment syndrome, although this is not universally agreed upon.\textsuperscript{17, 18, 55} The consequences of delayed treatment for compartment syndrome range from nerve palsy to muscle necrosis. Hence, prophylactic fasciotomy, defined as decompression of increased compartment pressure before the onset of related symptoms and signs, is preferable to therapeutic fasciotomy done after the development of compartment syndrome. Widely accepted indications for prophylactic fasciotomy as an adjunct in the management of civilian lower extremity arterial injury include combined arterial and venous injury, prolonged shock, ischemia longer than 6 h, venous ligation, and extensive soft tissue and skeletal injury.\textsuperscript{17, 18, 55} The most compelling indication for prophylactic fasciotomy is in the setting of military war injuries, as postoperative monitoring and timely intervention may be suboptimal or not possible. In the recent report from the Iraq conflict, fasciotomy was performed in all patients with vascular trauma of the lower extremity.\textsuperscript{10}

Calf fasciotomy involves complete incision and decompression of the skin and investing fascia of the four compartments of the calf through two longitudinal leg incisions, laterally and medially. Although the use of fasciotomy clearly saves limbs, the fasciotomy wounds are at risk of infection and incur a significant increased morbidity.\textsuperscript{55} The length of hospital stay is expectedly longer for patients in whom fasciotomy was done.\textsuperscript{5, 55} We and others have adopted a liberal use, rather than prophylactic, of fasciotomy in the management of civilian lower extremity injury.\textsuperscript{5, 26, 36, 52} We had an overall fasciotomy rate of 59% in patients with distal femoral and popliteal arterial injuries.\textsuperscript{5} In 21% of these cases, fasciotomy was done before the arterial reconstruction for compartment syndrome diagnosed upon presentation. Thirty-five percent of the patients in our study had fasciotomy immediately after revascularization, and 3% between 6 to 12 h after the initial arterial reconstruction. We made the diagnosis of compartment syndrome based on clinical suspicion, symptoms and signs. Blunt trauma and associated skeletal injuries were found to be predictors of the need for a fasciotomy. In all saved limbs, fasciotomy wounds were eventually closed using a split-thickness skin graft.\textsuperscript{5}

**Endovascular therapy**

Endovascular therapy is emerging as an alternative to conventional surgery in the management of vascular trauma. Catheter-based intervention is increasingly being considered as the treatment of choice for areas that are not readily amenable to surgical intervention, such as internal iliac artery and thoracic aortic injuries (not discussed in this chapter). The basic principles used in open surgery are applied for endovascular therapy: resuscitation, antibiotics use, and heparinization if not contraindicated. In the lower extremity, endovascular treatment can be used to either exclude the injured area with an uncovered stent or covered stent-graft, or to directly obliterate an unessential injured vessel by embolizing materials that will cause thrombosis. Complete traumatic occlusion or transection of the injured artery is typically recognized at the time of the injury. An arteriovenous fistula usually presents late with signs of venous hypertension, non-healing ulcers, steal syndrome, or high output cardiac failure. On physical exam, a continuous murmur can be heard over an arteriovenous fistula site. A pseudoaneurysm can present acutely or delayed, and is usually felt as a pulsatile mass. The application of endovascular therapy for trauma patients was initially reserved for either stable patients or those with judged too ill to undergo operative intervention. As we have gained more experience and have better catheter-based technology, endovascular therapy can now be offered to a wider range of patients. Currently, with the availability of high-quality fluoroscopic imaging capability in the operating suite, we are able to provide full diagnostic service, endovascular therapy, and operative intervention, all in one setting. We prefer to use a fixed angiographic suite if available for the high-quality image but a mobile C-arm unit is adequate in most cases for digital subtraction.

The injured patient is prepared fully for possible surgical intervention even though the intention is to perform endovascular therapy. First, we perform a diagnostic selective arteriogram usually by accessing the contralateral femoral artery in a retrograde fashion. An abdominal aortogram is useful to show the aortic bifurcation, but not necessary if the injury is distal. The contralateral iliac artery (the side of the injured leg) is then selected from an up-and-over approach. Selective views of the injured leg are then obtained. When an endovascular intervention is judged suitable, it can then be carried out at the same time. A long sheath is then placed adjacent to the lesion to be treated from
the up-and-over approach. Alternatively, if the area to be treated is in the mid to distal superficial femoral artery, or more distal in the injured leg, an antegrade ipsilateral transfemoral approach can be used. The antegrade approach is usually necessary for deploying the covered stent-grafts. These usually are packed in a large profile and relatively short delivery catheter. A transbrachial artery (typically the left) can also be accessed if the groin approach is not possible. A detailed account of the basic various wires, catheters, sheaths, balloons, stents, stent-grafts, and coils is beyond the scope of this chapter, but readers are referred to available published texts on this subject.56

Endovascular embolization

Percutaneous transcatheter embolization (embolotherapy) was first used to stop retroperitoneal bleeding due to pelvic fractures. The use of transcatheter embolization has been expanded to treat bleeding from other sites, including branches of the profunda, or tributary arteries, selected traumatic arteriovenous fistulas, and pseudoaneurysms.39,41,44,57 Vessel obliteration can be achieved by transcatheter embolization of various particulate materials or liquids, such as coils, gelfoam, acrylic copolymer spheres, polyvinyl alcohol (PVA), tissue adhesive (isobutyl-2-cyanoacrylate; glue), non-adhesive liquid composed of ethylene vinyl alcohol copolymer dissolved in 8% dimethyl sulfoxide (Onyx), or less commonly autologous blood clot or fat particles. The ideal embolic agent would be non-clumping, highly radiopaque, non-toxic, non-allergenic, and inexpensive. Coils are the most common embolic materials for small pseudoaneurysms. Often, a combination of two different agents is used (e.g. coils and gelfoam) to achieve complete obliteration. For large pseudoaneurysms, the glue has been used alone or in combination with coils. Onyx is a newer biocompatible liquid embolic agent consisting of ethylene vinyl alcohol copolymer dissolved in 8% DMSO.39,58 The main advantage of Onyx over the glue is its ease of handling. PVA particles are not usually used for obliteration of traumatic pseudoaneurysm or arteriovenous fistula. PVA embolization is more frequently done for occluding the origin of large vessels, such as the uterine or gastroduodenal artery, when precision is not as critical.39,60 Surgical exposure of deep muscular branches of the profunda may be difficult, particularly in large patient or in presence of a large hematoma, and hence endovascular treatment is particularly beneficial in this setting.39,41,61 Similarly, embolization of an isolated tributary artery pseudoaneurysm would also avoid a potentially difficult surgical exposure.44 However, open surgical decompression of a large hematoma may still be required even after successful endovascular treatment.

Endovascular stenting

Endovascular stents have been described in the treatment of traumatic intimal injury and arterial dissection. Uncovered stents have been used more frequently in the aorto-iliac, subclavian, and carotid arteries than in the lower extremity arteries.62,63 A bare stent is not adequate to exclude complete vessel wall injury. The added synthetic graft coverage to the metal stent frame (stent-graft) provides effective exclusion of the injured vessel. Endovascular exclusion using a thoracic stent-graft or several abdominal aortic stent-graft cuffs is increasingly employed as a definitive treatment for traumatic transection of the thoracic aorta, with good short-term to immediate outcome.64-67 Recent reports have emerged showing successful treatment of traumatic femoral and iliac arteries using stent-grafts.68,69 The first successful stent-graft treatment of a traumatic femoral arteriovenous fistula was reported using a custom-made covered balloon-expand-
Figure 5.—Endovascular stent-graft repair of thrombosed superficial femoral artery due to gunshot wound. Using a retrograde contralateral transfemoral approach, a selective arteriogram of the injured right leg showed thrombosis of the superficial femoral artery (A). The occlusion was successfully crossed (B) and two overlapping covered stent-grafts sizes 8x50 mm and 8x100 mm (Viabahn, Gore Inc.) were deployed across the injured segment (C). Complete exclusion of the injured segment and normal distal flow was restored (D).

Figure 6.—Catheter-directed thrombectomy and thrombolysis of occluded popliteal artery stent-graft. This patient had sustained popliteal artery injury related to a motorcycle collision several months prior to his presentation to our center. At the time of the injury, an above-knee to below-knee interposition bypass graft (saphenous vein) was used to reconstruct arterial flow and orthopedic fixation was carried out to reduce and stabilize a posterior knee dislocation. The patient subsequently had further orthopedic manipulation for instability of the knee and an iatrogenic arterial injury occurred. The arterial injury was treated successfully with a covered stent-graft deployed across the proximal vein graft anastomosis. About a month later, he developed acute leg ischemia, again associated with orthopedic manipulation of the involved knee. Selective femoral arteriogram showed occlusion of the stent-graft (A) with distal reconstitution (B). We were able to cross the occlusion (C); the large arrow points to the occluded stent-graft inside a vein graft, and the small arrow shows the tip of the thrombectomy catheter (Angiojet,Possis) with the two radiopaque markers. Patency of the stent-graft was successfully restored following catheter-directed thrombolysis and mechanical thrombectomy (D). Courtesy of Drs. E. Peden and I. Mohiuddin, The Methodist Hospital, Houston, Texas, USA.

able stent-graft,70 but many commercially available stent-grafts have since been introduced in the United States and Europe. In general, these consist of a graft made either of polyester (polyethylene terephthalate) or PTFE covering a self-expandable or balloon-expandable stent that is premounted under a retractable sheath, on an over-the-wire delivery system (a brief list of the various sizes and length of the
stent-grafts and their respective delivery system is shown in Table III). Although balloon-expandable stent-grafts provide accurate sizing and localization, self-expanding stent-grafts are preferred as the first choice due to their flexibility and resistance to external forces in superficial locations like the groin or popliteal fossa. In the lower extremity, the shortest stent-graft possible is recommended to avoid risk of compression or kinking, and reduce the risk of covering the side branches.

The advantages of the endovascular approach to repairing are related to the avoidance of surgical exploration in traumatized field and its potential complications. The main concern regarding endovascular therapy is the unknown long-term patency of the endovascular prosthesis. Although the initial findings on the immediate patency are promising, we still await the long-term reports. The risk of distal embolization has also limited more widespread use of endovascular treatment for traumatic arterial occlusion. Our early experience with the use of stent-graft for patients with traumatic femoral artery occlusion has been promising (Figure 5). The risk of distal embolization can be reduced with the use of distal protection device. Distal embolization can usually be treated using endovascular methods, such as catheter-directed intra-arterial thrombolysis alone or in combination with percutaneous mechanical thrombectomy. We have also successfully treated stent-graft occlusion using catheter-directed thrombolysis and thrombectomy (Figure 6).

Conclusions

The management of lower extremity arterial trauma has continued to evolve over the years. A multidisciplinary approach with prompt revascularization is essential for limb-salvage, particularly for the mangled extremity. Early reports on endovascular therapy in vascular trauma are promising with good early and intermediate results in selected patients. Trauma patients will most benefit from centers that provide both excellent open surgical treatment and state-of-the-art endovascular therapy.

References


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