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Management of Lower Extremity Vascular Injuries: State of the Art

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Abstract Expeditious evidence-based management of lower extremity vascular injury is essential to reduce morbidity. Advances in management, largely due to military conflicts, continue to improve outcomes and limb salvage. Diagnosis via an accurate physical exam and adjuncts such as arterial pressure index or computed tomography angiography allow for rapid management. Expedited restoration of flow to major vessels, temporary intravascular shunting in the damage control setting or to restore perfusion before fixation of skeletal injuries, and early fasciotomy remain fundamentals of treatment. While endovascular management has increased significantly in highly selected populations, there are no prospective randomized controlled trials on its use in lower extremity vascular injury and it remains an experimental, off-label approach without any long-term outcomes data. Knowledge of various complications, including those requiring early return to the operating room, are critical to ensure satisfactory outcome.

Keywords Trauma · Vascular injury · Lower extremity vascular injury · Limb salvage · Fasciotomy · Endovascular management

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Introduction

Advances in the management of vascular injury to the lower extremity over the past 65 years continue to improve outcomes. Rapid diagnosis, expedited restoration of flow to major vessels, and early fasciotomy remain fundamentals of treatment. The standard of care shifted from ligation to repair in the Korean War, with techniques refined during the Vietnam War [1, 2]. Successful use of temporary intravascular shunts (TIVS) during Operations Enduring Freedom and Iraqi Freedom led to rapid adoption in the civilian sphere [3]. While endovascular management has increased significantly, there are no prospective randomized controlled trials on its use in lower extremity vascular injury and it remains an experimental, off-label approach [4•].

Epidemiology

Lower extremity injury is the primary diagnosis in over half of all trauma admissions [5••]. While only 1.6 % of trauma involves an arterial injury, nearly half of arterial injuries are in an extremity [6]. Of vascular trauma, 26 % involve the lower extremity, and of extremity vascular trauma, 40 % involve the lower extremity [6, 7•]. Cause of injury is split evenly between penetrating and blunt mechanisms [6]. Though mortality for lower extremity vascular trauma is relatively low—3 % for penetrating and 5 % for blunt trauma—concomitant vascular injury in the trauma patient increases morbidity, mortality, and resource utilization [8–10].

The superficial femoral artery (SFA) is the most commonly injured artery in penetrating trauma and the popliteal artery is the most commonly injured artery in blunt trauma [6]. Injury to a vessel can include: vasospasm, which can be limb-threatening when severe; intimal injury including a flap, dissection, or intramural hematoma; wall defect leading to pseudoaneurysm or hemorrhage; arteriovenous fistula (AVF); or partial or complete transection [4•]. Occlusion is involved in nearly 40 %, transection in 30 %, laceration in 20 %, and dissection in 10 % of arterial injuries [11]. Amputation rates in penetrating trauma are 5 %, while the rate in blunt trauma is closer to 20 % due to energy transfer causing greater damage to surrounding structures [12, 13]. When considering vascular injuries to the lower extremity, there is a simultaneous soft tissue injury in 30 %, skeletal injury in 25 % of patients, venous injury in 25 %, and nerve injury in 10 % of cases [8, 14]. When there is combined vascular and skeletal injury, risk of limb loss increases tenfold [15].

Diagnosis

Physical examination remains the mainstay of diagnosis. Missing a "hard" sign of vascular injury—a finding mandating surgical intervention—on examination is the most common cause of limb-threatening complications [15]. Hard signs of vascular injury include thrill, bruit, expanding or pulsatile hematoma, pulsatile hemorrhage, and distal ischemia including lack of pulses or a cold, pale extremity. "Soft" signs, suggestive enough of vascular injury to require further workup, include diminished pulses, history of significant hemorrhage, neurologic deficit, and injury proximity to a vessel. While proximity alone is a poor predictor of clinically significant injury, with an incidence of 0.6 %, a combination of signs increases the likelihood of vascular injury significantly [16]. In penetrating trauma with arterial injury requiring operative intervention, physical exam has a positive predictive value of 100 % and negative predictive value of 99 % [17]. The specificity of hard signs is not universally high. For example, distal pulses may be present in an arterial injury requiring intervention due to collateral circulation [5••]. Further, in the extremity with multiple levels of injury, physical examination alone has demonstrated a false positive rate of nearly 90 % [18]. As such, adjunctive studies are utilized liberally when a diagnosis of vascular injury is considered.

When hard signs of vascular injury are not present, an arterial pressure index (API), sometimes referred to as an injured extremity index, is obtained. A ratio of less than 0.9 has a 95 % sensitivity and 97 % specificity for a clinically significant arterial injury [19]. An abnormal API can sometimes resolve with resuscitation, euthermia, or fracture reduction, and thus can be repeated [20••]. However, a persistent API less than 0.9 warrants further investigation. Plain radiography may be indicated to rule out an associated fracture or dislocation. Computed tomography angiography (CTA) has replaced angiography as first-line imaging for vascular injuries, with a 95 % sensitivity, 90 % specificity, and a false negative of 1.3 % [21•, 22]. When API and CTA are combined, the sensitivity and specificity approaches 100 % [23]. Compared to CTA, angiography is more costly and time-consuming, adding at least 1 h to the workup [23, 24]. Current indications for angiography include the presence of a thrill or bruit, preserved distal flow despite a significant hematoma, shotgun injuries due to artifact, and multilevel fractures or crush injury because of the risk of multiple injuries to a vessel [15]. Angiography has a sensitivity of 96 %, specificity of 98 %, and a complication rate of 1 %, with 3 % of studies being technically inadequate or equivocal [25]. Of note, however, even with retained metallic fragments, multidetector CTA is indeterminate in only 1.6 % of cases [26]. Duplex ultrasonography, while heavily utilized in nontraumatic vascular lesions, is of limited use in trauma. When readily available and performed by a certified technician or vascular surgeon, sensitivity is 95 % and specificity is 98 % [27]. However, such reliability has been difficult to replicate, with later studies reporting sensitivity as low as 50 % [28]. Current practice reflects this, as ultrasonography is used for diagnosis of vascular injury only 3 % of the time [7•]. Guidelines state that its use in trauma is not well-defined [21•].

Principles of Management

When a vascular injury to the lower extremity has been identified, principles of management are similar regardless of the vessel injured. Documentation of an initial neurovascular exam is critical, particularly in the multiply-injured patient with life-threatening injuries that delay management of the extremity injury. Frequent neurovascular examinations are performed in both the non-operative and post operative setting.

Tourniquets are indicated for lethal hemorrhage unable to be controlled by direct pressure [29]. When applied in the field before the onset of shock, mortality is 10 % [30]. When applied in the emergency department, mortality rises to 25 % [30]. If a tourniquet is applied after onset of shock, regardless of where it is applied, mortality rises to 90 % [30]. The overall complication rate of properly applied tourniquets is 1.7 %, with the majority consisting of temporary neurological deficits [30]. Every effort should be made to minimize tourniquet time in order to mitigate morbidity.

When restoration of flow occurs within 6 h of injury, the limb preservation rate is 87 % [31]. However, when revascularization occurs 8 h after injury, the limb preservation rate drops to 20 % [5••]. As such, in the patient with combined vascular and skeletal injuries, restoration of perfusion takes precedence over fixation [32].

Nonoperative Management

Non-operative management (NOM) involves neurovascular examinations in a monitored setting that is capable of frequent checks. Repeat imaging in 3–5 days is performed if needed. Indications for NOM include low-velocity injuries causing less than 5 mm wall disruption with intact distal circulation and no active hemorrhage [33].

Vasospasm usually resolves in 6–8 h [4•]. However, when limb-threatening, intra-arterial papaverine infusion can be of use [34]. Asymptomatic non-occlusive lesions can be managed non-operatively with a 99 % success rate [21•, 35]. For non-occlusive intimal tears and flaps without active hemorrhage or distal ischemia, NOM is successful in over 90 % of cases [35, 36]. Patients should return for serial surveillance examination and imaging, regardless. Those requiring operative intervention based on surveillance do not experience additional morbidity [36, 37]. Small pseudoaneurysms may be considered for NOM but require close imaging follow-up [15, 33]. Small AVFs will always require procedural intervention and NOM is not recommended [15]. Regardless of injury pattern, all vessels undergoing NOM require surveillance imaging.

Surgical Management

The operating table is prepared for anticipated angiography or orthopedic procedures with fluoroscopy. Patients are placed supine on the operating table. The entire injured extremity, the lower abdomen to allow for access to iliac vessels if necessary, and fasciotomy incisions, are included in the operative field. The contralateral limb is also included in the field for potential vein harvest and access to the femoral artery for possible angiography or bypass in complex proximal injuries. Any other sites of possible vein harvest should also be included in the field. A clinician's hand holding direct pressure over a vascular injury is prepped into the field. If a non-sterile tourniquet has been applied, a clinician applies direct pressure at the site of injury with his or her hand and the non-sterile tourniquet is removed. The limb, including the clinician's hand, is prepped into the field and a sterile tourniquet is applied.

Proximal and distal control is obtained before exposing the injury. This sometimes requires an incision distant from the injury. Silicone vessel loops are usually adequate for vascular control. Once the injury is fully exposed, flow is restored via TIVS in the damage control setting or definitive repair otherwise. Principles of surgical management include debridement of injured tissue, intraoperative systemic anticoagulation if not contraindicated, local flushing with heparin, a non-stenotic tension-free repair, completion angiography if definitive repair is undertaken, and adequate tissue coverage of the repair [4•, 21•].

In the hemodynamically unstable patient, damage control principles apply. Selective ligation can be considered if it would not threaten the limb [20••]. Otherwise, a TIVS should be inserted. Shunting has been shown to reduce the amputation rate by 50 % [31]. In the patient with multiple sites of life-threatening injury, two surgical teams are occasionally required to save both life and limb [34]. When TIVS are placed within 6 h of the injury and converted to definitive repair within 1 h, the limb salvage rate is 100 % and the shunt patency rate is 96 % [38]. Conversion to definitive repair may not always be accomplished so expeditiously. In such cases, anticoagulation is not required [39–41]. Given the lack of data to support anticoagulation and the risk of bleeding complications, expert opinion only supports selective use of anticoagulation for a particularly pressing indication such an initial shunt thrombosis or large distal clot burden [42]. Unfortunately, regardless of anticoagulation, infrapopliteal shunt patency ranges from 12 to 50 % [43, 44]. However, in one series, infrapopliteal shunt thrombosis did not deter limb salvage attempts nor change early limb viability [43]. In this situation, a Pruitt-Inahara shunt (LeMaitre Vascular, Burlington, MA) may be particularly useful given the side-port that allows continuous monitoring of arterial flow and pressure within the shunt as well as instillation of therapeutics [42, 45, 46]. Further, Inahara-Pruitt shunts accomplish occlusion via intraluminal balloons without the need for extraluminal fixation [42, 45]. Regardless of whether TIVS or definitive repair is performed, ischemia–reperfusion injury should be anticipated.

Once skeletal injuries have been fixed and the patient has been resuscitated, definitive repair is performed. The vessel is again debrided, as securing the TIVS damages the intima. Arteriorrhaphy can be performed if the less than 50 % of the vessel is injured [20••]. If greater than 50 % of the vessel is injured patch angioplasty with vein or synthetic material or end-to-end anastomosis is preferred if a non-stenotic, tension-free repair can be accomplished [12]. The end of the vessel should be spatulated if the diameter is less than 1 cm. Up to 3 cm can be gained by ligating collateral vessels to mobilize the ends of the artery [4•]. However, the geniculate arteries should be ligated with caution, as they are important collateral circulation to the leg if the SFA develops atherosclerosis [4•].

As is often the case, when a tension-free end-to-end anastomosis cannot be accomplished, an interposition graft is appropriate. Ideally, the contralateral greater saphenous vein (GSV) is harvested [20••]. However, when not available, use of the ipsilateral GSV is an alternative with higher but still acceptable rates of postoperative venous hypertension [8]. The lesser saphenous, cephalic, and basilic veins are alternative autologous vein grafts (AVGs) though they can sometimes be cumbersome to harvest [15]. In such cases or when there are multiple mangled extremities, an expanded polytetrafluoroethylene (ePTFE) graft is an option. In the proximal vessels, PTFE has similar patency and infection rates to AVGs [47, 48]. Further, PTFE has acceptable outcomes when used in a contaminated field [12, 49–52]. Of note, in military data supporting the use of ePTFE, its use was short-term, with most patients undergoing definitive repair with autologous vein once stabilized and transferred [47]. PTFE patency rates decrease significantly below a diameter of 6 mm and should be avoided in the popliteal artery or below [4•, 48, 50]. There are few studies examining long-term outcomes of PTFE interposition grafts in lower extremity trauma. One study found an 8-year complication rate of nearly 80 % compared to 30 % for AVGs in the same cohort [53•]. It is possible that a heparin-bonded ePTFE, with a 4-year patency rate of 70 %, will prove to be comparable to AVGs, but it has not yet been studied in the trauma population [54]. Currently, AVGs are the preferred conduit for definitive repair, with the understanding that ePTFE is an acceptable alternative in the severely injured patient. Proximal and distal balloon thrombectomy is performed before completing the repair if back-bleeding from the vessel is less than satisfactory or if imaging demonstrates a filling defect.

Regardless of conduit used, it is essential to maintain adequate tissue coverage of vascular anastomoses. This occasionally requires the involvement of a plastic surgeon to assist with a tissue flap. It is prudent to utilize a multidisciplinary approach before attempting definitive repair. When adequate tissue coverage cannot be achieved, for example, an extra-anatomic bypass can be created [55].

Fasciotomy is a mainstay of limb salvage and preserved limb function in the injured patient. Early fasciotomy, during the initial operation or shortly after, reduces the complication and amputation rate fourfold [56•]. Failure to perform an adequate fasciotomy at the appropriate time is the most common cause of preventable limb loss [15]. The anterior compartment of the leg is the most commonly missed compartment, leading to foot drop [20••]. To avoid mistaking the lateral compartment as the anterior compartment, the surgeon should identify the anterior tibial neurovascular bundle within the anterior compartment above the intermuscular septum after making the lateral incision. While not prospectively studied, predictors of requiring fasciotomy include: skeletal injury, vein or nerve injury, massive transfusion, and multiple arterial injures [57]. Regardless, fasciotomy should be performed for compartment syndrome, delayed revascularization, major vein ligation, and at surgeon discretion [15].

Endovascular Management

Since the turn of the century, there has been a fourfold increase in the use of endovascular procedures in vascular trauma with a 30-fold increase in the use of stent-grafts in particular [58]. In the past decade, endovascular repair has been used in 4–7 % of lower extremity trauma [59•, 60•]. Despite patients undergoing endovascular procedures having a higher Injury Severity Score and more comorbidities, the complication rate, length of stay, and mortality is lower [59•]. However, all data are retrospective and subject to selection bias. There are no data to support routine use of endovascular management of lower extremity vascular injury [21•].

Current indications include branch vessel hemorrhage, acute pseudoaneurysm, AVF, or balloon occlusion for proximal control [61, 62]. The only absolute contraindication is an inability to pass a wire. Relative contraindications include hemodynamic instability, uncontrolled hemorrhage, the need to stent over a joint, or stenting in a setting where anticoagulation will be contraindicated. A hybrid operating room is not required for successful use of endovascular therapy. A C-arm fluoroscope with digital subtraction, lead aprons, and the necessary endovascular tools are the only equipment required. Far more important is the preoperative planning and ensuring well-practiced and understood protocols are in place.

Embolization has been successfully used in hemorrhage from profunda femoris and shank arteries as well as small pseudoaneurysms and AVFs in nonessential vessels [21•, 62]. When flaps are occlusive, uncovered, self-expanding stents have been utilized [63]. While stent-grafts used for femoral pseudoaneursyms or AVFs have demonstrated a 100 % success rate, 86–100 % patency at 12 months, and a 0 % complication rate, data are based on three series of 3, 5, and 11 patients, respectively [62, 64]. Even with limited data, it is clear that stent-grafts have a lower patency rate than AVGs [62].

Specific Vessels

While fundamental principles of management of vascular injury remain consistent throughout the lower extremity, specific vessels warrant attention. However, due to the unique approach required for the treatment of junctional lower extremity vascular, first widely recognized in conflicts in Afghanistan and Iraq in the 2000s, their management is beyond the scope of this review [20••].

Femoral

Clinical signs are present in nearly all patients with a femoral artery injury [65]. However, a clinically significant profunda femoris artery injury can present with an API greater than 0.9, so a high index of suspicion based on history and location of injury is essential. Nerve injury is present in 10 % of cases and mortality is also 10 % [65]. The common femoral artery and SFA should be repaired. While repair of the profunda femoris artery is preferable if technically feasible and the patient's condition allows for it, it may be ligated or embolized if necessary. Proximal control in femoral artery injuries may require division of the inguinal ligament or a retroperitoneal or transperitoneal approach to the external iliac artery or even distal aorta. During dissection, care should be taken to avoid the iliac and femoral circumflex veins.

Popliteal

Given its location near the knee, popliteal artery injuries are unique. Approximately 60 % of popliteal artery injuries are due to blunt trauma [8]. Eighty-five percent of blunt popliteal artery injuries and 40 % of penetrating injuries are associated with a fracture or dislocation [8]. Twenty-five percent of posterior knee dislocations also have a concomitant popliteal artery occlusion and thus always warrant CTA [15]. Twelve percent of blunt popliteal artery injuries and 35 % of penetrating injuries are associated with a popliteal vein injury [8]. Fifteen percent of popliteal artery injuries are associated with nerve injury [66]. Of all lower extremity artery injuries, popliteal injuries have the highest rates of amputation, with up to 15–20 % of blunt popliteal artery injury eventually requiring amputation [5••, 67]. Clinical signs are present in most patients and nearly all patients who have experience blunt trauma [8, 68]. Pulse exam alone has a sensitivity of 79 % and hard signs of vascular injury are present in 67 % of patients [5••, 69]. Systemic anticoagulation is critical upon identification of the injury and intraoperatively when not contraindicated, as it reduces amputation rate from 30 % to less than 10 % by preventing small vessel thrombosis that cannot be addressed by flushing the popliteal artery with local anticoagulation during repair [68]. Intraoperative use of local anticoagulation should be used regardless. A two-incision medial approach is usually sufficient, though the pes anserinus can be divided or the incisions connected for further exposure. Vein should be used as graft material [70].

Shank

Two-thirds of patients with shank artery injury have experienced blunt trauma [71]. Thirty-three percent of penetrating and 97 % of blunt injuries are associated with fracture and 20 % of penetrating and 50 % of blunt injuries are associated with nerve injury [72]. The amputation rate in penetrating trauma is 8 % but jumps to 25 % in blunt trauma [71]. Importantly, 33 % of penetrating and 67 % of blunt vascular injuries are associated with other ipsilateral infrapopliteal artery injuries [73]. Single-vessel runoff is adequate to perfuse the leg and foot [74, 75]. However, recent retrospective data demonstrate that blunt injuries isolated to the anterior tibial artery have a fourfold increased amputation rate when compared to posterior tibial and peroneal injuries [71]. Further study is needed to delineate the role of mechanism and energy transfer on this observation.

Venous

Any vein can be ligated if necessary. Further, repair of venous injuries should only be attempted after restoration of flow to the extremity. Ligation of the popliteal, superficial femoral, or common femoral veins mandates intensive postoperative monitoring for evidence of impending compartment syndrome by experienced personnel. If this is not available, prophylactic fasciotomy is required. Elevation of the extremity and gentle compression with elastic bandages may limit swelling in the early postoperative period. Excluding femoral veins, while repair reduces transient edema by 50 %, interestingly, there is no long-term difference in edema between ligation and repair [76–79]. Permanent clinically significant edema occurs in 2 % of cases [76, 78]. When repair is attempted, the occlusion rate at 72 h is 45 % but drops to 12 % at 6 weeks due to recanalization [80]. At a mean follow-up of 6 years, patency rates are 100, 78, and 60 %, and 0 % for common femoral, femoral, popliteal, and infrapopliteal vein repairs, respectively [81]. Nevertheless, the rates of pulmonary embolism are similar whether the vein is repaired or ligated [82•, 83]. When repairing a vein, lateral venorrhaphy should be attempted if it does not decrease the circumference of the vein by half. Patch venoplasty, tension-free end-to-end anastomosis, or an interposition graft can be considered when venorrhaphy is not feasible. If TIVS is used for a proximal vein or a proximal confluence, systemic heparin is required to prevent shunt thrombosis [20••]. It is preferable to use a large diameter ePTFE graft over a panel or spiral vein graft created over a large-bore chest tube given the cumbersome technical nature of the latter [4•, 84]. Fasciotomy should always be considered with major vein ligation [15].

Postoperative Management

At the completion of the operation, a vascular examination should be performed. Doppler examination is a strongly recommended adjunct both intra- and postoperatively. In the hemodynamically stable patient, completion angiography can also be performed, particularly if there was a delay in diagnosis or treatment, there are no palpable pulses, a complex repair was performed, or at surgeon discretion

[4•]. Occlusion of distal vessels should be treated with balloon embolectomy, particularly in blunt trauma where shearing forces may disrupt collateral flow [4•].

Frequent neurovascular checks in a monitored setting are mandatory as a 5–10 % reoperation rate is expected [15]. Technical failure such as kinking or undue tension account for the majority of early occlusion [85]. Other causes of early occlusion include intimal flaps, platelet thrombus, and missed compartment syndrome [85]. In patients who do not undergo a fasciotomy at initial operation, serial assessment should include a clinical examination for compartment syndrome with or without direct compartment pressure measurements [4•, 86].

Aspirin should be used for at least 3 months, and as long as possible if feasible, for all patients with an arterial anastomosis, though this is based only on Level 5 evidence, expert opinion [4•, 87••]. There is a paucity of data on antithrombotic agents after repair of vein injury. Aspirin should be administered for at least 3 months or as long as feasible, and patients with an anastomosis should also receive at least 3 months of therapeutic anticoagulation. Postoperative use of continuous passive motion devices have been shown to reduce venous hypertension symptoms and prevent deep vein thrombosis after venous repair [88].

Early complications include infection, exsanguination, missed or underestimated injury, and compartment syndrome [85]. Even with adequate repair, patients can suffer poor functional outcome, neuralgia, and stigmata of venous hypertension [85]. Chronic complications include pseudoaneurysm with its concomitant risk of compression, erosion, or emboli when large [89]. AVFs can also develop, with significant fistulae leading to tenderness, edema, steal syndrome, and even congestive heart failure [89]. In patients with neurologic deficit, nerve conduction studies can be performed within 6 weeks in order to plan for delayed repair with a nerve graft, usually taken from the sural nerve [5••]. Physical examination and imaging surveillance at 1, 3, 6, 12, and 18 months is a cost-effective way to interrogate all arterial repairs and preserve limb function [90]. Yearly surveillance should continue afterward.

Conclusion

While vascular injury of the lower extremity is relatively uncommon, expeditious evidence-based management is essential to reduce morbidity. Advances in therapy, largely due to recent military conflicts, continue to improve outcomes and limb salvage. Fundamentals of care continue to be an accurate and thorough physical exam, use of adjuncts such as API and CTA to aid in diagnosis, rapid restoration of flow including using TIVS in the damage control setting or to restore perfusion before fixation of skeletal injuries, liberal and early use of fasciotomy, and after resuscitation, definitive repair with completion interrogation of the repair. While endovascular approaches are exponentially increasing in highly selected patient populations, its use remains to be supported by robust data and long-term outcomes data are lacking. Knowledge of various complications, including those requiring early return to the operating room, are critical to ensure satisfactory outcome.

Compliance with Ethics Guidelines

Conflict of Interest Drs. Rattan, Jones, and Namias declare no conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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