Evaluation of Experience with Lower Extremity Arterial Injuries at an Urban Trauma Center

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Int J Angiol 2018;27:29–34.

Abstract

Lower extremity arterial injuries (LEAIs) can be complicated injuries resulting in limb loss and death. Patients with LEAI often have multiple injuries increasing the risk for morbidity and mortality. We sought to evaluate the incidence and management of LEAI and to define associations between injuries and outcomes. We performed a retrospective review of LEAI at an urban level-1 trauma center from April 2005 to April 2015. Chi-square tests were used to compare independent groups with respect to mortality and amputation. Means were compared between independent groups using two-sample *t*-tests. From April 2005 to April 2015, 208 arterial injuries occurred in 163 patients. The majority (80.4%) suffered concomitant lower extremity injuries with 35.6% suffering systemic injuries. Surgical intervention was required for 72.1% of injuries. Amputation rate was 14.7%. Mortality rate was 8.0%. Data from 2010 to 2015 were more specifically analyzed. Injury severity score (ISS) was higher with fatalities (37 ± 13.16 vs. 11.8 ± 8.51 , $p < 0.0001$) and in patients requiring an amputation (25.4 ± 15.32 compared with 11.6 ± 9.05 , $p = 0.0015$). Popliteal artery injury was most likely to require an amputation (odds ratio [OR] = 2.9, $p = 0.04$). Mortality was more likely when systemic injuries were present (OR = 18.1, $p = 0.0005$). The majority of patients with arterial injuries require surgical management, most often with open surgical techniques. Arterial injuries associated with systemic injuries, blunt injury mechanisms, and higher ISS are at a significantly increased risk of mortality.

Keywords

- ▶ trauma
- ▶ lower extremity
- ▶ arterial injury
- ▶ fasciotomy
- ▶ amputation
- ▶ mortality
- ▶ injury severity score

Lower extremity arterial injuries (LEAIs) can lead to devastating consequences with a mortality rate of 1.5 to 10% and limb loss rate approaching 16%.^{1–3} The initial evaluation and management of LEAI has evolved over time from the routine use of preoperative angiogram to the now commonly used computed tomography angiography (CTA) used to correlate physical exam findings leading to a diagnosis and establishing a surgical plan.^{4–7} Multispecialty evaluation and management of LEAI is essential for maximizing positive outcomes in these often complex injuries.⁸ The goal of this

retrospective review was to evaluate our experience with LEAI and to assess the variables associated with mortality and limb loss, while describing the incidence of specific arterial injuries.

Methods

A retrospective chart review with Institutional Review Board approval was conducted at an urban level I trauma center in Columbus, OH evaluating the incidence and management of

lower extremity arterial trauma. The trauma database was searched to identify patients aged 16 year and older who were admitted to the trauma service with a diagnosis of a lower extremity vascular injury between April 2010 and April 2015; the variables listed later were analyzed in detail. Summary data from a previous review of the same population from April 2005 to April 2010 were included to build a 10-year population-based survey of injuries. The data from 2010 to 2015 were further analyzed to evaluate the relationships between the specific injury and mechanism of injury, treatment, and outcome.

Medical records were reviewed to record and analyze the following variables: age, gender, race, mechanism of injury, type of injury, associated lower extremity injuries, concomitant systemic injuries, surgical procedures and interventions, mortality, length of stay, and discharge disposition. Injury severity scores (ISSs) and abbreviated injury scale scores were also recorded. Descriptive statistics including mean, median, standard deviation, frequency, and percentage were used to describe numerical data. Chi-square tests were used to compare independent groups with respect to dichotomous outcomes such as mortality and amputation. Means were compared between independent groups using two-sample *t*-tests.

All subjects presented as a trauma alert with obvious signs of lower extremity injury and were evaluated according to standard Advanced Trauma Life Support and institutional protocols guided by clinical presentation.

Results

During the 10-year period from April 2005 to April 2015, there were a total of 33,453 admissions to the trauma service with 163 patients admitted with 208 LEAIs. Overall, the incidence of LEAI was 0.5%. Gender distribution was 142 male patients (87.1%) and 21 female patients (12.9%). Eighty-seven (53.37%) patients were classified as white. Thirty-four (20.9%) of the 163 patients suffered more than one arterial injury. Injuries were classified into type of arterial injury with 98 (47.1%) occlusions, 58 (27.9%) transections, 31 (14.9%) lacerations, and 21 (10.1%) dissections. The majority of patients (80.4%) suffered concomitant lower extremity injuries in addition to the arterial injury but only 58 (35.6%) patients suffered other systemic injuries (abdominal, thoracic, upper extremity, head, and neck) as outlined in ►Table 1. Mortality and amputation rate are outlined in ►Table 2. Mortality was suffered in 13 (8.0%) patients and amputations were performed for 24 (14.7%) patients. Of the 24 patients requiring amputation, 13 were performed as primary intervention for a nonsalvageable limb and 13 were performed as secondary intervention after failed attempts to save the limb. Two patients in the secondary amputation group required proximal conversion of a primary below knee amputation to an above knee amputation totaling 26 amputations performed for 24 patients. The distribution of arterial injuries is outlined in ►Table 3 with the most common arteries injured being the superficial femoral (SFA) and the tibial arteries, but injuries to the common femoral (CFA),

Table 1 Associated concomitant lower extremity injuries over 10 years^a

Concomitant lower extremity injuries	131 (80.4%)
Bony injury	94 (57.7%)
Venous injury	36 (22.1%)
Ligament/tendon injury	23 (14.1%)
Compartment syndrome	29 (17.8%)
Nerve injury	23 (14.1%)
Multiple lower extremity injuries ^a	33 (20.2%)
Systemic injuries	58 (35.6%)

^aTotal 163 patients.

Table 2 Mortality and amputation rate over 10 years^a

Mortality	13 (8.0%)
Amputation	24 (14.7%)
Amputation as primary intervention	13 (8.0%)
Amputation as secondary intervention ^b	13 (8.0%)

^aTotal 163 patients.

^bRelates to patients who initially underwent limb salvage attempts but subsequently required an amputation. Two patients in the primary intervention group required a revision from a below knee amputation to an above knee amputation and were counted as two amputations for each patient.

profunda femoris, popliteal, anterior tibial, posterior tibial, and peroneal arteries also being documented. The mechanism of injury (blunt or penetrating) is demonstrated in ►Table 4. Most arterial injuries were caused by a penetrating mechanism (55.3%) with the majority of patients suffering an injury from a gunshot wound (50.3%). Most injuries required surgical management as detailed in ►Table 5.

The data from April 2010 to April 2015 were analyzed in further detail. This period of time included 97 patients with 132 arterial injuries. The overall ISS was 14.2 ± 11.71 . The nine patients who suffered mortality had a higher ISS

Table 3 Distribution of arterial injuries over 10 years

Total injuries	208
Multiple injuries	34 (20.9%) ^a
Common femoral artery	10 (4.8%)
Profunda femoris artery	9 (4.3%)
Superficial femoral artery	53 (25.5%)
Popliteal artery	41 (19.7%)
Tibial artery	95 (45.7%)
Anterior tibial artery	36 (17.3%)
Posterior tibial artery	42 (20.2%)
Peroneal artery	17 (8.2%)

^aPercentage of patients with multiple injuries of the total 163 patients.

Table 4 Mechanism of arterial injury over 10 years

Arterial injury mechanism in 208 total arterial injuries	
Penetrating	115 (55.3%)
Blunt	93 (44.7%)
Mechanism of LEAI in 163 individual patients	
Penetrating	94 (57.7%)
Gunshot wound	82 (50.3%)
Stab/laceration	12 (7.4%)
Blunt	69 (42.3%)
Motorcycle accident	16 (9.8%)
Motor vehicle accident	17 (10.4%)
Other	36 (22.1%)

Abbreviation: LEAI, lower extremity arterial injury.

Table 5 Treatment strategy of 208 arterial injuries over 10 years

Surgical therapy	150 (72.1%)
Medical therapy	58 (27.9%)
Bypass grafts	58 (27.9%)
Vein bypass graft	52 (25.0%)
Prosthetic bypass graft	6 (2.9%)
Coil embolization	6 (2.9%)
Endograft	7 (3.4%)
Ligation	19 (9.1%)
Primary repair	19 (9.1%)
Thrombectomy	22 (10.6%)
Amputation	24 (11.5%)
Fasciotomy	47 (22.6%)

compared with patients who survived (37 ± 13.16 vs. 11.8 ± 8.51 , $p < 0.0001$). The ISS was similarly elevated in patients requiring an amputation compared with patients who did not require an amputation (25.4 ± 15.32 compared with 11.6 ± 9.05 , $p = 0.0015$). The ISS in relation to amputation resulted in an odds ratio (OR) of 1.10 (95% confidence interval: 1.04, 1.15). Amputations were most likely to be required for injuries to the popliteal artery (OR = 2.9, $p = 0.04$). The relationship of each individual artery injured compared with all other arterial injuries resulting in amputation or mortality is outlined in **Table 6**. Mortality was significantly increased in patients who suffered blunt injuries compared with penetrating injuries (15.9% mortality with blunt injuries compared with 3.8% mortality with penetrating injuries, OR = 4.8, $p = 0.04$). Mortality was also significantly more likely in patients who suffered systemic injuries. Thirty-five patients suffered systemic injuries and 8 died (22.9%) compared with only one mortality in 62 patients (1.6%) without systemic injuries (OR = 18.1, $p < 0.0005$). Fasciotomy was most likely to be required for injuries to the crural vessels (OR = 4.6, $p = 0.008$).

Table 6 Comparison of specific artery injured to all arterial injuries resulting in amputation and mortality (5-year period)

Artery injured	Amputation due to artery injured (%)	Amputation due to all other arterial injuries (%)	p-Value (chi-square)
CFA	2/6 (33%)	16/91 (17.6%)	0.34
PFA	1/4 (25%)	17/93 (18.3%)	0.74
SFA	6/29 (20.7%)	12/68 (17.7%)	0.72
Popliteal	8/25 (32%)	10/72 (13.9%)	0.04
Tibial	7/49 (14.3%)	11/48 (22.9%)	0.27
AT	6/26 (23.1%)	12/71 (16.9%)	0.49
PT	5/27 (18.5%)	13/70 (18.6%)	0.99
Peroneal	3/15 (20%)	15/82 (18.3%)	0.88
Other	0/5 (0%)	18/92 (19.6%)	0.27
Artery injured	Mortality due to artery injured (%)	Mortality due to all other arterial injuries (%)	p-Value (chi-square)
CFA	1/6 (16.7%)	8/91 (8.8%)	0.52
PFA	0/4 (0%)	9/93 (9.7%)	0.51
SFA	5/29 (17.2%)	4/68 (5.9%)	0.078
Popliteal	1/25 (4%)	8/72 (11.1%)	0.29
Tibial	2/49 (4.1%)	7/48 (14.6%)	0.07
AT	2/26 (7.7%)	7/71 (9.9%)	0.74
PT	1/27 (3.7%)	8/70 (11.4%)	0.24
Peroneal	2/15 (13.3%)	7/82 (8.5%)	0.56
Other	2/5 (40%)	7/92 (7.6%)	0.015

Abbreviations: AT, anterior tibial; CFA, common femoral artery; PFA, profunda femoris artery; PT, posterior tibial; SFA, superficial femoral artery.

Note: Other is not specified in the chart to which artery injured.

Treatment strategies from April 2010 to April 2015 were also analyzed in detail. A surgical bypass was required in 32 (21.21%) patients. Autologous vein was used as a bypass conduit in 28 (87.5%) patients with only 4 (12.5%) bypasses utilizing a prosthetic conduit. Vessels below the knee were statistically more likely to have an autologous vein (OR = 4.7, $p < 0.001$) compared with the remaining injuries repaired with autologous veins. A covered stent was most likely to be used in the popliteal artery (OR = 13.5, $p < 0.004$) and primary repair was most likely to be used for the CFA (OR = 10.9, $p < 0.004$). A thrombectomy was required for injuries in all the arterial regions but was most

likely to be required for injuries involving the CFA (OR = 5.1, $p < 0.04$) and popliteal artery (OR = 2.9, $p < 0.04$).

Discussion

Diagnosis

LEAI diagnosis can be obvious when hard signs of vascular injury are present (pulsatile external bleeding, loss of distal pulses, overt ischemia, rapidly expanding hematoma, or a palpable thrill/audible bruit⁹) and these patients should be brought immediately to the operating room for surgical exploration and repair.^{10–12} It is our practice to operate immediately on patients with hard signs of vascular injury. For patients with occult injuries or soft signs of vascular injury (diminished distal pulse, history of significant hemorrhage, neurological deficit, and proximity of wound to named vessel⁹), we obtain an ankle-brachial index (ABI) in the trauma bay and exercise liberal use of CTA of the lower extremity to identify and rule-out LEAI. For patients without hard signs of vascular injury, physical exam, and noninvasive studies, such as ABI and duplex ultrasonography, can be used to reliably screen patients with extremity trauma for occult arterial injuries.^{5,13} When physical exam is equivocal, CTA is a readily available modality that has essentially replaced conventional angiography.^{5,6,13} CTA has been repeatedly demonstrated to have a sensitivity and specificity equivalent to conventional angiography and may be used as the primary imaging modality to diagnose occult LEAI.^{4,14–16} In addition, having initial CT scans of the entire body in the multiply injured patient allows the vascular surgeon to safely administer heparin during the repair as intracranial and intra-abdominal hemorrhages are able to be reliably excluded.

Distribution of Injuries and Associated Injuries

All lower extremity arteries are vulnerable to injury with lower extremity trauma. Blunt force trauma would be expected to cause multiple arterial injuries compared with isolated penetrating trauma. In addition, concomitant lower extremity nonvascular injuries are likely to be present with arterial trauma.^{1–3,10,11,17} The distribution of arterial injuries in our review was previously described in ► **Table 3**. In our experience, the most commonly injured arteries were the SFA and popliteal artery which is similar to reports by Peck et al and Menzoian et al.^{3,11} We also encountered a significant number of crural artery injuries which has been previously reported to be the most common arteries injured in blunt lower extremity trauma.¹⁷ Of patients reviewed here, 131 (80.4%) had associated lower extremity nonvascular injuries, the majority of which (57.7%) are bony injuries. Orthopaedic fixation is typically performed after vascular repair. The exception being profoundly deformed extremities that, when reduced, would alter the vascular repair. These injuries are best treated with external reduction and fixation prior to vascular repair.¹⁰ Comanagement among the vascular, orthopaedic, plastic, and trauma surgery teams leads to the best outcomes in patients with LEAI and associated nonvascular injuries.^{3,8,11,18}

Medical Management of LEAI

Not every LEAI requires surgical management. Clinically, occult injuries found incidentally on trauma work-up imaging may safely undergo nonoperative management.^{19,20} Criteria for nonoperative management include: (1) nonflow limiting intimal tears, (2) intact distal perfusion, (3) lack of active hemorrhage or extravasation on imaging, and (4) lack of hard signs of vascular injury.^{8,13,19,20} In our experience, we were able to successfully manage 27.9% of vascular injuries medically. It is our practice to manage injuries fitting the earlier criteria with antiplatelet therapy with either aspirin or clopidogrel with repeat imaging in 4 to 6 weeks. This series supports the initial use of nonoperative management fitting the criteria described for clinically insignificant injuries as none of the patients treated medically was identified as requiring conversion to operative therapy during the hospital stay.

Fasciotomy

LEAI is a well-known risk factor for compartment syndrome, which subsequently requires fasciotomy.^{7,11,18,21} Routine measurements of compartment pressures are not performed at our facility and the decision to proceed with fasciotomy is based on clinical findings. Early fasciotomy is liberally performed at our institution for patients with ischemic times more than 6 hours and for patients who clinically present with severe ischemia and tense compartments. In this series, we had a moderate rate of fasciotomy being required for 47 (22.6%) arterial injuries which is consistent with previous reports.^{2,7,8,21} Fasciotomy was performed most frequently for injuries involving the popliteal artery and crural vessels. In general, fasciotomy should be considered for patients with combined artery and vein injury; ischemic times more than 4 to 6 hours, complex fractures, compartment pressures exceeding 25 mm Hg, and clinically significant calf swelling or compartment tension.^{2,8,17,22} Fasciotomy wounds typically require long-term management with negative pressure wound therapy and coverage with tissue transfer and skin grafting that, at our institution, is performed by plastic surgery. Early fasciotomy for patients at risk for compartment syndrome likely improves long-term outcomes and should be liberally performed.^{7,8,10,11,18}

Amputation

Complex extremity trauma and trauma involving multiple systems in conjunction with an arterial injury are at significantly higher risk for limb loss and mortality compared with isolated arterial injuries.^{1,2,21} In this review, patients were more likely to require an amputation as ISS increased and for injuries involving the popliteal artery. Patients suffering injuries to multiple body systems and more severe injuries overall will have increased ISS. This may be used as a predictor for patients with LEAI who are more likely to suffer an amputation. The decision to amputate may be obvious with a mangled extremity; however, this is more often a difficult decision and must be made based on individual patient condition and multidisciplinary physician consensus.^{1,2,7,8,10,18,21} Additional injury characteristics predictive of limb loss are the

presence of multiple arterial injuries, multiple extremity fractures, and popliteal artery injury.^{1,2,21,23}

Hafez et al² described indications for primary amputation for the initial treatment as being: extremely mangled limbs, fixed skin staining, gangrene, and nonviable superficial posterior compartment plus one other compartment on fasciotomy. It must be remembered that a neurologically devastated limb on presentation will not be reversed with revascularization. Injuries secondary to crush mechanisms, ischemia times more than 6 hours, and compartment syndrome at presentation are at high risk for neurological devastation even with adequate revascularization. These patients should have adequate discussions preoperatively between multidisciplinary teams and the patient, when possible, about the likelihood of primary amputation.

Mortality

Mortality from isolated LEAI is often from exsanguination secondary to prehospital blood loss and inability to control bleeding at the time of presentation.¹ In our series, only one patient suffered mortality from an isolated lower extremity injury without systemic injuries. This patient suffered a gun shot wound (GSW) isolated to the right groin. Pulses were lost in the emergency department and a resuscitative thoracotomy was performed with return of spontaneous circulation. A reversed saphenous vein interposition graft was used to repair the SFA transection and the femoral vein was ligated. The only injury was from the GSW. The patient expired as a result of decompensated shock secondary to the large volume of blood loss from the SFA transection. The remaining mortalities in the series were associated with systemic injuries. As the ISS increased, so did the likelihood of mortality (ISS 37 ± 13.16 vs. 11.8 ± 8.51 , $p < 0.0001$) suggesting that systemic injuries causing physiologic derangements are more likely to cause death than exsanguination from the arterial injury. Patients who are more systemically and critically ill will have increased ISS and should be expected to be at increased risk for mortality. The overall mortality for this review was 8%, similar to other previous reports.^{8,17,24}

Efforts to reduce mortality involve improved management by prehospital personnel and damage control surgery. Treatment by prehospital personnel includes the principles of permissive hypotension, limiting crystalloid resuscitation, and the liberal use of tourniquets for control of injuries distal to the CFA. The use of tourniquets for control of LEAI has been shown by multiple studies to be safe and effective for both wartime and civilian injuries.^{1,25-27} Damage control vascular surgery involves the placement of temporary intravascular shunts to control bleeding, allowing for resuscitation in the intensive care unit and definitive repair once the patient has been physiologically stabilized.

Surgical Management

The choice of surgical management of LEAIs is based on two factors: (1) clinical stability of the patient and (2) the anatomical definitions of the injury. The hierarchy of priorities in LEAI should be limb over looks and life over limb. A successful arterial repair should not be jeopardized by the

fear of the appearance of a scar or fasciotomy wound and the patient should not undergo life-threatening surgery for the sake of the limb. Damage control surgery is routinely performed in trauma and the same principles apply to traumatic vascular surgery.²⁸

Rapid control of hemorrhage and prompt restoration of blood flow is paramount to successful revascularization in traumatic arterial injuries.^{8,11} For injuries requiring bypass procedures, we prioritize use of autologous veins. Of the total 132 patients, 32 (24.2%) required bypasses and 87.5% used vein as a conduit. We preferentially harvest the contralateral leg, assuming no traumatic injuries occurred to this limb, to facilitate the use of an undamaged vein. Synthetic polytetrafluoroethylene (PTFE) is an acceptable conduit though there is obvious concern with using synthetic material in an infected field. Martin et al⁷ have previously reported that PTFE is a suitable interposition graft, even in contaminated fields, and that PTFE and vein are equally effective for repair of femoral artery injuries as an interposition graft. However, PTFE is an unacceptable conduit in the popliteal region as there is a high rate of thrombosis. Autologous vein should be preferentially used for bypasses targeting outflow below the knee.

Endovascular therapy is especially advantageous for injuries resulting in traumatic pseudoaneurysms, arteriovenous malformations, bleeding side branches, and intimal injuries too extensive for medical management.^{4,8,12,29} In this review, nine patients (6.8%) underwent an endovascular procedure, with both coil embolization and stent graft placement being performed. In our experience, endovascular repair is best suited for patients who have soft signs of vascular injury with defects discovered during noninvasive imaging. An additional therapeutic adjunct commonly utilized at our institution is the hybrid vascular operating room. The role of intraoperative radiography and completion angiography has obvious impacts on vascular surgery. Performing revascularization of traumatic arterial injuries in a hybrid suite allows for both open and endovascular procedures to be performed simultaneously with advanced imaging and interventional capabilities allowing each injury to have a tailored repair.

Conclusion

This review represents a heterogeneous population at a community, urban, tertiary Level-1 trauma center evaluating different LEAIs and the subsequent management and outcomes. This patient population often suffers polytrauma and ISS was found to correlate as a predictor for both limb loss and mortality. Patients incurring systemic injuries and injuries caused by blunt mechanism were at increased risk for mortality and limb loss. In addition, injuries to the popliteal artery were at a significantly increased risk for requiring an amputation.

Strengths of this study include the heterogeneous makeup of traumatic mechanisms and arterial injuries making this patient population applicable to a wide range of populations. The initial trauma evaluation is based on protocol and as a

result, patients are rapidly triaged and diagnosed with injuries and appropriate specialties are involved early in the treatment plan. Limitations are those inherent with descriptive retrospective reviews as well as the lack of long-term follow-up of the patients included. In addition, detailed patient data from the early 5-year time period was unavailable for specific analysis and as such may only be used for population descriptive purposes. With the advent of electronic medical records, more detailed diagnostic and therapeutic protocols, and advancement in treatment techniques, it would be expected that future reviews be able to more specifically identify risk factors associated with individual injuries.

The successful outcomes for the patients, including the low amputation and mortality rate, are due in large part to the multidisciplinary approach to the injured patient. The initial trauma work-up allows for rapid diagnosis and early involvement of multiple specialists. As a result, the vascular surgeons are able to rapidly revascularize appropriate patients and the nonoperative injured patient is initially stabilized and revascularized as soon as physiologically possible.

Acknowledgments

Special thank you to data collection contributors Michael Messina and Alexander Malik.

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