




Management of lower extremity vascular injuries in pediatric trauma patients: 20-year experience at a level 1 trauma center

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ABSTRACT

Introduction Pediatric lower extremity vascular injuries (LEVI) are rare but can result in significant morbidity. We aimed to describe our experience with these injuries, including associated injury patterns, diagnostic and therapeutic challenges, and outcomes.

Methods This was a retrospective review at a single level 1 trauma center from January 2000 to December 2019. Patients less than 18 years of age with LEVI were included. Demographics, injury patterns, clinical status at presentation, and intensive care unit (ICU) and hospital length of stay (LOS) were collected. Surgical data were extracted from patient charts.

Results 4,929 pediatric trauma patients presented during the 20-year period, of which 53 patients (1.1%) sustained LEVI. The mean age of patients was 15 years (range 1–17 years), the majority were Black (68%), male (96%), and most injuries were from a gunshot wound (62%). The median Glasgow Coma Scale score was 15, and the median Injury Severity Score was 12. The most commonly injured arteries were the superficial femoral artery (28%) and popliteal artery (28%). Hard signs of vascular injury were observed in 72% of patients and 87% required operative exploration. There were 36 arterial injuries, 36% of which were repaired with a reverse saphenous vein graft and 36% were repaired with polytetrafluoroethylene graft. One patient required amputation. Median ICU LOS was three days and median hospital LOS was 15 days. There were four mortalities.

Conclusion Pediatric LEVIs are rare and can result in significant morbidity. Surgical principles for pediatric vascular injuries are similar to those applied to adults, and this subset of patients can be safely managed in a tertiary specialized center.

Level of evidence Level IV, retrospective study.

INTRODUCTION

Pediatric lower extremity vascular injuries (LEVI) are rare and can result in significant morbidity including limb loss, limb length discrepancy, growth and developmental complications, claudication, decreased perfusion, and poor quality of life.^{1,2} Early diagnosis is critical and, when indicated, timely revascularization can improve outcomes.³

Extremity arterial trauma in pediatric patients presents a unique set of challenges as children have smaller vessels and high rates of vasospasm, which can complicate management and obscure

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Pediatric lower extremity vascular injuries are rare and can result in significant morbidity; however, there is a relative lack of data on these injuries which makes developing management guidelines difficult.

WHAT THIS STUDY ADDS

⇒ This is one of the largest single-center studies on pediatric lower extremity vascular injuries. We found that surgical principles of vascular surgery are similar to those applied to an adult and these patients can be safely managed in a tertiary specialized center.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Continued efforts are necessary to improve follow-up care, assess long-term patency and overall morbidity, and develop management guidelines for these injuries.

the diagnosis.^{1–4} Additionally, pediatric patients have less total blood volume, exsanguinate earlier, and remain asymptomatic for longer, potentially leading to delays in diagnosis.¹ As these injuries are rare, management options for pediatric LEVI have largely been extrapolated from the experiences in adult trauma patients.⁵ Peripheral vascular trauma has been well studied in adults and management guidelines have been established; however, less data exist on these injuries in pediatric patients and most of the existing evidence comes from small, single-center retrospective studies.^{1,6–8}

Pediatric-specific management of these potentially devastating and disabling injuries has the potential to improve outcomes for these patients; however, the relative lack of data on these injuries makes developing management guidelines difficult. We aimed to describe our experience with these complex injuries, including associated injury patterns, diagnostic and therapeutic challenges, and outcomes.

METHODS

This was a retrospective review of pediatric trauma patients who presented to a single level 1 trauma center. The STROBE (Strengthening the Reporting of Observational Studies in Epidemiology)

guidelines were followed.⁹ All pediatric trauma patients who presented to our institution from January 2000 to December 2019 were screened for inclusion. Patients less than 18 years of age with LEVI or vasospasm of an artery in their lower extremity secondary to trauma were included in the study.

Demographics, traumatic mechanism, injury characteristics, clinical status at presentation, Injury Severity Score (ISS), Glasgow Coma Scale (GCS) score, and intensive care unit (ICU) and hospital length of stay (LOS) were collected. Shock was defined as a systolic blood pressure (SBP) $<[70+(2 \times \text{age in years})]$ mm Hg for patients up to 10 years and SBP <90 mm Hg for those over 10 years.^{6,10} Hard signs of vascular injury included pulsatile bleeding, expanding or pulsatile hematoma, bruit, thrill, absent distal pulse, and/or signs of distal limb ischemia including poikilothermia, paralysis, pallor, paresthesia, and pain. Surgical data including vessels injured, operative repair performed, associated complications, and outcomes were obtained from the patient charts. Additionally, discharge disposition, 30-day readmission, date the patient was last seen by anyone in our health system, if the patient was ever incarcerated after their injury (determined by whether or not they had a note from correctional health services), and if they presented with another violence-related injury.

LEVI consisted of vessels below the inguinal ligament, including arterial, venous, and/or combined injuries. Diagnostic studies of the lower extremity were routinely performed for bony fractures and a CT angiography (CTA) was performed at the discretion of the surgeon when a vascular injury was suspected without the presence of hard signs or an abnormal ankle-brachial index (<0.9) at presentation.

Categorical patient characteristics are presented using percentages and frequencies, while continuous measures are summarized using means with SDs or medians with IQRs where appropriate. Statistical analysis was performed using SPSS V.23.0 (SPSS Inc., Chicago, IL).

RESULTS

Demographic information

In total, 4,929 pediatric trauma patients presented during the 20-year period, of which 53 (1.1%) patients sustained a LEVI with 65 vessels injured. The mean age was 15 (3.1) years with a range of 1–17 years. The majority were male (96%) and Black (68%). Median ISS was 12 (9–19). Median SBP was 125 (112–142) mm Hg and 11% of patients presented in shock. Median GCS score was 15 with 13% of patients presenting with a GCS score less than or equal to 8. Median admission lab values consisted of a hematocrit of 35% (30–38%), pH of 7.37 (7.30–7.42), and a base deficit of -3 (-6 to -1) mEq/L. The majority of injuries resulted from a gunshot wound (62%). Finally, 38% had an associated fracture and 36% had additional injuries to the neck or torso (table 1).

Characteristics of vascular injuries

The most commonly injured arteries were the superficial femoral artery (28%) and popliteal artery (28%), with 28% of patients sustaining multiple LEVIs. Hard signs of vascular injury were observed in 72% of patients. CTA was ordered selectively for 19 (36%) patients. Most of them had soft signs of vascular injury; however, five (26%) had a pulseless lower extremity at the time of imaging. Of these, two initially had pulses that were subsequently lost and two underwent orthopedic reduction with a follow-up pulse examination. The last one had concern for a concomitant injury of a vessel in the chest so since he was

Table 1 Demographic information for pediatric lower extremity vascular injuries

Demographic information	N=53
Age, mean (SD)	15 (3.1)
0–5 years	1 (1.9%)
6–12 years	8 (15%)
≥13 years	42 (79%)
Gender	
Male	51 (96%)
Race	
Black	36 (68%)
White	14 (26%)
Hispanic	3 (5.7%)
Injury Severity Score, median (IQR)	12 (9–19)
Vital signs	
Systolic blood pressure, median (IQR)	125 (112–142)
Shock	6 (11%)
Glasgow Coma Scale, median (IQR)	15 (15–15)
GCS≤8	7 (13%)
Admission lab values, median (IQR)	
Hematocrit	35 (30–38)
pH	7.37 (7.30–7.42)
Base deficit	-3 (-6 to -1)
Mechanism	
Penetrating	
Gunshot wound	33 (62%)
Blunt	
Motor vehicle collision	5 (9.4%)
Pedestrian struck	4 (7.5%)
Bicyclist struck	3 (5.7%)
Motorcycle/moped collision	3 (5.7%)
Fall	2 (3.8%)
Other	2 (3.8%)
Scooter struck	1 (1.9%)
Associated injuries	
Neck/torso	19 (36%)
Fracture	20 (38%)
GCS, Glasgow Coma Scale.	

already getting a CT chest done, a CTA of the lower extremity was performed simultaneously. Arterial duplex was not used as an alternative to CTA for any patients; however, it was used intraoperatively as an adjunct for a few patients (table 2).

In total, 46 (87%) patients required operative intervention at presentation for their vascular injury. There were 36 arterial injuries, 36% of which were repaired with a reverse saphenous vein graft and 36% were repaired with polytetrafluoroethylene (PTFE) graft. The rest were repaired primarily (11%), ligated (14%), or repaired with Dacron graft (2.8%). Of those undergoing arterial repair, 21 received systemic heparinization intraoperatively, while only heparinized saline was used for six patients during the vessel repair. The decision to only use heparinized saline without systemic anticoagulation was based on whether the patient was unstable or bleeding from concomitant injuries. The medications given intraoperatively could not be determined for four of the patients who underwent arterial repair. There were 15 venous injuries, most of which were ligated (80%) with a minority repaired primarily (20%). Notably, none of the patients underwent endovascular management of their injury. Of the 46 patients requiring surgery, over half (26) were only operated on

Table 2 Details of patients undergoing surgical treatment for lower extremity vascular injuries

Surgical information, n (%)	N=53
Clinical presentation	
Hard sign	38 (72%)
Pulseless extremity	28 (53%)
Soft sign	12 (23%)
No pulse after orthopedic procedure	2 (3.8%)
Palpable distal pulses	1 (1.9%)
Vessel injured	
Common femoral artery	7 (13%)
With common femoral vein	3 (5.7%)
Superficial femoral artery	15 (28%)
With superficial femoral vein	5 (9.4%)
Deep femoral artery	7 (13%)
Popliteal artery	15 (28%)
Tibioperoneal vessels	13 (25%)
Multiple vessel injuries	15 (28%)
CT angiography	
Soft signs of vascular injury	12 (23%)
No pulses after orthopedic procedure	2 (3.8%)
Pulseless lower extremity	5 (9.4%)
Vascular repair	
Arterial injuries	36 (68%)
Primary repair/patch	4 (7.5%)
Ligation	5 (9.4%)
Saphenous vein graft	13 (25%)
PTFE graft	13 (25%)
Dacron graft	1 (1.9%)
Venous injuries	15 (28%)
Primary repair/patch	3 (5.7%)
Ligation	12 (23%)
Other	
Intraoperative angiogram only	3 (5.7%)
Thrombectomy	3 (5.7%)
Embolization	1 (1.9%)
Surgical specialty	
Trauma surgery	26 (49%)
Pediatric surgery	11 (21%)
Vascular surgery	4 (7.5%)
Multiple surgical specialties	5 (9.4%)
Trauma and vascular surgery	3 (5.7%)
Trauma and pediatric surgery	2 (3.8%)
Additional procedures	
Fasciotomy	16 (30%)
Therapeutic	8 (15%)
Prophylactic	8 (15%)
Fracture repair	20 (38%)
Amputation	
Initial operation	1 (1.9%)
Delayed	2 (3.8%)
PTFE, polytetrafluoroethylene.	

by a trauma surgeon, 11 by a vascular surgeon, four by a pediatric surgeon, and five by multiple surgical specialties for their vascular injury. Overall, many patients underwent additional procedures with 30% requiring a lower extremity fasciotomy, 38% undergoing fracture repair, and one patient requiring a below knee amputation as the initial operation. The patient

was brought in after a motorcycle collision and had a Mangled Extremity Severity Score of 11. Their lower extremity was deemed unsalvageable after a joint discussion between trauma, vascular, and orthopedic surgery and a below knee amputation was performed.¹¹

Clinical outcomes of pediatric LEVIs

The median ICU LOS was 3 (2–6) days, and total LOS was 15 (6–24) days. There were a total of four mortalities, all teenage boys who sustained multiple gunshot wounds with proximal vascular injuries, including a right internal iliac artery injury, presumed injuries to the aorta and inferior vena cava, and right common femoral artery and femoral vein transections. The majority of patients were discharged home (74%), 10 (18%) were sent to inpatient rehabilitation, and four (8%) died. Fifteen patients were discharged on aspirin, one on Coumadin, and one on a week of enoxaparin injections. Postoperative clinic follow-up was relatively low at only 55%. Finally, 30-day readmission was 9%. Only one of the five readmissions was related to their vascular repair. The patient presented to the emergency room with groin/thigh pain and was found to have pseudoaneurysms at his anastomoses. He underwent placement of a covered stent in the external iliac artery down to his graft, followed by a left axillary to profunda artery bypass with a jump bypass to the superficial femoral artery, left groin exploration with ligation of both the proximal superficial femoral artery and profunda artery, and ligation of the proximal external iliac artery.

A total of 32 (60%) patients received blood products. Among those patients, the median number of transfused units of packed red blood cells, platelets, fresh frozen plasma, and cryoprecipitate was 4 (IQR 3–9; range 1–61), 0 (IQR 0–0; range 0–10), 0 (IQR 0–6; range 0–35), and 0 (IQR 0–0, range 0–10), respectively (table 3).

Long-term outcomes

On long-term follow-up of over one year, 39 (74%) patients were seen by someone in our county health system. Median (IQR) follow-up was 8.3 years (4.7–11.5). Of these, nine (23%) complained of chronic leg/foot pain and one experienced leg paresthesia. Only one chart had a specific mention of monitoring for long-term sequelae after the patient’s vascular repair: patient ‘reports full ambulation and range of motion of leg, no pain, no skeletal or growth abnormalities of the right leg’. Of the

Table 3 Clinical outcomes for patients undergoing surgical treatment for lower extremity vascular injuries

Clinical outcome	N=53
ICU length of stay (days), median (IQR)	3 (2–6)
Hospital length of stay (days), median (IQR)	15 (6–24)
Mortality	4 (7.5%)
Discharge disposition	
Home	39 (74%)
Rehabilitation	10 (19%)
Postoperative clinic follow-up	29 (55%)
30-day readmission	5 (9.4%)
Blood transfusions, median (IQR), range	
Packed red blood cells	4 (3–9), 1–61
Platelets	0 (0–0), 0–10
Fresh frozen plasma	0 (0–6), 0–35
Cryoprecipitate	0 (0–0), 0–10
ICU, intensive care unit.	

39 seen for follow-up, 29 (74%) have been incarcerated since their injury and 10 (26%) have returned to our hospital with a violence-related injury, 6 (15%) of whom suffered a gunshot wound.

DISCUSSION

In this 20-year review, 53 patients were found to have LEVIs with 72% presenting with hard signs of vascular injury and the majority were of adolescent age. In recent years, the number of children and teens killed by gunfire in the USA increased 50% between 2019 and 2021.¹² Despite the rarity of pediatric LEVIs (1.1% in this study), the majority in our cohort were firearm-related injuries, underscoring the major public health concern of gunshot wounds in children in the USA.

When compared with adults, most deaths in children secondary to trauma are within 24 hours of arrival to the hospital; however, hemorrhage and early versus late mortality is poorly understood.^{13 14} We observed four deaths, all of which occurred in the first 24 hours. They all had a cardiac arrest on arrival and underwent emergent left resuscitative thoracotomy. Return of spontaneous circulation was achieved in all of them; however, two died intraoperatively and the other two died shortly after surgery in the trauma ICU.

Using the National Trauma Databank, Prieto *et al* identified 702 pediatric patients treated for both upper and/or LEVI.¹⁵ In that study, 38.5% were diagnosed with a LEVI but only 16% received definitive care at American College of Surgeons (ACS)-verified adult trauma centers. Unfortunately, these large registries are limited by the relative paucity of clinical details available. Our data demonstrate that pediatric LEVIs can be safely managed at urban ACS-verified level 1 adult trauma centers with readily available specialty trained surgeons which aligns with the contemporary management of adult vascular injuries observed in the literature.¹⁶

The operative repair of pediatric LEVI can be more technically challenging than in adults. The preferred repair techniques included reverse saphenous vein graft and PTFE graft with high limb salvage rates and low mortality. The potential for growth and developmental complications, such as limb length discrepancy, chronic lower extremity ischemia, and potential for future insults, must be considered during their management. As these patients are young, the long-term complications should be carefully weighed along with the likelihood of further vessel growth when selecting a repair.¹⁵ The principles of vascular repair for adults were generally used for the management of these pediatric patients. If primary repair of the artery is not feasible, the remaining options should be carefully considered. Autologous grafts are preferred; however, contralateral saphenous vein harvesting may not be an option if there are other injuries that need to be addressed, it is of inadequate size, or it is also potentially injured.^{7 8} If the patient is unstable, shunting or ligation are viable options.

At our institution, these injuries were generally managed by following the American Association for the Surgery of Trauma guidelines for the diagnosis and management of peripheral vascular injuries in adults.⁶ Most patients with hard signs of LEVI were transported directly to the operating room for surgical exploration. The remaining patients were then selectively evaluated with CTA to better delineate the injury. Most of these had soft signs of vascular injury; however, five had a pulseless lower extremity. As loss of a distal pulse is more likely to be a result of vasospasm in children, hemodynamically stable patients with this sign can selectively receive a CTA. Generally, if

there is concern for a vascular injury, an ankle-brachial index is performed, and if it is <0.9 the patient is sent for a CTA if they are hemodynamically stable. Whereas in adults an absent distal pulse is a hard sign of vascular injury, this may be a result of vasospasm in children. Therefore, if the patient is hemodynamically stable, one can consider a CTA or an intraoperative angiogram to differentiate between vascular injury and vasospasm. Vasospasm was found to be the cause of an absent distal pulse in several of our patients.

Most vascular injuries in this series were repaired by trauma surgeons. At our institution, vascular surgery consultation is requested for vascular injuries distal to the elbow, below the knee, or complex injuries. Pediatric surgery generally manages trauma patients less than 14 years old, and all the patients operated on by them were less than this age. We recommend consulting vascular surgery or pediatric surgery following these criteria or when their expertise is thought to be needed based on attending preference if they are available at your institution.

The most notable limitations of our study are that it is retrospective and from a single center, limiting its generalizability. As we are a level 1 trauma center, management and outcomes may be different from centers with other designations or in other locations. Prior work has shown that ACS-verified trauma centers such as ours have greater pediatric limb salvage rates for extremity vascular trauma.¹⁵ Our postoperative clinic follow-up rate was also low at only 55%, so we are unable to accurately report long-term outcomes of these injuries such as limb length growth or bypass occlusion rate.¹⁷ We also had a relatively small sample size of 53 given the rarity of this injury. For this reason, we were unable to accurately attribute injuries to individual arteries with different outcomes such as mortality or limb loss. However, prior studies have shown proximal injuries above the common femoral artery are associated with a higher risk of mortality, whereas popliteal artery and anterior tibial artery injuries are associated with limb loss.³ Future multi-institutional, prospective studies should be done to evaluate these injuries and make recommendations.

CONCLUSION

Pediatric LEVIs are rare and can result in significant morbidity. Surgical principles of vascular surgery are similar to those applied to an adult. Our data support that this subset of patients can be safely managed in a tertiary specialized center; however, continued efforts are necessary to improve follow-up care and further assess long-term patency and overall morbidity.

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Contributors JDS conceived the study. NBL, AB, and JDS designed the study. NBL, AB, BLC, KGP, NN, and JDS made substantial contributions to the conception or design of the work. NBL, AB, JPM, JES, CMT, LRP, ACM, and JDS contributed to the acquisition, analysis, or interpretation of data for the work. NBL, AB, and JDS were involved in drafting the work. All authors revised it critically for important intellectual content. All authors gave final approval of the version to be published. All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. NBL and JDS are the guarantors of this article and accept full responsibility for the work and/or the conduct of the study, had access to the data, and controlled the decision to publish.

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The deidentified data that support the findings of this study are available from the corresponding author upon reasonable request.

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