Contemporary outcomes of lower extremity vascular repairs extending below the knee: A multicenter retrospective study

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OBJECTIVES: To determine the outcomes of vascular injury interventions extending below the knee.

METHODS: Vascular injury repairs extending below the knee from January 2008 to December 2014 were collected from six American College of Surgeons Level I trauma centers. Demographics, management, and outcomes were collected and analyzed.

RESULTS: A total of 194 vascular injuries were identified. The mean age was 33.7 years, with 88.1% male, and 71.1% had blunt injury. Admission systolic blood pressure was less than 90 mm Hg in 10.8%; prehospital tourniquets were used in 5.6%. Median mangled extremity severity score (MESS) was 6.0 [interquartile range, 6]. Imaging used included computed tomography angiography (58.2%) and angiography (7.2%); with 66 (34.0%) proceeding directly to OR based on examination alone. Vascular interventions were conducted primarily by vascular (66.0%) and trauma (25.3%) surgeons at a median time from injury of 8 hours (interquartile range, 7 hours). Initial interventions included graft interposition (57.7%) with saphenous vein (111) or synthetic graft (1), primary repair (14.9%), endovascular stent-graft (1.5%), and patch angioplasty (2.1%). Fasciotomy was performed at initial operation in 41.8%, and for delayed compartment syndrome in 2.1%. Vascular reintervention was required in 20 patients (6.7%) for bleeding (seven patients) or thrombosis (13 patients). There was a higher reintervention rates for thrombosis among interposition grafts with distal anastomotic sites at the below-knee popliteal compared to those extending to the tibioperoneal trunk or distal trifurcation vessels, but this was not significant. (4/60, 6.7% vs. 6/49, 12.2%; $p = 0.34$). Postintervention amputation rates were significantly higher among interposition grafts extending distal to the popliteal (4/60 [6.7%] vs. 15/49 [30.6%]; $p = 0.006$).

CONCLUSIONS: The management of vascular injuries extending below the knee remains a complex issue of extremity trauma care. The need for delayed amputation is significantly more common when revascularization below the distal popliteal artery is required. (*J Trauma Acute Care Surg.* 2016;81: 63–70. Copyright © 2016 Wolters Kluwer Health, Inc. All rights reserved.)

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KEY WORDS: Lower extremity vascular repairs; below the knee; amputation; limb salvage.

The treatment of the injured extremity remains a clinical challenge, particularly among patients with severe limb trauma and vascular injuries requiring distal revascularization. While several groups have attempted to correlate the initial degree of overall extremity injury with ultimate outcomes, the findings have proven disappointing. Even among patients who are offered aggressive attempts at limb salvage, there are significant gaps in correlating interventions and subsequent outcomes.[1–7]

While a variety of factors affect limb outcomes after injury, including mechanism of trauma, associated venous or orthopedic injury, number of vessels injured, and type of vessel injured, the restoration and preservation of vascular flow remains one of the most important factors for subsequent success. While much has been written about the diagnosis of vascular injury in this setting, particularly the use of imaging for vascular injury characterization,[8–24] comparatively less is known about the natural history of vascular repairs conducted in the context of an injured distal lower extremity.

Our study is designed to determine outcomes of patients undergoing revascularization attempts with distal outflow targets for bypass extending below the knee following extremity injury. It is hoped that this effort will provide knowledge regarding patency rates and outcomes that can then be used to more effectively determine optimal triage and treatment approaches for these patients.

MATERIALS AND METHODS

The Lower Extremity Vascular Injury Outcomes Group was formed through a collaborative venture of 6 American College of Surgeons (ACS) Level I verified trauma centers in the United States and Canada. All collaborating centers obtained individual local institutional board review approval before participation. Data were collected retrospectively from trauma registry, chart, and imaging review conducted at each center. Data were then collated and analyzed for reporting.

Adult trauma patients (ages ≥15 years) with vascular injuries requiring interventions or repairs below the knee from January 2008 to December 2014 were identified. Patients undergoing damage-control amputation were excluded. Demographics, presentation, management, and outcomes were analyzed. A subset of patients requiring interposition bypass were also examined, comparing those who had a distal bypass target at the below-knee popliteal (BKP) artery to those requiring distal bypass targets at the tibioperoneal trunk or distal peroneal/tibial vessels.

Acute renal failure, for the purpose of our study, was defined as a two-fold increase in serum creatinine or an increase in glomerular filtration rate of greater than 5 following intervention. Centers for Disease Control and Prevention definitions were used for surgical site infection.

Continuous variables are reported as median values and interquartile range (IQR). Categorical variables are expressed as percentages. Analyses were performed using the Statistical Package for Social Sciences (SPSS Mac), version 22.0 (SPSS Inc, Chicago, IL).

RESULTS

Six ACS Level I trauma centers contributed 194 patients with vascular injuries requiring intervention below the knee. Median age was 28.0 years (IQR, 23), with 88.1% of patients being male. Most mechanisms recorded were blunt in character (138/194 [71.1%]), with the most common specific mechanism proving motor vehicle collisions (48/138 [34.9%]; Table 1). Median Injury Severity Score (ISS) was 10.0. Median Abbreviated Injury Severity (AIS) score for the extremity was 3 (IQR, 1). Median admission systolic blood pressure was 122 mm Hg (IQR, 35), with 10.8% of patients presenting hypotensive (systolic blood pressure [SBP], < 90 mm Hg). Median mangled extremity severity score (MESS) was 6.0 (IQR, 6; Table 1).

A variety of modalities were used to diagnose the documented arterial injuries, including clinical examination (72.7%), ankle-brachial index (ABI; 38.7%), and computed tomographic angiography (58.2%). No imaging was used in 34.0%, with a combination of examination, ABI, or operative exploration used to define arterial injury (Table 2). A tourniquet was used as

TABLE 1. Demographics

Demographics	
Age, median (IQR), years	28.0 (23)
Male sex, n/N (%)	171/194 (88.1%)
Mechanism	
Blunt, n/N (%)	138/194 (71.1%)
Motor vehicle collision, n/N (%)	48/138 (34.9%)
Auto vs. pedestrian, n/N (%)	22/138 (15.9%)
Penetrating, n/N (%)	56/194 (28.9%)
Gunshot wound, n/N (%)	31/56 (55.5%)
Injury Severity Score, median (IQR)	10.0 (9)
Abbreviated Injury Score—Head, median (IQR)	0 (0)
Abbreviated Injury Score—Chest, median (IQR)	0 (2)
Abbreviated Injury Score—Abdomen, median (IQR)	0 (1)
Abbreviated Injury Score—Extremity, median (IQR)	3 (1)
Systolic blood pressure on arrival (mm Hg), median (IQR)	122 (35)
Systolic blood pressure < 90 mm Hg on arrival, n/N (%)	21/194 (10.8%)
Mangled Extremity Severity Score (MESS), median (IQR)	6.0 (6)

Overall population of patients with vascular injuries extending below the knee (N = 194).

preintervention in 12.9% of patients, more commonly following penetrating mechanisms (11/56 [19.6%] of penetrating injuries). Tourniquets were used in 6 of 21 of the patients presenting as hypotensive on admission. Among patients treated with tourniquets, 44.0% (11/25) were used in the prehospital setting.

Providers participating in vascular interventions (to include ligation, vascular repair, bypass, and associated fasciotomies) included primarily vascular surgeons (66.0%) and trauma surgeons (25.3%) (Table 2). Associated venous injuries were definitively noted in 30.4% of patients, with most (52.5%) undergoing ligation. There was no significant difference between provider types with regard to the use of venous ligation versus venous repair, with trauma surgeons ligating at similar rates to vascular surgery counterparts (18 venous injuries with 10 ligations for trauma; 39 injuries with 21 ligation; $p = 0.91$). Median packed red-blood cell transfusion requirement intraoperatively was 1 unit [IQR, 4]. Fasciotomy was performed at initial operation in 41.8% of patients. A temporary vascular shunt was used in 13 of 194 patents (6.7%). The median time from injury to definitive vascular repair was 8 hours (IQR, 7; Table 2).

A variety of arterial-specific procedures were performed at the initial operation (Table 2), most commonly interposition bypass (56.2%) or primary repair (14.9%). Intraoperative systemic heparinization was used to facilitate intervention in 51.5% of cases. Perfused tissue flap coverage was used to cover the vascular intervention site at the initial operation in 8.2% of patients, with an additional 30.9% of patients undergoing tissue flap coverage at a subsequent operation. Postoperative antiplatelet or anticoagulation therapy use was documented in less than half of patients, most commonly aspirin (28.9%; Table 2).

Vascular reinterventions were required for 10.3% (20/194) of patients, for thrombosis (13) and bleeding (7) (Table 3). Reintervention for thrombosis was more common among interposition grafts with distal anastomotic sites at the BKP compared to those extending to the tibioperoneal trunk or distal trifurcation vessels, but this trend did not prove statistically significant

TABLE 2. Diagnostic and Therapeutic Interventions (N = 194)

Interventions	
Modalities used to diagnose arterial injury preintervention	
Clinical examination, n/N (%)	141/194 (72.7%)
ABI, n/N (%)	75/194 (38.7%)
Traditional angiography, n/N (%)	14/194 (7.2%)
Computed tomographic angiography, n/N (%)	113/194 (58.2%)
Operative exploration, n/N (%)	62/194 (32.0%)
Examination/ABI/Operative alone (no imaging), n/N (%)	66/194 (34.0%)
Tourniquet used—any setting, n/N (%)	25/194 (12.9%)
Tourniquet used—Penetrating mechanism, n/N (%)	11/56 (19.6%)
Tourniquet used—Blunt mechanisms, n/N (%)	12/138 (8.7%)
Tourniquet used—Hypotensive on admission, n/N (%)	6/21 (28.6%)
Location of tourniquet placement—setting	
Prehospital, n/N (%)	11/25 (44.0%)
Emergency department, n/N (%)	2/25 (8.0%)
Operating room, n/N (%)	11/25 (44.0%)
Preoperative blood products (data available = 106)	
Preoperative PRBCs—units, median (IQR)	0 (0)
Preoperative FFP—units, median (IQR)	0 (0)
Preoperative platelets—units, median (IQR)	0 (0)
Providers participating in vascular intervention(s)	
Vascular surgeon, n/N (%)	128/194 (66.0%)
Trauma surgeon, n/N (%)	49/194 (25.3%)
Interventional radiologist, n/N (%)	2/214 (0.5%)
Pediatric surgeon, n/N (%)	3/194 (1.5%)
Plastic surgeon, n/N (%)	5/194 (2.6%)
Orthopedic surgeon, n/N (%)	2/194 (2.6%)
Associated venous injury identified, n/N (%)	59/194 (30.4%)
Vein injury ligated, n/N (%)	31/59 (52.5%)
Vein injury primarily repaired, n/N (%)	16/59 (27.1%)
Vein injury—interposition repair, n/N (%)	3/59 (5.1%)
Vein injury—initial shunt with delayed interposition, n/N (%)	1/59 (1.7%)
Intraoperative blood products (data available = 146)	
Intraoperative PRBCs—units, median (IQR)	1 (4)
Intraoperative FFP—units, median (IQR)	0 (2)
Intraoperative platelets—units, median (IQR)	0 (0)
Fasciotomy performed at initial operation, n/N (%)	81/194 (41.8%)
Temporary vascular shunt used—initial operation, n/N (%)	13/194 (6.7%)
Shunt left in at completion—removed 2nd operations, n/N (%)	5/13 (38.5%)
Time—injury to definitive vascular repair, median (IQR), hours	8 (7)
Arterial specific procedures performed at initial operation	
Ligation, n/N (%)	1/194 (0.5%)
Endovascular embolization, n/N (%)	1/194 (0.5%)
Endovascular stent graft repair, n/N (%)	3/194 (1.5%)
Open thrombectomy/embolectomy alone, n/N (%)	19/194 (9.8%)
Open primary repair alone, n/N (%)	29/194 (14.9%)
Open patch repair with SVG or other native vein, n/N (%)	4/194 (2.1%)
Open patch repair with synthetic or biosynthetic, n/N (%)	0/194 (0%)
Interposition graft with SVG or other native vein, n/N (%)	108/194 (55.7%)
Interposition with synthetic or biosynthetic graft, n/N (%)	1/194 (0.5%)
Intraoperative systemic heparinization used, n/N (%)	100/194 (51.5%)
Perfused tissue flap coverage *initial* operation, n/N (%)	16/194 (8.2%)
Perfused tissue flap coverage *subsequent* operation, n/N (%)	60/194 (30.9%)
Postoperative ASA utilization, n/N (%)	56/194 (28.9%)
Postoperative ASA day start, median (IQR), days	0 (0)

(Continued next page)

TABLE 2. *(Continued)*

Interventions	
Postoperative Plavix utilization, n/N (%)	4/194 (2.1%)
Postoperative Plavix day start, median (IQR), days	0 (0)
Postoperative warfarin utilization, n/N (%)	7/194 (3.5%)
Post-operative warfarin day start, median (IQR), days	0 (0)

ABI, Ankle-Brachial Index; ASA, aspirin; FFP, fresh frozen plasma, PRBC, packed red blood cells; SVG, saphenous vein graft.

(4/60 [6.7%] vs. 6/49 [12.2%]; $p = 0.34$). Fasciotomy for delayed compartment syndrome development was required in 4 of 194 patients (2.1%). Acute renal failure occurred in 6.7% of the patients following intervention. Surgical site infection developed in 10.3%.

Amputation of the extremity with the vascular injury was required in 11.9% at subsequent operation, with 7.7% ultimately requiring above the knee amputation (AKA) and 4.2% requiring below-the-knee amputation. Among the overall population, median intensive care unit (ICU) length of stay (LOS) was 2 days (IQR, 4) and median hospital LOS was 16 days (IQR, 19). Overall, in-hospital mortality was 1.5% (3/194; Table 3).

Outcomes of Below-the-Knee Arterial Bypass

Interposition bypass approaches were used to restore adequate distal perfusion for 109 patients, including 108 bypasses with saphenous vein or other native vein graft and one synthetic graft (Table 4). The distal anastomosis target for these bypasses was the BKP artery in 60 patients and the tibioperoneal trunk, peroneal, or tibial vessels (TPT) in 49 patients. Demographic comparison of these groups revealed that patients undergoing TPT bypasses had a significantly higher median MESS score than BKP counterparts [8.0 vs. 6.5; $p = 0.034$). There were no other significant differences related to demographics, presentation, or management noted on evaluation (Table 4), with the exception that more patients undergoing TPT-targeted bypass were more likely to undergo perfused tissue flap coverage at a subsequent operation after bypass (47.9% vs. 26.7%, $p = 0.022$).

Below-knee popliteal and TPT distal target bypass patients were similar in their rates of need for reintervention for either thrombotic or hemorrhagic complications related to arterial bypass. Similar rates of acute renal failure, surgical site infection, and delayed compartment syndrome were also observed. There was, however, a significantly higher rate of overall amputation of the treated extremity among patients undergoing bypass with TPT targets, with these patients requiring amputation at rates of approximately three times that of BKP counterparts (8.3% vs. 26.5%; $p = 0.018$). Patients with TPT were also noted to have a longer hospital LOS than more proximal bypass comparisons. (33.5 days vs. 20 days; $p = 0.001$).

DISCUSSION

The optimal management of the severely injured lower extremity remains a matter of active investigation. While well-developed management algorithms for these entities exist,[25] there remains significant knowledge gaps regarding ideal treatment approaches. One matter of less debate is that any attempt at limb salvage after injury requires adequate vascular perfusion for healing and recovery of function.

Dua et al. at the University of Texas Medical School in Houston have previously demonstrated that the number of patent vessels to the distal lower extremity correlates with the ability to salvage an injured limb. Their single-center review of 84 patients with computed tomography angiography confirmed limited or no flow to the tibial arteries; they showed that amputation rate was inversely related to the number of patent tibial vessels after injury. Specifically, they noted that there were 2.7 open tibial vessels in the limb salvage group compared to 1.1 in those patients ultimately proceeding to amputation ($p < 0.05$).[26]

In a subsequent multicenter study conducted by Branco et al.,[24] researchers examined the impact of the number of patent tibial vessels in 398 patients treated at two ACS Level I trauma centers. In this larger retrospective study, conducted over a four-year time frame, there was also a direct correlation between the number of patent tibial outflow vessels and the subsequent limb preservation rate. Specifically, they noted that no amputations occurred in patients with two or more patent vessels to the foot (68.2% amputation rate for no patent vessels, 16.0% for 1 patent vessel, 0% for two or three patent vessels). This stepwise increase in the need for operative intervention supports the need for establishment of adequate vascular outflow to the distal extremity as an important component of limb salvage efforts.

Our present work was designed to define the natural history and outcomes of patients undergoing surgical intervention for vascular injuries extending below the knee. While our primary objective for this study was to determine outcomes

TABLE 3. Complications and Outcomes Total Population Below-Knee Vascular Injuries (N = 194)

Complications and Outcomes	
Overall vascular reintervention rate, n/N (%)	20/194 (10.3%)
Reintervention for *thrombosis*, n/N (%)	13/194 (6.7%)
Open thrombectomy, n/N (%)	7 / 13 (53.8%)
Revision of SVG interposition, n/N (%)	5/13 (38.5%)
Synthetic/biosynthetic graft revision, n/N (%)	1/13 (7.7%)
Reintervention for *bleeding*, n/N (%)	7/ 194 (3.6%)
Ligation, n/N (%)	1/7 (14.3%)
Revision SVG interposition, n/N (%)	3/7 (42.9%)
Angioembolization, n/N (%)	1/7 (14.3%)
Endovascular stent graft, n/N (%)	1/7 (14.3%)
Revision of primary repair, n/N (%)	1/7 (14.3%)
Fasciotomy for delayed compartment syndrome, n/N (%)	4/194 (2.1%)
Acute renal failure, n/N (%)	13/194 (6.7%)
Surgical site infection, n/N (%)	20/194 (10.3%)
Amputation of extremity following intervention, n/N (%)	23/194 (11.9%)
Above knee amputation, n/N (%)	15/194 (7.7%)
Below knee amputation, n/N (%)	8/194 (4.2%)
Intensive care unit LOS, median (IQR), days	2 (4)
Hospital LOS, median (IQR), days	16 (19)
In-hospital mortality, n/N (%)	3/194 (1.5%)

TABLE 4. Interposition Graft (SVG) Outcomes Comparison by Distal Target; Below-Knee Popliteal [BKP] (n = 60) Versus Tibioperoneal Trunk or Tibial Vessels (TPT) (n = 49)

	Total (N = 109)	BKP (n = 60)	TPT (n = 49)	*p*
Age, median (IQR), years	26.5 (28)	25.0 (36)	30.0 (25)	0.417
Mechanism—blunt, n/N (%)	84/109 (77.1%)	18/60 (30.0%)	7/49 (14.3%)	0.052
Mechanism—penetrating, n/N (%)	25/109 (22.9%)	42/60 (70.0%)	42/49 (85.7%)	0.052
Injury Severity Score, median (IQR)	10 (5)	9.0 (4)	10.0 (11)	0.242
AIS –Head, median (IQR)	0 (0)	0 (0)	0 (2)	0.572
AIS —Chest, median (IQR)	0 (2)	0 (1)	0 (2)	0.889
AIS —Abdomen, median (IQR)	0 (0)	0 (0)	0 (2)	0.327
AIS—Extremity, median (IQR)	3.0 (1)	3.0 (0)	3.0 (1)	1.000
Systolic blood pressure on arrival, median (IQR), mm Hg	126 (36)	126 (29)	125 (41)	0.819
Systolic blood pressure < 90 mm Hg on arrival, n/N (%)	8 (7.3%)	5/60 (8.3%)	3/49 (6.1%)	0.663
MESS, median (IQR)	8.0 (5)	6.5 (8)	8.0 (6)	0.034
Tourniquet used—any setting, n/N (%)	9/109 (8.2%)	3/60 (5.0%)	6/49 (12.2%)	0.172
Prehospital tourniquet used, n/N (%)	5/9 (55.5%)	2/3 (33.3%)	3/6 (50.0%)	0.310
Preoperative blood products (data available = 106)				
Preoperative PRBCs—units, median (IQR)	0 (0)	0 (0)	0 (0)	0.112
Preoperative FFP—units, median (IQR)	0 (0)	0 (0)	0 (0)	0.058
Provider conducting vascular repair				
Vascular surgeon, n/N (%)	86/109 (78.9%)	47/60 (78.3%)	39/49 (79.6%)	0.873
Trauma surgeon, n/N (%)	21/109 (19.3%)	12/60 (20.0%)	9/49 (18.4%)	0.830
Pediatric surgeon, n/N (%)	1/109 (0.9%)	1/60 (1.7%)	0/49 (0%)	0.364
Plastic surgeon, n/N (%)	1/109 (0.9%)	0/60 (0%)	1/49 (2.0%)	0.267
Associated venous injury, n/N (%)	33/109 (30.3%)	16/60 (26.7%)	17/49 (34.7%)	0.364
Intraoperative blood products				
Intraoperative PRBCs - units, median (IQR)	2 (4)	2 (5)	2 (4)	0.074
Intraoperative FFP - units, median (IQR)	0 (2)	0 (2)	0 (0)	0.193
Fasciotomy performed at initial operation, n/N (%)	79/109 (72.5%)	44/60 (73.3%)	35/49 (71.4%)	0.825
Temporary vascular shunt used—initial operation, n/N (%)	7/109 (6.4%)	5/60 (8.3%)	2/49 (4.1%)	0.455
Time—injury to definitive vascular repair, median (IQR), hours	8.0 (6)	9.0 (5)	9.5 (9)	0.148
Arterial specific procedures performed at initial operation				
Interposition graft with SVG or other native vein, n/N (%)	108/109 (99.1%)	59/60 (98.3%)	49/49 (100%)	1.000
Interposition with synthetic or biosynthetic graft, n/N (%)	1/109 (0.9%)	1/60 (1.7%)	0/49 (0%)	1.000
Intraoperative systemic heparinization used, n/N (%)	84/109 (77.1%)	50/60 (83.3%)	34/49 (69.4%)	0.085
Perfused tissue flap coverage *initial* operation, n/N (%)	11/109 (10.1%)	4/60 (6.7%)	7/49 (14.6%)	0.211
Perfused tissue flap coverage *subsequent* operation, n/N (%)	39/109 (35.8%)	16/60 (26.7%)	23/49 (47.9%)	0.022
Postoperative heparin continuous infusion, n/N (%)	19/109 (17.4%)	10/60 (16.7%)	9/49 (18.4%)	0.816
Postoperative ASA utilization, n/N (%)	39/109 (35.8%)	19/60 (31.7%)	20/49 (40.8%)	0.322
Postoperative Plavix utilization, n/N (%)	3/109 (2.8%)	2/60 (3.3%)	1/49 (2/0%)	1.000
Postoperative warfarin utilization, n/N (%)	3/109 (2.8%)	1/60 (1.7%)	2/49 (4.0%)	0.350
Reintervention for *thrombosis* of repair, n/N (%)	10/109 (9.2%)	4/60 (6.7%)	6/49 (12.2%)	0.340
Reintervention for *bleeding* from repair, n/N (%)	1/109 (0.9%)	1/60 (1.7%)	0/49 (0.0%)	1.000
Fasciotomy for delayed compartment syndrome, n/N (%)	2/109 (1.8%)	2/60 (3.3%)	0/49 (0%)	0.501
Acute renal failure, n/N (%)	5/109 (4.6%)	4/60 (6.7%)	1/49 (2.0%)	0.376
Surgical site infection, n/N (%)	12/109 (11.0%)	6/60 (10.0%)	6/49 (12.2%)	0.710
Any amputation of extremity following repair, n/N (%)	18/109 (16.5%)	5/60 (8.3%)	13/49 (26.5%)	0.018
Above knee amputation during initial hospitalization, n/N (%)	10/209 (9.2%)	5/60 (8.3%)	5/49 (10.2%)	0.751
Below-knee amputation during initial hospitalization, n/N (%)	11/109 (10.1%)	2/60 (3.3%)	9/49 (18.4%)	0.012
Intensive care unit LOS, median (IQR), days	3.0 (4)	4.0 (6)	5.5 (8)	0.700
Hospital LOS, median (IQR), days	18.0 (18)	20 (20)	33.5 (26)	0.001
In-hospital mortality, n/N (%)	0/109 (0%)	0/60 (0%)	0/49 (0%)	1.000

after repair, our data secondarily serve to highlight other opportunities for improvement in the care of patients with vascular injuries of the lower extremities. This is most notable in the finding that tourniquet use was only used in 6 of 21 (28.6%) patients presenting with hypotension after injury. Despite growing evidence that early tourniquet use may benefit in the civilian setting,[27,28] the failure to use this tool represents an opportunity for ongoing study and improvement in care.

The primary objective of our study was to define outcomes among patients with vascular injuries who underwent revascularization as part of limb salvage attempts. Relative to the body of literature regarding the prediction of limb outcomes before intervention, there exists a paucity of research regarding the natural history of vascular repairs after they are undertaken. This is particularly true for interventions extending distal to the knee. Our present report identifies that while there are appreciable needs for arterial reintervention after these interventions (10.3% in our series), reasonable outcomes can be achieved with aggressive attempts at revascularization. In our series, amputation was required in only 11.9% of patients, despite a median MESS score of 6 [IQR, 6]. These results were obtained despite additional challenges in the managed population, including prolonged time form injury to repair (median, 8 hours), the presence of confirmed associated venous injury in 30.4%, and the use of intraoperative systemic heparinization in only more than half (51.5%) of patients.

Specifically examining bypass grafts extending below the knee, we identified an appreciably higher risk of amputation with bypasses that required a distal anastomotic target below the level of the BKP. Our findings suggest that patients requiring more distal bypass targets may represent a higher risk population, with a higher MESS than BKP counterparts (8.0 vs. 6.5; $p = 0.034$) and a higher likelihood of requiring perfused tissue flap coverage for limb salvage. Despite these differences, there was no significance in thrombosis of the arterial repair or the need for arterial re-intervention between the two groups. Amputation rates were, nevertheless, approximately three times higher in the TPT group than in the BKP counterparts. However, TPT patients went on to amputation in 26.5% of instances. These data suggest that with appropriate forethought and planning, limb salvage can be obtained in approximately 75% of patients undergoing bypass revascularization to the level of the tibial vessels after significant extremity injury.

A number of other important issues regarding lower extremity vascular bypass after trauma have recently been investigated, including the exploration of alternative theories related to revascularization approaches following limb injury. In a recent examination conducted by Scalea et al,[29] investigators noted that among bluntly injured lower extremities, anterior tibial artery injuries were considerably more likely to require amputation compared to posterior tibial or peroneal artery injured extremities. These findings suggest that the characterization of limb injury may benefit from thoughtful application of the angiosome concepts commonly applied to revascularization for ischemic vascular lesions.[30,31] These principles seek to identify bypass or recanalization strategies designed to restore optimal flow to the outflow distribution, most likely to support healing of vascular ischemic lesions. The application of these principles for use in the trauma setting warrants investigation but requires improved delineation of the outflow distribution most affected by the specific injury. However, we were unable to adequately capture the specifics of soft tissue injury for consideration in this fashion. This is a limitation of our present work and warrants additional study.

Our study has several other important limitations that must be recognized, including those inherent to retrospective design. These prove particularly problematic in our inability to better characterize key potential contributors to adverse outcome after these injuries, including the reason for prolonged delays in repairs or the intent of the surgeon in making an attempt at associated venous repair. The capabilities and outcomes achieved at the participating ACS Level I centers should not be extrapolated to other settings. We also do not have follow-up beyond discharge for our patients, or limb function metrics. These latter deficiencies are worth highlighting, as they speak to the need for future study to better capture long-term outcomes following these revascularization attempts.

CONCLUSION

The optimal management of severely injured extremities remains a significant challenge of trauma care. Regardless of management approach, however, the restoration of adequate perfusion to distal tissues is likely paramount to limb salvage success. Our present data demonstrate that aggressive revascularization attempts extending below the knee have reasonable early outcomes and can contribute to successful limb salvage in severely injured extremities with vascular trauma.

AUTHORSHIP

This work represents the original efforts of the investigators. All listed authors contributed to study design, data collection, data interpretation, and manuscript development.

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DISCLOSURE

The authors declare no conflicts of interest.

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EDITORIAL CRITIQUE

I'd like to thank EAST for the privilege to critique this very well written manuscript by Dr. Fortuna and his colleagues, describing their multicenter review of outcomes after extremity injuries requiring below the knee vascular repair. Despite a long history of investigation, successful limb salvage after severe extremity injury remains a challenge, even at high volume centers with experienced multi-disciplinary teams. The data presented here offers a novel, and focused look at the high-risk cohort that requires revascularization with a below knee distal target. Hats off to Dr. Fortuna and his colleagues on attempting to tackle this complex issue in multi-center fashion, which is always a challenge. I have a few questions for the authors.

Perhaps the most striking, but not surprising, finding in your series is that the majority of these repairs in this contemporary time period were performed by vascular rather than trauma surgeons. This is in stark contrast to what Shackford et al showed in their Western Trauma Association multi-center study of extremity arterial injuries between 1995 and 2010, which showed that 70% of injuries were repaired by trauma or general surgeons with equitable outcomes to subspecialists. In your series the ratio is essentially the inverse. My thought is that this is likely because of your much higher rate of high-severity, blunt injuries requiring bypass with distal tibeo-peroneal targets, which a non-vascular specialist is likely much less comfortable repairing, as compared to a primary repair or straight-forward, short length, interposition graft, sufficient for most proximal extremity penetrating injuries. One could argue that changes in training and practice over the past 20 years now produce acute care surgeons that no longer have the comfort level, or skill-set, to perform these types of complex distal bypasses. Do you think that is true? If so, is it a necessarily a bad thing to have a vascular specialist assist with salvage attempt of these injuries, that we know are among the highest risk for amputation.

Along the same lines, a concerning finding was that the median time to definitive repair was 8 hours, as it's been shown that warm ischemia time greater than 6 hours predicts amputation. Interestingly, in the WTA study, the mean time to definitive repair by trauma surgeons was approximately 2 hours, as compared to 11 hours for a subspecialist. Given that the rate of vascular shunt use here was less than 7%, it seems unlikely that this delay is due to widespread adoption of shunting by acute care surgeons as they wait for the vascular specialist to arrive. Is there any indirect evidence to help shed light on the causes of these delays? Are they related to the need of external fixation or other concomitant procedures for multisystem injury? And if acute care surgeons are not going to perform these complex repairs, are temporizing shunts underutilized?

Finally, the true meat of the matter is limb salvage. What I found myself longing for, was more detail on predictors of salvage failure in this already high-risk cohort. While injuries requiring distal targets had triple the amputation risk, the thrombosis and intervention rate was no higher than those with more proximal targets. What then determines the ultimate need for amputation? Is it inadequate tissue coverage, loss of neurologic function, need for Sepsis control, or something else?

Finally, I find your reference to the angiosome hypothesis intriguing, because honestly, I'm having a hard time thinking of any other way to improve outcomes with these types of devastating injuries. Do you think a careful assessment of pre-op CT, or on-table angio could help with choosing the best distal target to optimize perfusion and improve limb salvage rates? Again hats off to you and all of your colleagues for helping us to further understand, and hopefully improve outcomes, for these highly morbid injuries.

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