Long-term functional outcomes after traumatic popliteal artery injury: A 20-year experience

Louis J. Magnotti, MD, John P. Sharpe, MD, Betsy Tolley, PhD, Fritjof Thomas, PhD, Richard H. Lewis, Jr, MD, Dina M. Filiberto, MD, Cory Evans, MD, Leo Kokorev, MD, Timothy C. Fabian, MD, *and* **Martin A. Croce, MD***, Memphis, Tennessee*

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The authors have nothing to disclose.

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BACKGROUND: Traumatic popliteal arterial injury (TPAI) is associated with a risk of both limb loss and long-term morbidity due to prolonged ischemia and the often-associated musculoskeletal injuries. Long-term functional outcome following this injury has not been adequately studied. We evaluated patients with TPAI to determine if there was an improvement in functional outcome over time. We hypothesized that both the initial severity of ischemia and the associated injuries limited the ability of patients to improve functional outcome.

METHODS: Patients with TPAI for 20 years were identified. All patients had at least a 2-year follow-up. Functional outcomes were measured using the Boston University Activity Measure for Post-Acute Care to assess basic mobility (BM) and daily activity (DA). Multiple linear regression, adjusted for age, severity of injury and shock, operative complexity, associated injuries, ischemic time, and length of follow-up were used to identify predictors of functional outcome after TPAI.

RESULTS: A total of 214 patients were identified: 123 penetrating (57%) and 91 blunt (43%). Overall mortality was 1.9% (all in-hospital), and amputation occurred in 10%. Of the 210 survivors, follow-up was obtained in 145 patients (69%). Median follow-up was 9.2 years (interquartile range, 5.7–15.7 years). Mean Activity Measure for Post-Acute Care scores for BM and DA were 78 and 75, respectively, both signifying mild impairment (normal, >84). Multiple linear regression failed to identify increasing length of follow-up as a predictor of improved functional outcomes. Only age, lower extremity fracture, and ischemic time were identified as predictors of decreased BM and DA.

CONCLUSION: Increasing age, lower extremity fracture, and prolonged ischemic time worsened long-term functional outcomes. Functional outcome did not improve over time, suggesting that maximal recovery may be achieved within the first 2 years postinjury. Thus, early and effective revascularization remains the only potentially *modifiable* risk factor for improving functional outcomes following TPAI. (*J Trauma Acute Care Surg.* 2020;88: 197–206. Copyright © 2019 American Association for the Surgery of Trauma.)

LEVEL OF EVIDENCE: Prognostic, level III.

KEY WORDS: Long-term; functional outcomes; popliteal artery injury.

Popliteal arterial trauma, although uncommon, has the highest risk of limb threat of all peripheral vascular injuries.[1,2] Numerous studies have documented that timely and effective restoration of arterial flow is essential for limb salvage.[3–5] Despite advances in early diagnosis with CT angiogram and improved management with damage control techniques including shunting, limb loss from calf muscle necrosis remains a significant threat.[2] There is also evidence that the commonly associated musculoskeletal injuries can result in an initially poor functional outcome for those who do not suffer limb loss.[6] However, the long-term outcomes for patients with traumatic popliteal arterial injury (TPAI) have not been adequately studied. We evaluated patients with TPAI to determine if there was an improvement in functional outcome over time. We hypothesized that both the initial severity of ischemia and the associated injuries limited the ability of patients to improve functional outcome over time.

PATIENTS AND METHODS

Identification of Patients

Following approval from the institutional review board at the University of Tennessee Health Science Center, consecutive patients sustaining traumatic popliteal artery injury requiring operative intervention for a 20-year period (from January 1996 to December 2015) were identified from the trauma registry of the Presley Regional Trauma Center in Memphis, Tennessee. All patients had at least a 24-month follow-up at the time of contact to better evaluate long-term functional outcomes and limit the impact of time postinjury as a potential bias. Charts were reviewed for data regarding patient demographics, severity of injury and shock, associated injuries, operative complexity, and outcomes. These data were then merged with patient data from the trauma registry (NTRACS version 4.1; Digital Innovations, Forest Hill, MD) to compile the database for this study. Patients under the age of 18 years or with a head Abbreviated Injury Scale (AIS) of greater than 3 or with a spinal cord injury or who declined to participate at the time of follow-up were excluded.

Follow-up

The last known contact information of all eligible patients was obtained from the medical records. When no valid contact information was available, an online locator service (http://www. peoplefinder.com) was queried for the patient and all known associates to obtain additional numbers. All valid telephone numbers were called until follow-up was completed. Patients were deemed lost to follow-up or dead when all contact information was exhausted or if the patient was found in the Social Security Death Master File, respectively.

Outcome Measurement

The Boston University Activity Measure for Post-Acute Care (AM-PAC) computerized adaptive test was administered to the patient over the phone. The AM-PAC functional assessment tool is an adaptive computer assessment that allows for a sophisticated evaluation of a patient's ability to function in three domains: basic mobility (BM), daily activities (DAs), and cognitive capability. In the current study, only BM and DAs were evaluated. Full or independent function was defined as BM score greater than 84 and DA score greater than 84. This assessment was chosen over others for its enhanced ability to demonstrate more sensitive measures of change in functional activity performance over time in the general population of persons compared with other assessment tools.[7,8]

Submitted: July 31, 2019, Revised: October 3, 2019, Accepted: October 19, 2019, Published online: November 27, 2019.

From the Department of Surgery (L.J.M., J.P.S., B.T., F.T., R.H.L., D.M.F., C.E., T.C.F., M.A.C.), University of Tennessee Health Science Center, Memphis, Tennessee; and Department of Surgery (L.K.), University of Mississippi Oxford, Mississippi.

This study was presented at the 78th Annual Meeting of the American Association for the Surgery of Trauma and the Clinical Congress of Acute Care Surgery, September 18–21, 2019, in Dallas, Texas.

Address for reprints: Louis J. Magnotti, MD, MS, Department of Surgery, University of Tennessee Health Science Center, 910 Madison Ave, 220, Memphis, TN 38163; email: lmagnotti@uthsc.edu.

DOI: 10.1097/TA.0000000000002548

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Additional outcomes measured included hospital length of stay, intensive care unit length of stay, and ventilator days.

Statistical Analysis

All analyses were performed using SAS version 9.4 (SAS Institute, Cary, NC). Comparisons between patients that were followed-up and those lost to follow-up or dead were performed using a Student *t* test and χ^2 analysis or Wilcoxon rank sum test where appropriate to ensure that the results were generalizable to all patients. Multiple linear regression analysis was performed to determine significant predictors of BM and DAs in the study population. Simple linear regression was performed initially, and variables exhibiting a significance less than 0.2 were considered for inclusion in the full multiple regression model. A separate multiple linear regression model was developed for each measured outcome variable. Model building included a detailed assessment for influential outliers and collinearity, as well as an analysis of residuals. Final model selection was based on choosing predictor variables with clinical and statistical significance, minimizing collinearity, evaluating relationships among predictors with principle component analysis, and maximizing R^2 values. Differences were considered significant at $p < 0.05$. Identified main effects in the model were tested for pairwise interactions.

RESULTS

Patient Characteristics — All Patients

A total of 237 patients with operative traumatic popliteal artery injuries were identified over the study period (January 1996 to December 2015). A total of 214 patients met the inclusion criteria and comprised the study population. These patients ranged in age from 18 to 88 years and included 179 men (84%) and 35 women (16%). The majority (57.5%) sustained penetrating popliteal artery injuries.

All patients underwent open repair: all blunt injuries were repaired using reverse saphenous vein bypass, and 15 penetrating injuries were managed with resection plus anastomosis. There were no endovascular repairs during the study period. Twenty-four patients underwent leg amputations during the initial hospitalization: 18 blunt injuries (12 secondary to bone/soft tissue injury and 6 secondary to ischemia) and 6 penetrating injuries (all secondary to ischemia). Six patients with blunt injuries and 2 patients with penetrating injuries required above knee amputations. There were no postdischarge amputations identified in the study population.

Overall mortality (all in-hospital) was 1.7%. There were no postdischarge deaths identified in the study population. Of the 210 survivors, 145 (69%) were contacted and completed the functional assessment. Only 65 (31%) of the survivors were lost to follow-up. Mean follow-up was 10.6 years and ranged from 29 months to 22 years. The median follow-up was 9.2 years (interquartile range, 5.7–15.7 years). Figure 1 illustrates how the final study population was reached.

Table 1 shows the demographic and clinical characteristics, and Table 2 depicts selected outcomes for all patients included in the study as well as a comparison of those who were followed-up and those that were lost to follow-up. The only statistically significant (but clinically insignificant) difference between the groups was shock index, indicating that the cohort with follow-up closely approximates the entire population of patients with traumatic popliteal artery injuries at our institution, making a careful assessment of functional outcomes possible.

Functional Outcomes — All Patients

Of the 145 patients with traumatic popliteal artery injuries, 51 patients had a normal measure of BM, Ninety-three patients

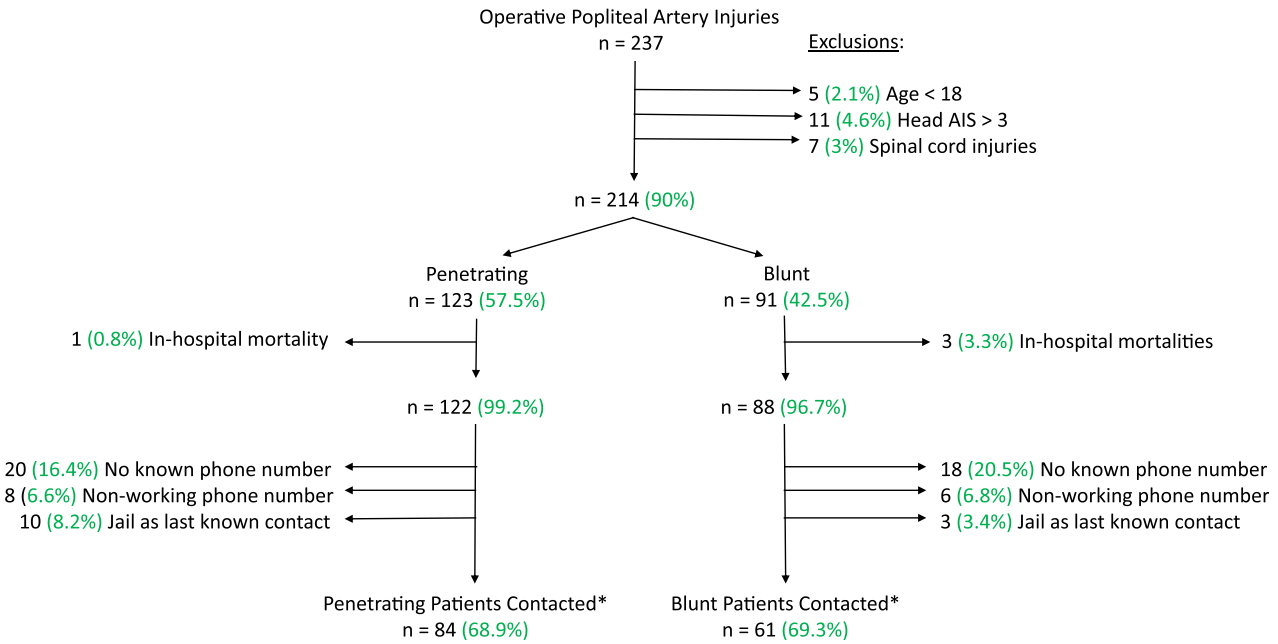

Figure 1. Flow diagram depicting arrival at final study population. *There were no refusals to participate. All patients contacted by phone participated in the study.

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TABLE 1. Patient Characteristics — All Patients

	All	FU	No FU	*p*
n	214	145	69	
Age	34 (14)	34 (14)	35 (15)	0.58
Male, %	84	83	86	0.61
GCS	15 (15, 15)	15 (15, 15)	15 (15, 15)	0.72
ISS	9 (9, 10)	9 (9, 10)	9 (9, 10)	0.37
Base excess	−3.9 (4.7)	−3.8 (4.9)	−4.1 (4.4)	0.65
Shock index	0.85 (0.63, 0.94)	0.73 (0.62, 0.89)	0.80 (0.65, 1.2)	0.02
OR time	364 (132)	367 (142)	358 (110)	0.49
Intraop PRBCs	4 (0, 8)	4 (0, 10)	4 (0, 7)	0.65
Nerve injury, %	18	15	23	0.15
Fracture, %	47	47	46	0.94
Amputation, %	16	17	13	0.43
Ischemic time	355 (127)	347 (136)	372 (103)	0.14

FU, follow-up; no FU, no follow-up; GCS, Glasgow Coma Scale Score; ISS, Injury Severity Score; OR, operating room; Intraop, intraoperative; PRBCs, packed red blood cells; *p*, *p* value for comparison between FU and No FU groups.

displayed only mild impairment, and only one patient had moderate impairment. There were no patients with severe impairment. The mean ± SD BM score for all patients with traumatic popliteal artery injuries was 78 ± 15.

In contrast, 62 patients with traumatic popliteal artery injuries had a DA score that fell within the normal range, 37 patients had mild impairment, and 46 patients displayed a moderate degree of impairment. There were no patients with severe impairment. The mean ± SD DA score for all patients with traumatic popliteal artery injuries was 75 ± 24.

Multiple Linear Regression — All Patients

Simple linear regression analysis for all patients with traumatic popliteal artery injuries identified potential predictors of both BM and DA (Table 3). The final models were then constructed using stepwise backward elimination and included predictor variables of age, ischemic time, and presence of an associated lower extremity fracture. The final models for both BM ($F_{3,\ 141} = 72.09$; $p < 0.0001$) and DAs ($F_{3,\ 141} = 68.71$; $p < 0.0001$) were significant, with $R^2 = 0.6053$ and 0.5938, respectively. Age was predictive of both decreasing mobility ($\beta = -0.42$, $p < 0.0001$) and DA scores ($\beta = -0.78$, $p < 0.0001$). Ischemic time was also predictive of both decreasing mobility ($\beta = -2.38$, $p < 0.0001$) and DA scores ($\beta = -3.60$, $p < 0.0001$). Presence of an associated lower extremity fracture was predictive of both substantially limited BM ($\beta = -6.44$, $p = 0.0002$) and DAs ($\beta = -8.26$, $p = 0.003$).

Patient Characteristics — Penetrating Popliteal Artery Injuries

A total of 123 patients with penetrating popliteal artery injuries were identified over the study period. These patients ranged in age from 18 to 70 years and included 116 men (94%) and 7 women (6%). The majority of patients suffered gunshot wounds (96%), followed by stab wounds (4%). Overall mortality (all in-hospital) was 0.8%. Of the 122 survivors, 84 (68.8%) were contacted and completed the functional assessment. Only 38 (31%) of the survivors were lost to follow-up. Mean follow-up was 9.8 years and ranged from 29 months to 22 years. The median follow-up was 8.5 years (interquartile range, 4.9–14.5 years).

Table 4 shows the demographic and clinical characteristics, and Table 2 depicts selected outcomes for all patients with penetrating popliteal artery injuries as well as a comparison of those who were followed-up and those that were lost to follow-up. There was no significant difference between the groups, underscoring the overall similarity between those patients with penetrating popliteal artery injuries who were contacted for follow-up and those lost to follow-up, making a careful assessment of functional outcomes possible.

Functional Outcomes — Penetrating Popliteal Artery Injuries

Of the 84 patients with penetrating popliteal artery injuries, 39 patients had a normal measure of BM and 45 patients

TABLE 2. Comparison of Outcomes

	All Patients			Penetrating			Blunt		
	FU	No FU	*p*	FU	No FU	*p*	FU	No FU	*p*
n	145	69		84	39		61	30	
Ventilator days	1 (0, 2)	1 (0, 1)	0.41	0 (0, 1)	0 (0, 1)	0.92	1 (0, 3)	1 (0, 1)	0.22
ICU LOS	4 (1, 7)	3 (1, 6)	0.18	2 (1, 4)	1 (1, 4)	0.45	6 (3, 9)	4 (2, 9)	0.23
Hospital LOS	16 (9, 25)	13 (9, 21)	0.46	10 (7, 20)	11 (7, 17)	0.98	21 (14, 30)	21 (11, 30)	0.35

FU, follow-up; no FU, no follow-up; ICU, intensive care unit; LOS, length of stay.

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displayed only mild impairment. There were no patients with either moderate or severe impairment. For these patients, the mean ± SD BM score was 79 ± 14, which is clinically similar to that for all patients (see previous data).

In contrast, 47 patients with penetrating popliteal artery injuries had a DA score that fell within the normal range, 16 patients had only mild impairment, and 21 patients displayed a moderate degree of impairment. There were no patients with severe impairment. The mean ± SD DA score for patients with penetrating popliteal artery injuries was higher (80 ± 23) than the score for the overall study population. However, clinically, there is little difference in functional outcome as this score falls within the same range on the AM-PAC Daily Activity Expected Performance scale.

Multiple Linear Regression — Penetrating Popliteal Artery Injuries

Simple linear regression analysis for patients with penetrating popliteal artery injuries identified potential predictors of both BM and DA (Table 3). The final models were then constructed using stepwise backward elimination and included predictor variables of age, ischemic time, and presence of an associated lower extremity fracture for BM but only age and ischemic time for DA. The final models for both BM ($F_{3,\ 80} = 75.27$; $p < 0.0001$) and DAs ($F_{2,\ 81} = 99.14$; $p < 0.0001$) were significant, with R^2 of 0.7384 and 0.7100, respectively. Age was predictive of both decreasing mobility ($\beta = -0.82$, $p < 0.0001$) and DA scores ($\beta = -1.33$, $p < 0.0001$). Ischemic time was also predictive of both decreasing mobility ($\beta = -1.28$, $p = 0.048$) and DA scores ($\beta = -2.33$, $p = 0.03$). Presence of an associated lower extremity fracture was also most likely predictive of decreased mobility, although the p value just failed to reach significance ($\beta = -3.32$, $p = 0.063$).

TABLE 3. Simple Linear Regression Results

	BM		DAs	
All Patients	β	p	β	p
Age	−0.71	<0.0001	−1.19	<0.0001
ISS	−0.38	0.05	−0.64	0.05
Base excess	0.45	0.07	0.53	0.197
Intraop PRBCs	−0.38	0.02	−0.63	0.02
OR time	−1.28	0.01	−2.08	0.01
Ischemic time	−4.10	<0.0001	−6.49	<0.0001
Nerve injury	−8.05	0.02	−14.59	0.01
Fracture	−13.17	<0.0001	−19.74	<0.0001
Amputation	−10.57	0.001	−19.92	0.0001
Penetrating	β	p	β	p
Age	−1.02	<0.0001	−1.60	<0.0001
Intraop PRBCs	−0.36	0.07	−0.53	0.10
Ischemic time	−5.20	<0.0001	−8.45	<0.0001
Fracture	−10.89	0.0003	−14.97	0.002
Amputation	−8.27	0.14	−17.69	0.05
Blunt	β	p	β	p
Age	−0.42	0.0001	−0.79	<0.0001
ISS	−0.36	0.11	−0.52	0.16
Base excess	1.41	0.004	2.07	0.01
Shock index	−8.45	0.12	−17.50	0.06
Intraop PRBCs	−0.42	0.09	−0.81	0.05
OR time	−1.23	0.09	−1.96	0.11
Ischemic time	−2.96	<0.0001	−4.65	0.0001
Nerve injury	−9.47	0.04	−17.57	0.02
Fracture	−14.34	<0.0001	−23.18	<0.0001
Amputation	−8.21	0.03	−16.04	0.01
FU length	0.04	0.14	0.03	0.49

β, estimated regression coefficient; ISS, Injury Severity Score; OR, operating room; Intraop, intraoperative; PRBCs, packed red blood cells; FU, follow-up.

TABLE 4. Patient Characteristics — Penetrating Popliteal Artery Injuries

	All	FU	No FU	p
n	123	84	39	
Age	32 (12)	31 (12)	32 (12)	0.63
Male, %	94	94	95	0.85
GCS	15 (15, 15)	15 (15, 15)	15 (15, 15)	0.96
ISS	9 (9, 9)	9 (9, 9)	9 (9, 9)	0.42
Base excess	−3.9 (5.4)	−3.7 (5.7)	−4.3 (4.9)	0.57
Shock index	0.74 (0.63, 0.92)	0.81 (0.63, 0.89)	0.77 (0.70, 1)	0.11
OR time	340 (122)	339 (130)	342 (105)	0.90
Intraop PRBCs	4 (0, 8)	4 (0, 10)	4 (0, 8)	0.74
Nerve injury, %	15	13	21	0.29
Fracture, %	42	35	44	0.84
Amputation, %	8.1	7	7.7	0.90
Ischemic time	317 (109)	302 (112)	330 (73)	0.09

FU, follow-up; no FU, no follow-up; GCS, Glasgow Coma Scale Score; ISS, Injury Severity Score; OR, operating room; Intraop, intraoperative; PRBCs, packed red blood cells; p, p value for comparison between FU and No FU groups.

Patient Characteristics — Blunt Popliteal Artery Injuries

A total of 91 patients with blunt popliteal artery injuries were identified over the study period. These patients ranged in age from 18 to 88 years and included 63 men (69%) and 28 women (31%). The majority of patients presented following motor vehicle collision (40%), followed by autopedestrian (17%), motorcycle or all-terrain vehicle crash (15%), falls (14%), crush (industrial) injuries (11%), and sports injuries and assaults (3%). Mean age and Injury Severity Score were 38 years and 9, respectively. Overall mortality (all in-hospital) was 3.3%. Of the 88 survivors, 61 (69.3%) were contacted and completed the functional assessment. Only 27 (31%) of the survivors were lost to follow-up. Mean follow-up was 11.6 years and ranged from 30 months to 22 years. The median follow-up was 11.2 years (interquartile range, 6.6–16 years).

Table 5 shows the demographic and clinical characteristics and Table 2 displays selected outcomes for all patients with blunt popliteal artery injuries included in the study as well as a comparison of those who were followed-up and those that were lost to follow-up. Once again, there was no significant difference between the groups, indicating that the cohort with follow-up closely approximates the entire population of patients with penetrating popliteal artery injuries at our institution, rendering a careful assessment of functional outcomes possible.

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TABLE 5. Patient Characteristics — Blunt Popliteal Artery Injuries

	All	FU	No FU	*p*
n	91	61	30	
Age	38 (16)	37 (16)	38 (17)	0.79
Male, %	69	67	73	0.55
GCS	15 (15, 15)	15 (15, 15)	15 (15, 15)	0.67
ISS	9 (9, 17)	9 (9, 14)	9 (9, 18)	0.64
Base excess	−3.8 (3.6)	−3.8 (3.6)	−3.8 (3.8)	0.93
Shock index	0.76 (0.61, 0.96)	0.75 (0.61, 0.89)	0.82 (0.62, 1.2)	0.11
OR time	397 (139)	405 (151)	380 (113)	0.43
Intraop PRBCs	4 (0, 8)	4 (0, 9)	3.5 (0, 6)	0.53
Nerve injury, %	21	18	27	0.34
Fracture, %	53	54	50	0.71
Amputation, %	26	30	20	0.33
Ischemic time	415 (133)	409 (143)	426 (112)	0.56

FU, follow-up; no FU, no follow-up; GCS, Glasgow Coma Scale Score; ISS, Injury Severity Score; OR, operating room; Intraop, intraoperative; PRBCs, packed red blood cells; *p*, *p* value for comparison between FU and No FU groups.

Functional Outcomes — Blunt Popliteal Artery Injuries

Both the mean ± SD mobility score (71 ± 14) and the mean ± SD DA score (67 ± 23) for patients with blunt popliteal artery injuries were lower than the scores for patients with penetrating popliteal artery injuries and the overall study population. Only 12 patients with blunt popliteal artery injuries had a BM score that fell within the normal range, 48 patients displayed mild impairment, and only 1 patient had a moderate degree of impairment. There were no patients with severe impairment. Similarly, 15 patients with blunt popliteal artery injuries had a normal measure of DA, 21 patients had only mild impairment, and 25 patients displayed a moderate degree of impairment. There were no patients with severe impairment. Clinically, there is little difference in functional outcome as these scores fall within the same ranges on the AM-PAC BM and DA Expected Performance scales.

Multiple Linear Regression — Blunt Popliteal Artery Injuries

Simple linear regression analysis for all patients with blunt popliteal artery injuries identified potential predictors of BM and DA (Table 3). Both final models were constructed using stepwise backward elimination and included predictor variables of age, ischemic time, and presence of an associated lower extremity fracture. The final models for both BM ($F_{3,\ 57} = 16.68$; $p < 0.0001$) and DAs ($F_{3,\ 57} = 16.24$; $p < 0.0001$) were significant, with R^2 of 0.4676 and 0.4608, respectively. Age was predictive of both decreasing mobility ($\beta = -0.22$, $p = 0.023$) and DA scores ($\beta = -0.50$, $p = 0.003$). Ischemic time was also predictive of both decreasing mobility ($\beta = -1.98$, $p = 0.002$) and DA scores ($\beta = -2.85$, $p = 0.007$). Presence of an associated lower extremity fracture was predictive of both substantially limited BM ($\beta = -9.47$, $p = 0.002$) and DAs ($\beta = -14.26$, $p = 0.005$).

DISCUSSION

In our analysis of two decades of experience with TPAI, we found that long-term outcomes were related to the patient's age, duration of ischemia, and associated injuries. We were able to identify 60% of our patients who were at least 2 years out from TPAI. The mean duration of follow-up was over 10 years. We used the AM-PAC survey tool to show that, beyond 2 years, patients were limited in their ability to regain lost function and that their functional status did not subsequently improve. We found that all patients with TPAI had long-term functional deficits, with at least mild impairments in both BM and DAs. Our study is the largest single-institution review of patients with traumatic popliteal artery injuries with the longest follow-up that evaluates long-term functional outcomes after TPAI.

The implications of our findings of impaired function with the AM-PAC scores translated to a variety of problems with everyday activities. The mild range of impairment scores would be equivalent to someone who is able to walk inside without any difficulty and may be able to move about outdoors without any limitations but likely has difficulty with climbing a full flight of stairs or rising from a chair and has little difficulty with activities of daily living such as bathing or dressing, grooming, and eating independently. When patients were analyzed by mechanism, those with blunt injuries demonstrated lower scores in both functional domains compared with those with penetrating injuries. This finding is consistent with previous studies in which blunt mechanism was found to have a negative effect on short-term functional outcomes in patients with popliteal artery injuries.[2,4,9,10]

Peripheral vascular injuries comprise approximately 4% to 6% of all major traumas.[11] Popliteal vessel injuries, although uncommon, accounting for only 0.2% of all trauma, represent the most limb-threatening and challenging of all peripheral vascular injuries.[1,12,13] These injuries are often associated with extensive soft tissue wounds, bony fractures, and nerve deficits, further complicating patient care and contributing to relatively poor outcomes.[2,14,15] Traumatic disruption of the popliteal artery with its associated injuries can often result in permanent physical deficits for the patient. Nevertheless, there remains a paucity of data in the current literature regarding long-term functional outcomes of these injuries, most of which suffer from smaller sample sizes or lack of substantial patient follow-up.[9,10]

Popliteal artery injuries have been associated with the highest rate of amputation after lower-extremity vascular injury. During World War I, popliteal artery injuries were associated with an amputation rate of 73%, as ligation was the primary method of treatment.[16] With advances in vascular surgery, improved triage, and stabilization of casualties coupled with the gradual replacement of arterial ligation with arterial repair, the amputation rates fell to approximately 30% to 40% during the Korean and Vietnam conflicts.[17,18] Recent military data from Iraq and Afghanistan demonstrate an amputation rate of approximately 30%.[19] In civilian practice, amputation rates range from 14.5 to 25%.[1,2,6,20] In fact, in the current study, the amputation rate was 15.9%, comparable with the 14.5% reported by Mullenix et al.[2] in a recent analysis of the National Trauma Data Bank and the 16.2% identified by Hafez et al.[15] in a review of a busy metropolitan vascular unit.

The results of the AM-PAC scores in the functional domains of BM and DAs highlight the difficulties that patients suffering these injuries may face long term. The casual assumption that survivors of trauma should return to normal function given enough time does not appear to be true. In a recent study, only

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23% of patients following major trauma had returned to preinjury function at 2 years.[21] Thus, to better evaluate long-term functional outcomes and limit the impact of time postinjury as a potential bias, all patients had at least a 24-month follow-up in the present study (minimum postinjury follow-up was 29 months).

There was no association of length of follow-up with either BM or DAs following penetrating injury. Instead, simple linear regression analysis only identified length of follow-up as a potential predictor of BM but not DAs after blunt injury. However, multiple regression analysis failed to identify increasing length of follow-up as a predictor of improved mobility after adjusting for age, severity of shock, injury severity, operative complexity, associated injuries, and ischemic time. This finding underscores the previous concept[21] and suggests that there may be a ceiling effect in terms of time postinjury for maximal functional recovery to occur. Thus, efforts should be focused on early and intensive rehabilitation for these injuries to achieve optimal functional outcomes for patients.

In the present study, multiple linear regression analysis identified increasing age, prolonged ischemic time, and associated lower extremity fracture as predictors of worse functional outcome in all patients following traumatic popliteal artery injury and specifically in those with blunt injuries. For those patients with penetrating injuries, only increasing age and prolonged ischemic time led to mild impairments in BM and DAs. Once again, these findings underscore the impact that mechanism exerts on outcome, specifically with associated lower extremity fractures having a more pronounced negative influence on long-term functional outcomes following blunt injury.

Given these results, we are not recommending immediate revascularization for all patients with traumatic popliteal artery injury. Instead, the approach needs to be tailored to the individual patient. Clearly, those with blunt injury will require identification and management of all potentially life-threatening injuries before any attempts at revascularization. Similarly, those with multiple penetrating injuries not just isolated to the extremity will require operative management of their immediate life-threatening injuries first. Thus, we are advocating a more expeditious work-up for those with blunt injury and little, if any, preoperative diagnostic interventions coupled with liberal use of damage control techniques for those with either penetrating or blunt injuries. The liberal use of abbreviated laparotomy for those with penetrating torso injuries and temporary intraluminal shunts for those with associated lower extremity fractures before fracture stabilization allows for prompt revascularization in the face of multiple other injuries. Unfortunately, there is not one simple answer for all patients, because not all critically injured patients are physiologically created equal. However, what we do know is that early revascularization, regardless of the mechanism of injury, improves long-term functional outcomes in patients with traumatic popliteal artery injuries.

LIMITATIONS

This study has several inherent limitations. The primary limitation of this study is the number of patients available for complete follow up. Despite extensive efforts to contact all patients with traumatic popliteal artery injury, approximately 30% of the study population was lost to follow-up. This limited number means that the prediction models are sensitive to each respondent, especially any outliers. We believe that this is partially mitigated by the fact that the cohort with follow-up closely approximates the entire population of patients with traumatic popliteal artery injury at our institution. Another limitation is the fact that the preinjury functional status of the patients comprising the cohort is unknown. This uncertainty could impact our conclusions if a deficit existed before injury. However, based on the demographics of the cohort, we believe the effect of preinjury functional impairment to be minimal. Finally, no patient underwent endovascular repair. In a recent study, Butler et al.[22] showed that open repair (compared with endovascular) following popliteal artery injury was associated with lower rates of index admission arterial thromboembolus and postdischarge amputation. Clearly, choice of repair impacts long-term functional outcomes, increasing the potential for bias.

CONCLUSIONS

In this study, mean BM and DA scores in the overall group suggested only mild impairment following traumatic popliteal artery injury. Maximal functional improvement appears to be achieved within the first 2 years postinjury (minimum follow-up was 29 months). Increasing age, associated lower extremity fracture, and prolonged ischemic time led to worse long-term functional outcomes. Multiple linear regression analysis consistently identified increasing age and prolonged ischemic time and, to a lesser extent, associated lower extremity fracture as predictors of both decreased mobility and DAs among all patients and specifically among those with either penetrating or blunt injuries only. Although the interval from injury to trauma center arrival rarely is controlled by the surgeon, the time from arrival to operation is directly under the surgeon's control. Functional outcome did not improve over time, suggesting that maximal recovery may be achieved within the first 2 years postinjury. Thus, early and effective revascularization remains the only potentially *modifiable* risk factor for improved functional outcomes following traumatic popliteal artery injuries.

AUTHORSHIP

L.J.M. contributed in the study design, literature search, data collection, data analysis/interpretation, writing, and critical revision. J.P.S. contributed in the data analysis and critical revision. B.T. contributed in the study design, data analysis/interpretation, and critical revision. F.T. contributed in the study design, data analysis/interpretation, and critical revision. R.H.L. data collection and critical revision. D.M.F. contributed in the data collection and critical revision. C.E. contributed in the data collection and critical revision. L.K. contributed in the data collection. T.C.F. contributed in the critical revision. M.A.C. contributed in the data interpretation and critical revision.

DISCLOSURE

The authors declare no conflicts of interest.

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DISCUSSION

MATTHEW MARTIN, M.D. (San Diego, California): Good morning. For any of you who are worried that Mike Sise looks four inches shorter and much paler, I'm Matt Martin. I am not Mike Sise. He had to leave urgently last night and I'm honored to fill in as the Discussant on this excellent paper.

As we heard yesterday during Dr. Spain's introduction to the Presidential Address, Dr. Croce and colleagues in Memphis are renowned for doing clinically important and relevant studies that are immediately useful. This study, led by Dr. Magnotti, continues that proud tradition.

If Dr. Sise were here I know he would say this is "news you can use." The authors obtained long-term follow-up on 70 percent of survivors of popliteal artery injuries, a number that's respectable in most patient populations and a miracle in our trauma patient population.

This is high-stakes poker when we're talking about popliteal artery injuries, with permanent limb dysfunction or amputation hanging in the balance. So understanding factors associated with the ultimate outcomes and, in particular, long-term outcomes, are critical if we are ever going to improve in their care.

I have four questions for the authors.

These are truly excellent results, particularly in regard to no delayed amputations and the lack of any patients with severe functional impairment on long-term follow-up. Can you share your center's approach to these injuries? Are they being repaired by the trauma surgeons, vascular surgeons, or both? And has that changed over the time period of the study?

Second question, there appeared to be a significant disparity between the degree of impairment reported on the mobility measure versus the daily activities component. And since residual dysfunction related to the popliteal artery would seem to be most likely to affect mobility, do you think the disparity was related to associated injuries and not to the popliteal injury?

Third, as one of your conclusions is that ischemic time was a modifiable risk factor, can you please clarify how you defined ischemic time? Did this include prehospital time and/or pre-OR time or was this just intraoperative ischemic time, some of which may be relatively non-modifiable?

And, finally, I've anecdotally noted an increased request for CT angiograms prior to going to the OR, even for patients with an isolated penetrating injury and no distal pulses when there is really no mystery as to where the injury is located or what type of injury it is. Did you notice any changes in time over the pre-operative evaluation strategies that were utilized and how they affected the ischemic time or the time from arrival to the OR?

Again, I congratulate the authors on an important study. I think this truly adds to our understanding of these challenging and morbid injuries, and I thank the AAST for the honor of the podium.

ROBERT J. WINCHELL, M.D. (New York City, New York): So my question also pertains to the operative management. We've noticed a trend among more electively-based vascular surgeons to try and use a bypass rather than a direct interposition to repair these. Do you have any data on the type of repair and can that be correlated to long-term outcome?

AJAI K. MALHOTRA, M.D., M.Sc., M.B.B.A. (Burlington, Vermont): Really enjoyed it. Great work and very well presented.

But while it's important for your models to look at the average score, do you have data to say what percentage were severely-limited and what percentage were highly-functional because I think that is much more relevant to what you can tell the patient?

CLAY COTHREN BURLEW, M.D. (Denver, Colorado): Again, jumping off the questions around ischemic time, what percentage of your patients had shunts placed intraoperatively?

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And, also, did the timing of fracture fixation or external fixation impact the time to restoration of distal perfusion?

ANNE G. RIZZO, M.D. (Fairfax, Virginia): Maybe just the patients in Northern Virginia are larger in size but did you guys do any looking at the BMI as we found we had a significant issue with recovery as well as amputation with larger-sized patients?

BRYAN TROOP, M.D. (Saint Louis, Missouri): I would question how many of these patients had rehabilitation. And that's another potentially modifiable factor in recovery of these patients.

DAVID J. SKARUPA, M.D. (Jacksonville, Florida): What was the approach? Was it posterior or was it medial? And if it was medial was the pes anserinus preserved or taken down and then reconstructed?

DEBORAH KUHLS, M.D. (Las Vegas, Nevada): Did you track fasciotomies and if they were performed at the time of initial operation or upon return to the OR or post-initial operation? Thank you.

LOUIS J. MAGNOTTI, M.D., M.S. (Memphis, Tennessee): I would like to thank Dr. Martin for filling in at the last minute – it was very much appreciated – and for providing his own evaluation and discussion rather than just reading what Dr. Sise had prepared.

I'd like to give my thanks to Dr. Sise even though he is not here because he did provide me with some thoughtful insights and some key evaluation of the manuscript and what he thought was good and what he thought needed to be included in it before he had to leave.

Dr. Martin, the vast majority of these repairs were done by the trauma surgeons during the study, especially during the early years of the study when at our trauma center we had one, then zero, then one, again, board-certified vascular surgeon.

We have had a few more over the years and we're back down to essentially one so the coverage really hasn't changed much over that time period. In fact, our hospital is sort of unique in that all the current staff or at least the staff that were involved in this study were either fellows or residents at Memphis and, as such, we were all trained under the watchful eyes of Drs. Fabian and Croce who believe this is an injury that should be repaired by trauma surgeons. And, as such, we were expected, encouraged and more or less forced to deal with this injury.

You asked about the disparity in the scores. The nice thing about these patients is that all these patients had mild impairments in their functional outcomes.

The scoring system looks at these three functional domains but we really focused on the first two, the first one being basic mobility which is clearly involved in just ambulating.

Daily activities takes into account both, though. It takes into account some ambulation and some things such as grooming and eating. It's a computerized scoring system, with a bank of questions, and depending on the patient's answer will generate a different question.

So the answers to questions such as "Can you carry groceries from your car to your house?", "Can you, then, move an object within your house from one room to the other?", although they are part of daily activities also speak to mobility.

So although there is a disparity, the short answer is that, yes, not everything is explained solely by the popliteal artery injury, as nothing in trauma can be solely explained by one thing.

We did define ischemic time as the time of injury as best that we could obtain from the chart to the time of revascularization. So this takes into account your prehospital time, including those patients that get transferred to us, as well as any preoperative workup.

But really the take-away message from the study is that the only thing that we can modify on the front-end, as I will get to in a later question, the only thing that we as trauma surgeons can modify on the front-end is ischemic time. We can't affect their age. We can't affect if they have a fracture or not. And the only chance we have at modifying ischemic time is once they hit our door.

So if we're ordering a bunch of tests, if we're ordering CTAs, if we're not taking the patient to the OR in a timely fashion, that's going to increase the ischemic time and that's the only chance we get to modify that.

There is an increased use in our institution for CTA, especially as the technology has gotten better, but this is primarily or exclusively in the blunt-injured patients that are getting the rest of their diagnostic workup anyway in order to help plan the operative approach.

Those patients that are shot that have no pulse get taken directly to the operating room without a CTA.

For those questions from the floor. Dr. Winchell, all of the blunt repairs were done with reverse saphenous vein graph, whether it was above knee, below knee, bypass or interposition.

For penetrating injuries, 15 of them were done with resection and anastomosis which is where the injury is resected to clean ends and brought back together, not a primary repair but a resection anastomosis.

Dr. Malhotra, you asked about the scores. The score is a continuous linear score. It goes from Zero to 107.9. It's sort of like the QBR ratings for NFL quarterbacks; it really doesn't make sense why it wouldn't be Zero to 100. And it actually is different, slightly, between basic mobility and daily activity.

But the vast majority of patients had mild impairments. Very few had moderate and none of the patients had severe impairment when breaking it down by those categories.

We choose not to analyze it by category, that is, we felt that by categorizing this continuous variable we would potentially lose valuable information. It was felt it was much better to use as a continuous variable to get as much information out of the results as possible.

Dr. Burlew, shunts were used. And, again, the important thing is to cut down on the ischemic time as much as possible. We typically will have multiple people in the operating room – a fellow, a chief, an attending – so while we are doing the exposure and gaining control someone is gaining access to the saphenous vein to use to save time.

For those combined injuries, those with orthopedic fractures, we typically allow our orthopedic colleagues to pull it out to length under fluoroscopy so that we know exactly, more or less, the distance that we have to span rather than allowing them to put the ex-fix on because although that sounds intuitively like a great idea, sometimes with the more challenging repairs it can actually get in the way and make the repair harder.

We didn't look at BMI.

Rehab also plays an important role but what this study really shows, and something I was not expecting going into the study, that follow-up time failed to impact functional outcomes.

In fact, because of the way the study was designed, the shortest follow-up time was 29 months. And length of follow-up

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fell out of each and every model, meaning that the best you're going to get is during that first two years.

And sometime during that two years, probably early-on if we could get these patients for rehab that would increase all of these functional outcome scores.

The majority of repair approaches are through lateral approaches where everything is taken down. However, one of my former partners was a big fan of the posterior approach which when you know how to do it and it's right there, according to him, is a great approach.

Fasciotomies were all done intraoperatively and the vast majority of patients did get fasciotomies. There were no postoperative fasciotomies.

I think that answers everybody's questions, Dr. Mohr. Once again, I would like to thank the association for the privilege of the floor.

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