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Popliteal scoring assessment for vascular extremity injuries in trauma study

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CME Activity

Purpose or Statement of Need The purpose of this journal-based CME activity is to enhance the vascular specialist's ability to diagnose and care for patients with the entire spectrum of circulatory disease through a comprehensive review of contemporary vascular surgical and endovascular literature.

Learning Objective

- Explain to patients and families about the risk of amputation after the patient has had a popliteal artery injury.

Target Audience This activity is designed for vascular surgeons and individuals in related specialties.

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ABSTRACT

Objective: Traumatic popliteal vascular injuries are associated with the highest risk of limb loss of all peripheral vascular injuries. A method to evaluate the predictors of amputation is needed because previous scores could not be validated. In the present study, we aimed to provide a simplified scoring system (POPSAVEIT [popliteal scoring assessment for vascular

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extremity injuries in trauma]) that could be used preoperatively to risk stratify patients with traumatic popliteal vascular injuries for amputation.

Methods: A review of patients sustaining traumatic popliteal artery injuries was performed. Patients requiring amputation were compared with those with limb salvage at the last follow-up. Of these patients, 80% were randomly assigned to a training group for score generation and 20% to a testing group for validation. Significant predictors of amputation ($P <$ .1) on univariate analysis were included in a multivariable analysis. Those with $P <$ .05 on multivariable analysis were assigned points according to the relative value of their odds ratios (ORs). Receiver operating characteristic curves were generated to determine low- vs high-risk scores. An area under the curve of >0.65 was considered adequate for validation.

Results: A total of 355 patients were included, with an overall amputation rate of 16%. On multivariate regression analysis, the risk factors independently associated with amputation in the final model were as follows: systolic blood pressure <90 mm Hg (OR, 3.2; $P =$ .027; 1 point), associated orthopedic injury (OR, 4.9; $P =$ .014; 2 points), and a lack of preoperative pedal Doppler signals (OR, 5.5; $P =$ .002; 2 points [or 1 point for a lack of palpable pedal pulses if Doppler signal data were unavailable]). A score of ≥3 was found to maximize the sensitivity (85%) and specificity (49%) for a high risk of amputation. The receiver operating characteristic curve for the validation group had an area under the curve of 0.750, meeting the threshold for score validation.

Conclusions: The POPSAVEIT score provides a simple and practical method to effectively stratify patients preoperatively into low- and high-risk major amputation categories. (J Vasc Surg 2021;74:804-13.)

Keywords: Lower extremity trauma; Popliteal artery; Popliteal injury; Vascular trauma

Traumatic popliteal vascular injuries present a serious clinical challenge, because they are associated with the highest risk of limb loss of all peripheral vascular injuries, with major amputation rates of 14% to 25% in the civilian population.[1-4] The amputation rate is high in part because of the association with mangled extremities, which represent a subset of these injuries. In 1988, Johansen et al,[5] at Harborview Medical Center, developed the mangled extremity severity score (MESS) in an effort to determine for which patients attempts at limb salvage would be futile. Their study examined 25 patients retrospectively and 26 patients prospectively and determined that a score of ≥7 accurately predicted amputation.[5] However, the use of the MESS proved to be quite complex, and many variables require subspecialty surgical assessment, which might not be readily determined before surgery. The LEAP (lower extremity assessment project) prospective multicenter trial was unable to successfully validate the MESS, which they attributed to technical advances across surgical subspecialties, allowing more severely injured limbs to be routinely salvaged.[6] Subsequent analysis of the LEAP found that neither the MESS nor any of the previously proposed scoring systems were able to predict the functional outcome after successful limb salvage.[7] Loja et al[7] called for a revision of the MESS in 2018 after their evaluation of 230 patients in the American Association for the Surgery of Trauma PROOVIT (prospective vascular injury treatment) registry found that the MESS did not effectively predict the need for amputation. They concluded that a significant need remains to evaluate other predictors of amputation after severe lower extremity injury.[8]

The improvements in trauma care might have limited the current utility of these previous scoring systems. Several recent studies have highlighted the need for a relevant and predictive scoring system that can be easily applied across all patient populations.[8,9] In the present study, we aimed to provide an easy to use scoring system that could be used to preoperatively and effectively risk stratify patients with traumatic popliteal vascular injuries for major amputation. This aim differed from previous scoring systems whose goal was to determine a threshold beyond which repair was futile, because we recognize that this determination is often not achievable until after revascularization has already been performed. The scoring system we have developed can be used to improve communication between institutions, providers, and patients and for future studies to assess the a priori risk of limb loss.

METHODS

The POPSAVEIT (popliteal scoring assessment for vascular extremity injuries in trauma) study was a multicenter retrospective analysis of all patients sustaining traumatic popliteal vascular injuries across Western Vascular Society member institutions from 2007 to 2018. The institutional review board approved the protocol at each institution with a waiver of patient informed consent because of its retrospective design, and data use agreements were used as necessary. The demographics, mechanism of injury (blunt vs penetrating), physiologic parameters on arrival (Glasgow coma scale, initial systolic blood pressure [SBP], laboratory values), vascular examination findings, and associated orthopedic injuries were recorded. The orthopedic injuries were categorized as open or closed long bone fracture (femur, tibia/fibula) or knee dislocation of the affected extremity. The Gustilo classification

(the most widely accepted classification system of open fractures) was also used to classify all open fractures. Associated orthopedic injuries were defined as fracture or knee dislocation. For the vascular examination findings, the data points included the presence or absence of palpable pedal pulses and pedal Doppler signals and the findings from the motor and sensory examinations. To address missing Doppler examination data and create a scoring system that could also be used in austere environments lacking Doppler equipment, a composite variable for the vascular examination was formulated, with a value of 0 for the presence of preoperative pedal Doppler signals, 2 for the lack of pedal Doppler signals, and 1 for the lack of pulse in patients without Doppler signal data available. The injury severity score (ISS) and the MESS were calculated as a part of the dataset.

The primary objective was to create the POPSAVEIT score by comparing patients who had required major lower extremity amputation (above the ankle) with those with successful limb salvage at the last follow-up. Descriptive statistics of the overall dataset were reported. Of the patients, 80% were then randomly assigned into a training group for score generation and 20% to a testing group for score validation using a random number generation algorithm. This apportionment was chosen a priori to maximize the power in the training arm. Using the training dataset, descriptive univariate analyses were performed. Categorical variables are reported as frequencies and percentages. For the continuous variables, the normally distributed variables are reported as the mean ± standard deviation, and the non-normally distributed variables are reported as the median and interquartile range (IQR). The χ^2 test and the Fisher exact test were used to analyze the categorical variables. The Wilcoxon rank sum test was used to analyze the non-normally distributed continuous variables with two unpaired groups.

The variables that were preoperative predictors ($P <$ .10) for major amputation on univariate analysis were included in a multivariable logistic regression, and variables not independently associated with amputation were removed from the final model. The predictive variables in the final multivariate model were assigned points according to the relative value of their odds ratios (ORs; rounded to the nearest integer). The POPSAVEIT score was defined as the sum of these points. A receiver operating characteristic (ROC) curve was generated to determine the optimal threshold for a low- vs high-risk score that would provide the greatest sensitivity and specificity. Logistic regression analysis was used to calculate the predicted probability for amputation according to the final model and was compared to the actual rate of amputation for each score. For validation of the score, a ROC curve was generated using the score validation group to evaluate the ability of the POPSAVEIT score to discriminate for major amputation, and an area under the curve (AUC) of 0.65 was considered adequate for validation. The statistical analysis was performed using the SPSS, version 24.0 (IBM Corp, Armonk, NY).

ARTICLE HIGHLIGHTS

- **Type of Research:** A multicenter, retrospective cohort study
- **Key Findings:** In the present review, a systolic blood pressure <90 mm Hg (1 point), associated orthopedic injury (2 points), and a lack of preoperative pedal Doppler signals (2 points) or a lack of palpable pedal pulses (1 point) if Doppler is unavailable, were associated with an increased risk of amputation. A score of ≥3 was associated with a high risk of amputation.
- **Take Home Message:** The POPSAVEIT (popliteal scoring assessment for vascular extremity injuries in trauma) score provides a simple and practical method to effectively stratify patients preoperatively into low- and high-risk major amputation categories.

RESULTS

A total of 355 patients from 11 institutions had been admitted with traumatic popliteal vascular injuries. Their mean age was 33 ± 14 years, 285 were men (80%), and the overall major lower extremity amputation rate was 16% (57 patients; Table I; Supplementary Table I, online only). The median follow-up period was 69 days (IQR, 19-343 days). Of the 355 patients, 233 (66%) had sustained a blunt mechanism of injury and 31 (9%) had presented with an initial SBP of <90 mm Hg. The median MESS was 5 (IQR, 4-6) and the median ISS was 10 (IQR, 9-16). In addition, 286 patients (80%) had had an associated orthopedic injury, of whom 118 (41%) had had a dislocation injury. Of those patients with preoperative imaging studies available, 237 (67%) had undergone computed tomography angiography and 45 (13%) had undergone conventional angiography. The decision for the preoperative imaging modality was at the discretion of the trauma team and operating surgeon.

The vascular injuries included isolated popliteal artery injury (n = 252; 71%), isolated venous injury (n = 7; 2%), and concomitant arterial and venous injury (n = 97; 27%). A total of 42 patients (12%) had not undergone revascularization of their vascular injuries. Of those patients, 15 (34%) had required a primary amputation (Supplementary Table II, online only). Of the 335 patients, 313 (88%) were taken to the operating room for intended revascularization. Of these 313, 2 had undergone diagnostic angiography without intervention, 1 had undergone endovascular stenting, 3 had undergone isolated venous repair, and 307 had undergone

Table I. Demographics and comorbidities of entire cohort

Variable	Amputation		Total	*P* value
	No	Yes		
Patients	298 (84)	57 (16)	355 (100)	NA
Demographics				
Transfer in	77 (26)	17 (30)	94 (26)	.53
Male sex	237 (80)	48 (84)	285 (80)	.42
Race/ethnicity				.74
White	97 (40)	19 (38)	116 (40)	
Asian	10 (4)	1 (2)	11 (4)	
Hispanic	98 (41)	20 (40)	118 (41)	
African American	36 (15)	10 (20)	46 (16)	
Weight, kg	86 ± 25	93 ± 30	87 ± 26	.12
Height, cm	170 ± 25	173 ± 9	170 ± 23	.54
Age, years	32 ± 14	38 ± 17	33 ± 14	.060
Comorbidity				
CAD (n = 333)	2 (1)	0 (0)	2 (1)	.55
Diabetes mellitus (n = 336)	14 (5)	5 (10)	19 (6)	.18
Dialysis (n = 339)	1 (0)	0 (0)	1 (0)	.66
Smoker (n = 314)	90 (34)	12 (24)	102 (32)	.14
Hypertension (n = 335)	38 (14)	6 (11)	44 (13)	.63
Hyperlipidemia (n = 323)	16 (6)	1 (2)	17 (5)	.26
Blunt mechanism	187 (63)	46 (81)	233 (66)	**.009**
SBP on arrival, mm Hg	122 ± 26	126 ± 61	122 ± 34	.83
Pulse on arrival, bpm	99 ± 22	103 ± 26	100 ± 23	.24
Injury severity score	12 ± 9	17 ± 11	13 ± 10	**<.001**
Glasgow coma scale on arrival	14 ± 3	13 ± 4	14 ± 3	**.003**
Ischemia time to OR, hours	5 ± 6	6 ± 6	5 ± 6	.78
Ischemia time to OR >6 hours (n = 309)	81 (31)	20 (41)	101 (33)	.19
Affected vessel				.73
Popliteal artery	214 (72)	38 (67)	252 (71)	
Popliteal vein	5 (2)	1 (2)	6 (2)	
Artery and vein	79 (26)	18 (31)	97 (27)	
Arterial injury location				.059
P1	73 (25)	7 (13)	80 (23)	
P2	138 (48)	26 (47)	164 (48)	
P3	79 (27)	22 (40)	101 (29)	

CAD, Coronary artery disease; *NA*, not applicable; *OR*, operating room; *P1*, proximal segment from adductor canal to upper border of patella; *P2*, middle segment from upper border of patella to the joint line; *P3*, distal segment from joint line to the bifurcation of the anterior tibial artery and tibioperoneal trunk; *SBP*, systolic blood pressure.
Data presented as mean ± standard deviation or number (%). Boldface *P* values represent statistical significance.

open arterial repair. Forty-three patients had undergone temporary intravascular shunting before definitive repair. Of the 103 patients with venous injuries, 16 (16%) had been treated nonoperatively, 41 (40%) had undergone ligation, and 46 (45%) had undergone repair. Between the patients who had required major lower extremity amputation and those with successful limb salvage, no significant differences were found in the baseline demographics, comorbidities, interval to vascular repair, or the rate of popliteal vein injury in the overall dataset (Table I).

After randomly assigning the patients to the training and validation groups, the training group for score generation included 284 patients and the testing group for score validation included 71 patients. In the training group, a blunt mechanism of injury (P = .015), initial

Table II. Univariate analysis of risk factors for major amputation (score generation training group)

Variable	Amputation		Total	*P* value
	No	Yes		
Patients, No.	236	48	284	NA
Physiology				
Blunt mechanism	143 (61)	38 (79)	181 (64)	**.015**
Perioperative vasopressors (n = 241)	21 (10)	5 (13)	26 (11)	.66
Initial SBP <90 mm Hg	19 (8)	8 (17)	27 (10)	**.064**
Base deficit on arrival, mmol/L	−3.4 ± 5.9	−7.4 ± 5.4	−4.2 ± 6.0	**<.001**
Lactic acid on arrival, mmol/L	3.7 ± 5.1	4.3 ± 2.9	3.8 ± 4.7	.52
WBC count on arrival, $\times 10^9$/L	13.7 ± 5.9	14.7 ± 7.1	13.9 ± 6.1	.32
Hemoglobin on arrival, g/dL	12.6 ± 2.3	11.8 ± 2.2	12.4 ± 2.3	**.038**
Mangled extremity severity score	5 ± 2	7 ± 2	5 ± 2	**<.001**
Injury severity score	12 ± 9	17 ± 10	13 ± 9	**.001**
Glasgow coma scale on arrival	14 ± 2	13 ± 4	14 ± 3	**.063**
Limb ischemia				
Ischemia time to OR	5.4 ± 5.6	5.3 ± 6.6	5.4 ± 5.8	.99
Ischemia time to OR >6 hours (n = 248)	64 (31)	16 (39)	80 (32)	.31
Sensorimotor deficit on arrival (n = 243)	123 (60)	32 (82)	155 (64)	**.010**
Absence of initial palpable pedal pulse (n = 283)	198 (84)	44 (92)	242 (86)	.18
Absence of initial pedal Doppler signals (n = 237)	122 (62)	35 (90)	157 (66)	**.001**
Musculoskeletal injury				
Associated orthopedic injury	179 (76)	45 (94)	224 (79)	**.006**
Gustilo scale				
No open fracture	86 (48)	15 (33)	101 (45)	.076
I (clean wound <1 cm)	16 (9)	4 (9)	20 (9)	.70
II (wound 1-10 cm without extensive tissue damage)	15 (8)	0	15 (7)	.073
IIIa (wound >10 cm; adequate periosteal coverage)	10 (6)	3 (7)	13 (6)	.54
IIIb (wound >10 cm; massive contamination)	2 (1)	1 (2)	3 (1)	.44
IIIc (wound >10 cm; associated with arterial injury requiring repair)	50 (28)	22 (49)	72 (32)	**<.001**
Knee dislocation				**.029**
None	163 (70)	26 (54)	189 (67)	
Yes, closed	55 (24)	14 (29)	69 (25)	
Yes, open	15 (6)	8 (17)	23 (8)	

MESS, Mangled extremity severity score; *NA*, not applicable; *OR*, operating room; *SBP*, systolic blood pressure; *WBC*, white blood cell.
Data presented as mean ± standard deviation or number (%). Boldface *P* values represent statistical significance.

SBP <90 mm Hg (*P* = .067), base deficit on arrival (*P* < .001), hemoglobin level on arrival (*P* = .038), MESS (*P* < .001), ISS (*P* = .001), Glasgow coma scale on arrival (*P* = .063), sensorimotor deficit on arrival (*P* = .010), absence of initial pedal Doppler signals (*P* = .001), associated orthopedic injury (*P* = .006), Gustilo scale (*P* = .055), and knee dislocation (*P* = .029) met the predetermined level of significance (*P* < .10) for association with amputation on univariate analysis. These variables were subsequently included in the multivariate model. The ischemia time and an ischemia time >6 hours were not associated with amputation (Table II).

On multivariate regression analysis, the significant preoperative risk factors were independently associated with amputation in the final model included SBP <90 mm Hg (OR, 3.2; *P* = .027), associated orthopedic injury (OR, 4.9; *P* = .014), and lack of preoperative pedal Doppler signals (OR, 5.5; *P* = .002; Table III). Blunt injury, MESS, ISS, and Gustilo scale were not independently associated with amputation. Because 47 patients (17%) were missing preoperative Doppler signal data, the composite variable for the vascular examination findings was assessed as a surrogate for the lack of Doppler signals in the final model and was found to not significantly alter the relative ORs or predictive value of the model. The relative ORs in this final model defined the POPSAVEIT score, with 1 point for an SBP <90 mm Hg, 2 points for associated orthopedic

Table III. Multivariate analysis of risk factors for major amputation for score generation training group

Risk factor	*P* value	OR	Relative OR
Initial SBP <90 mm Hg	.027	3.2	1
Associated orthopedic injury	.014	4.9	1.5
Absence of pedal Doppler signals	.002	5.5	1.7
Vascular assessment composite variable			**POPSAVEIT score**
Initial SBP <90 mm Hg	.083	2.3	1
Associated orthopedic injury	.006	5.7	2
Absence of pedal Doppler signals (regardless of pulse) or absence of palpable pulse (if no Doppler available)	.002	2.0	2; or 1 if the latter

OR, Odds ratio; *POPSAVEIT*, popliteal scoring assessment for vascular extremity injuries in trauma; *SBP*, systolic blood pressure.

Table IV. Distribution of patients stratified by amputation and POPSAVEIT score

	Amputated	
Variable	Yes	No
Training group, No.	48	236
High-risk score (n = 161)	41 (25.5)	120 (74.5)
Low-risk score (n = 123)	7 (5.7)	116 (94.3)
Validation group, No.	9	62
High-risk score (n = 41)	8 (19.5)	33 (80.5)
Low-risk score (n = 30)	1 (3.3)	29 (96.7)

POPSAVEIT, Popliteal scoring assessment for vascular extremity injuries in trauma.
Data presented as mean ± standard deviation or number (%).

injury, 2 points for the lack of pedal Doppler signals, 0 points for presence of pedal Doppler signals (or 1 point for the lack of pedal pulses if Doppler signal data were not available; Table III).

The ROC curve for the score generation training group had an AUC of 0.704 (standard error, 0.039; 95% confidence interval, 0.628-0.779), and a score of ≥3 was found to maximize the sensitivity (85%) and specificity (49%) for a high risk of amputation (Table IV; Fig, *A*). The predicted probability for amputation using the final model was consistent with the actual amputation rates for each score (Fig, *B*). The rate of amputation in the high-risk group (score, 3-5) was 25.5% compared with 5.9% in the low-risk group (score, 0-2; $P < .001$).

In the score validation group, the ROC curve had an AUC of 0.724 (standard error, 0.092; 95% confidence interval, 0.569-0.931) and, thus, met the prespecified threshold for score validation (Fig, *C*). In the validation group, a score of ≥3 had a sensitivity of 89% and specificity of 47% for amputation, and the predicted probability for amputation was, again, consistent with the actual amputation rates for each score (Table IV; Fig, *D*).

DISCUSSION

Popliteal injuries have the highest amputation rate of any extremity vascular injury. Consequently, the value of an effective preoperative assessment tool to predict the likelihood of eventual amputation for these patients has long been understood. During the past several decades, many scoring systems have been developed for this purpose. The MESS, NISSA (nerve injury, ischemia, soft-tissue injury, skeletal injury, shock, and age of patient) score, limb salvage index, predictive salvage index, and Hannover fracture scale all aimed to determine salvageability of mangled lower extremities during the preoperative assessment with the goal of identifying a subset of patients who would benefit from primary amputation. However, these studies were limited by small sample sizes of <50 patients; and MESS, which pioneered this concept in the 1990s, was developed from only 25 patients with a validation group of 26 patients.[5,10-13] Numerous subsequent studies found that the diagnostic accuracy of MESS was insufficient and have called for the examination of additional predictors of amputation in this population.[7,8,11,14-16] These scoring systems had a, perhaps overly ambitious, aim to determine a clear threshold for when limb salvage would be futile. To achieve this, the ideal score would have 100% specificity and high sensitivity because amputation is clearly irreversible. However, with improvements in multidisciplinary trauma care, more severely injured limbs are being saved than in years past—a trend that seems likely to continue over time. Because immediate revascularization is often necessary to preserve limb salvage as an option, it is often undertaken before a full multidisciplinary assessment. Our findings in the small cohort of 42 patients without an attempt at revascularization suggest that these patients had either had minor injuries that could be managed without revascularization or had had such severe injuries that they required primary amputation. For these reasons, the goal of the present study differed from that of previous studies to develop scores by aiming to develop a score that could estimate the a priori risk of amputation for patients with traumatic popliteal vascular injuries using factors readily known preoperatively. This preoperative assessment tool could be used to effectively communicate and risk stratify patients across centers similar to the American Association for the Surgery of Trauma injury scoring scales, which are widely accepted and used across trauma centers.[17] Additionally, the ability to risk stratify could be useful in discussing the prognosis and setting expectations with patients, their families, and other providers.

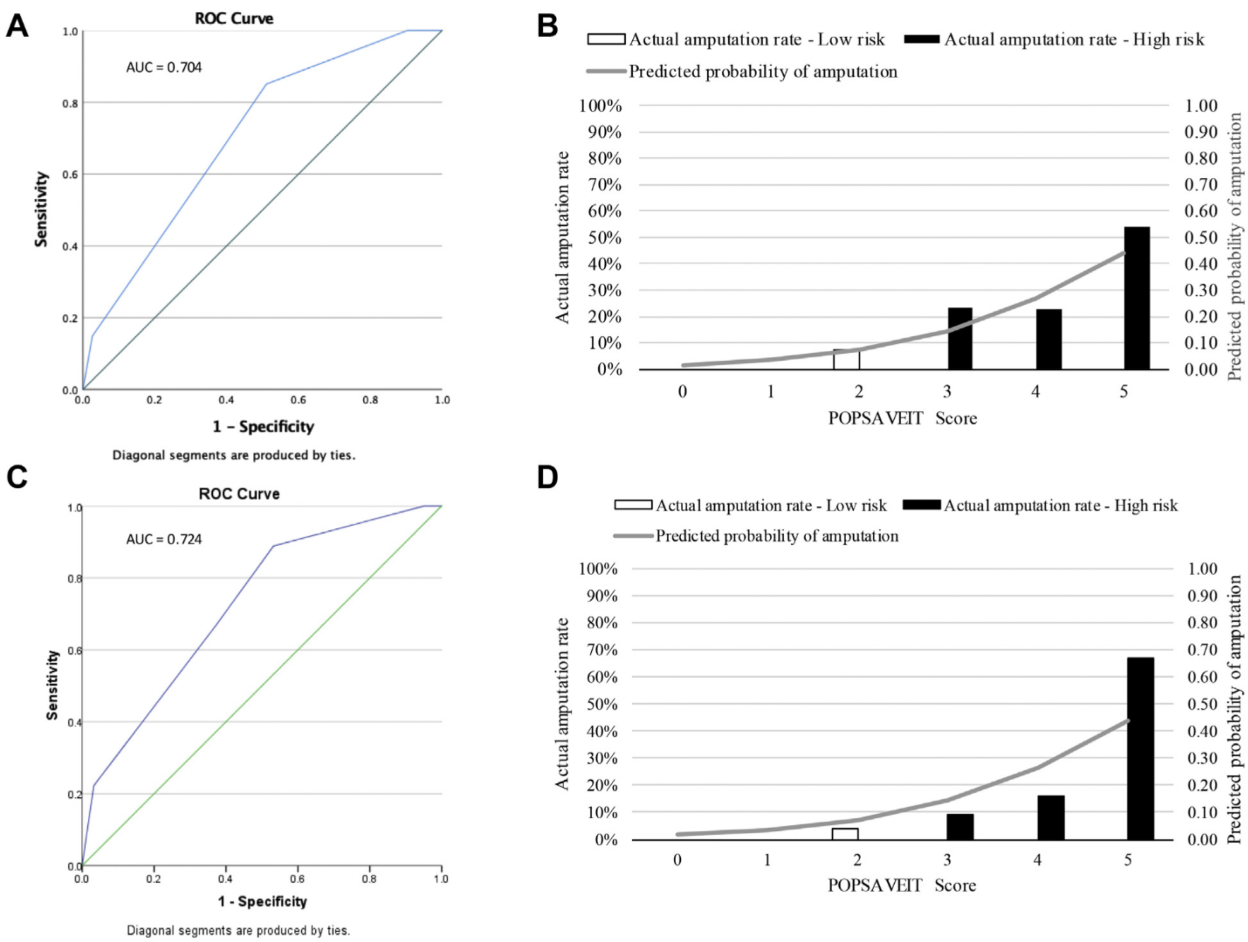

Fig. A, Receiver operating characteristic (ROC) curve for score generation training group. **B,** Rate and predicted probability of major amputation using the popliteal scoring assessment for vascular extremity injuries in trauma (*POPSAVEIT*) score for score generation training group. **C,** ROC curve for score testing validation group. **D,** Rate and predicted probability of major amputation using the POPSAVEIT score for score testing validation group.

In the present study, the overall amputation rate was 16%, comparable to current national averages reported across studies.[3,18-20] The patient demographics, comorbidities, interval to vascular repair, and rate of popliteal vein injury did not differ between the patients who had required amputation and those who had not. Although multiple factors were associated with amputation on univariate analysis, SBP <90 mm Hg, associated orthopedic injury, and the absence of pedal Doppler signals were the only variables independently associated with amputation on multivariate analysis. This is likely because a high degree of covariance was found between factors such as blunt mechanism with orthopedic injury, base deficit and lactic acid with SBP <90 mm Hg, and sensorimotor deficit with an absence of Doppler signals. The POPSAVEIT score was generated solely from variables demonstrated to be the most predictive of amputation without the influence of preconceived notions. Although the effect of concomitant popliteal vein injury is considered by many to portend a greater risk of amputation, the present study confirmed the results of other recent reports that concomitant popliteal vein injury is not associated with amputation.[21-24]

One of the limitations of previous scoring systems is that they had either vaguely defined ischemia or relied on the palpability of pulses to determine the extent of ischemia,[5,10,11] although it has been well demonstrated that the results from pulse examinations are often inaccurate, subjective, and do not correlate well with the degree of ischemia.[25-29] Alternatively, a Doppler examination and ankle brachial index have been shown to correlate well with the degree of ischemia and limb threat.[30-32] Although a Doppler examination is considered routine for the evaluation and assessment of severity in patients with acute limb ischemia, this tool will not always be available in every trauma setting, especially in austere environments. In the present study,

which had included mostly level I trauma centers, 17% of the patients did not the results of a preoperative Doppler assessment documented. To address this potential limitation, a composite variable for vascular assessment was formulated, giving a lack of pedal pulse (when Doppler signals were not available) one half the value of a lack of Doppler signals. When this composite variable was used in the place of an absence of Doppler signals, the multivariate model remained largely unchanged. As such, the composite variable was used in the final POPSAVEIT score with a value of 2 points for the lack of pedal Doppler signals or 1 point for the lack of a palpable pedal pulse if the Doppler examination findings were not available.

The present study has demonstrated that although SBP <90 mm Hg, lactic acid, and base deficit were all associated with amputation on univariate analysis, only SBP <90 mm Hg remained an independent predictor on multivariate analysis. SBP <90 mm Hg remains the most commonly used cutoff in the trauma surgery literature to date as the definition of hypotension.[33] Although lactic acid and base deficit are routinely used as objective measurements for the degree of shock and these numbers are predictive of a variety of complications, we found that these variables were not routinely available at admission.[34] Hypotension adds to the ischemic insult of the affected limb by decreasing collateral flow around the arterial injury due to both decreased perfusion pressure and the often profound compensatory peripheral vasoconstriction. Perhaps with the promulgation of the use of tourniquets for extremity hemorrhage and the "Stop the Bleed" campaign, the frequency of profound hypotension in this population has been relatively low and, we hope, will continue to decline.[35,36] In this cohort, a SBP of <90 mm Hg occurred in only 10% of patients and in 17% of those requiring amputation, which might explain why it was less predictive of amputation than the other two variables in the multivariate regression. Therefore, an initial SBP of <90 mm Hg contributes 1 point to the POPSAVEIT score.

Musculoskeletal deformity clearly presents an independent challenge in the management of lower extremity injuries vis-à-vis the ability to restore a functional limb that can bear weight and ambulate.[7,37,38] The present study found that associated orthopedic injury, type of injury (fracture vs dislocation and closed vs open), and Gustilo classification were all associated with amputation on univariate analysis but that associated orthopedic injury was the simplest and most predictive risk factor on multivariate analysis. In the final multivariate model, it had double the OR of SBP <90 mm Hg for predicting amputation and, therefore, contributes 2 points to the POPSAVEIT score. The simplicity of this score is a major potential advantage over the MESS and other scoring systems that might require specialist examination to obtain the correct score.

When evaluating the patient comprehensively, the POPSAVEIT score divides the findings into three critical components: the lack of pedal Doppler signals can be thought of as a measure of ischemia, an SBP of <90 mm Hg as a measure of global physiologic insult, and associated orthopedic injury as the presence of musculoskeletal deformity. Perhaps it should come as no surprise that these factors represent independent risks and that the accumulation of these risk factors exponentially increases the likelihood of amputation. The POPSAVEIT score appears to accurately assign patients to high-risk (3-5 points) and low-risk (0-2 points) categories for major amputation. However, importantly, even with the highest score of 5, the predicted probability of amputation is <50%. Therefore, clearly, the POPSAVEIT score should not be used as the sole factor in determining which patients require primary amputation. Although the concept of life over limb remains paramount, the salvageability of limbs is often indeterminate until further into the treatment course. Many centers have demonstrated that multidisciplinary limb salvage teams consisting of trauma, vascular, orthopedic, and plastic reconstructive surgeons who work together to formulate a patient-centered treatment plan have improved results.[39-41]

One of the advantages of the POPSAVEIT score is that an Advanced Trauma Life Support-based trauma survey routinely includes the initial blood pressure, evaluation for musculoskeletal deformities, and an extremity vascular assessment, making the POPSAVEIT score potentially broadly applicable. Furthermore, although the actual rates of amputation might differ dramatically across centers, we postulate that the high- and low-risk categorizations within a given center will likely be preserved. The POPSAVEIT score might help with refining improved reporting standards in lower extremity vascular trauma and enable better, more comprehensive studies in the future.

The strength of the present study was the inclusion of a large number of patients from numerous institutions. However, the present study also had several limitations, inherent to its retrospective design. Treatment bias and center bias could have been present; however, these were somewhat attenuated, given the number of centers involved. The median follow-up was only 2 months, demonstrating once again that long-term follow-up of vascular injuries remains a significant unmet need. With the advancements in trauma care, it is extremely difficult to predict precisely which patients will ultimately require amputation, let alone those who will have a good functional result after reconstruction. Functional ambulatory status, which has been proposed as an important factor for eventual amputation, was not assessed in the present study, because that was not the primary aim. However, this would certainly be valuable to assess in future studies.[7,42,43] Perhaps factors not known at the initial evaluation such as specifics of the revascularization

attempt and anatomic details of the injury that were not included in the present study might provide additional information that will be of benefit. Because our stated aim was to provide an easy-to-use, practical tool for risk stratification preoperatively, the factors found intraoperatively (eg, nerve transection) were not included in the present analysis. We plan to evaluate these factors in a subsequent study.

CONCLUSIONS

Traumatic popliteal vascular injuries carry significant risk for major lower extremity amputation. The POPSAVEIT score provides a simple and practical method to effectively stratify patients preoperatively into low- and high-risk categories for major amputation. Although high scores do not preclude limb salvage, the POPSAVEIT score can be used to effectively communicate risk stratification between institutions, providers, and patients. This might enable improved reporting standards in lower extremity vascular trauma. Further studies are necessary to evaluate the validity of the POPSAVEIT score in different patient populations and are currently under investigation.

AUTHOR CONTRIBUTIONS

Conception and design: LO, RD, EF, GM
Analysis and interpretation: LO, RD, GM
Data collection: LO, RD, EF, NSR, WY, CP, CF, AC, SS, MN, BB, JB, SK, HB, VC, VH, WZ, AL, NB, YC, KW, JU, GM
Writing the article: LO, RD, GM
Critical revision of the article: LO, RD, EF, NSR, WY, CP, CF, AC, SS, MN, BB, JB, SK, HB, VC, VH, WZ, AL, NB, YC, KW, JU, GM
Final approval of the article: LO, RD, EF, NSR, WY, CP, CF, AC, SS, MN, BB, JB, SK, HB, VC, VH, WZ, AL, NB, YC, KW, JU, GM
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Supplementary Table I (online only). Demographics and comorbidities of amputation cohort

	Revascularization before amputation			
Variable	Yes	No	Total	*P* value
Patients, No.	42	15	57	NA
Demographics				
Transfer in	12 (29)	5 (33)	17 (30)	.73
Male sex	34 (81)	14 (93)	48 (84)	.26
Age, years	36 ± 16	43 ± 20	38 ± 17	.33
Blunt mechanism	34 (81)	12 (80)	46 (81)	.94
SBP on arrival, mm Hg	136 ± 67	100 ± 28	126 ± 61	.003
Pulse on arrival, bpm	104 ± 26	101 ± 28	103 ± 26	.43
Injury severity score	16 ± 11	20 ± 10	17 ± 11	.18
Glasgow coma scale on arrival	14 ± 3	12 ± 5	13 ± 4	.36
Ischemia time to OR, hours	6 ± 7	5 ± 4	6 ± 6	.89
Ischemia time to OR >6 hours (n = 49)	15 (42)	5 (38)	20 (41)	.84
Affected vessel				.41
Popliteal artery	26 (62)	12 (80)	38 (67)	
Popliteal vein	1 (2)	0	1 (2)	
Popliteal artery and vein	15 (36)	3 (20)	18 (32)	
Arterial injury location				.15
P1	7 (17)	0 (0)	7 (13)	
P2	20 (49)	6 (43)	26 (47)	
P3	14 (34)	8 (57)	22 (40)	
Physiology				
Initial SBP <90 mm Hg	6 (14)	5 (33)	11 (19)	.11
Base deficit on arrival, mmol/L	−7.0 ± 5.1	−7.3 ± 6.4	−7.1 ± 5.4	.86
Lactic acid on arrival, mmol/L	3.9 ± 2.6	5.6 ± 2.9	4.3 ± 2.7	.12
WBC count on arrival, $\times 10^9$/L	15.1 ± 6.6	13.8 ± 7.7	14.7 ± 6.9	.20
Hemoglobin on arrival, g/dL	12.2 ± 1.8	11.0 ± 2.9	11.9 ± 2.2	.19
Mangled extremity severity score	7 ± 2	8 ± 3	7 ± 2	.29
Limb ischemia				
Sensorimotor deficit on arrival (n = 46)	31 (89)	7 (64)	38 (83)	.057
Absence of initial palpable pedal pulse	38 (90)	13 (87)	51 (90)	.68
Absence of initial pedal Doppler signals (n = 46)	31 (91)	11 (92)	42 (91)	.96
Musculoskeletal injury				
Associated orthopedic injury	39 (93)	14 (93)	53 (93)	.95
Gustilo scale				.11
No open fracture	14 (36)	3 (21)	17 (32)	
I (clean wound <1 cm)	3 (8)	1 (7)	4 (8)	
II (wound 1-10 cm without extensive tissue damage)	0 (0)	0 (0)	0 (0)	
IIIa (wound >10 cm; adequate periosteal coverage)	3 (8)	0 (0)	3 (6)	
IIIb (wound >10 cm; massive contamination)	0 (0)	2 (14)	2 (4)	
IIIc (wound >10 cm; associated with arterial injury requiring repair)	19 (49)	8 (57)	27 (51)	

Supplementary Table I (online only). Continued.

Variable	Revascularization before amputation		Total	*P* value
	Yes	No		
Knee dislocation				.62
None	22 (52)	10 (67)	32 (56)	
Yes, closed	13 (31)	3 (20)	16 (28)	
Yes, open	7 (17)	2 (13)	9 (16)	
VEIT score	3 ± 1	4 ± 1	3 ± 1	.40

NA, Not applicable; *OR,* operating room; *P1,* proximal segment from adductor canal to upper border of patella; *P2,* middle segment from upper border of patella to the joint line; *P3,* distal segment from joint line to the bifurcation of the anterior tibial artery and tibioperoneal trunk; *POPSAVEIT,* popliteal scoring assessment for vascular extremity injuries in trauma; *SBP,* systolic blood pressure; *WBC,* white blood cell.
Data presented as mean ± standard deviation or number (%).

Supplementary Table II (online only). Characteristics of patients without a revascularization attempt

Variable	Amputation No	Amputation Yes	Total	*P* value
Patients, No.	27	15	42	NA
Demographics				
Transfer in	6 (22)	5 (33)	11 (26)	.43
Male sex	24 (89)	14 (93)	38 (90)	.64
Age, years	38 ± 16	43 ± 20	39 ± 17	.52
Blunt mechanism	19 (70)	12 (80)	31 (74)	.50
SBP on arrival, mm Hg	125 ± 19	100 ± 28	116 ± 26	.004
Pulse on arrival, bpm	95 ± 20	101 ± 28	97 ± 23	.66
Injury severity score	7 ± 3	20 ± 10	12 ± 9	<.001
Glasgow coma scale on arrival	14 ± 3	12 ± 5	13 ± 4	.025
Affected vessel				.23
Popliteal artery	25 (93)	12 (80)	37 (88)	
Popliteal vein	0 (0)	0 (0)	0 (0)	
Popliteal artery and vein	2 (7)	3 (20)	5 (12)	
Arterial injury location				.020
P1	7 (28)	0 (0)	7 (18)	
P2	13 (52)	6 (43)	19 (49)	
P3	5 (20)	8 (57)	13 (33)	
Physiology				
Initial SBP <90 mm Hg	1 (4)	5 (33)	6 (14)	.009
Base deficit on arrival, mmol/L	−0.9 ± 3.1	−7.3 ± 6.4	−4.2 ± 6.0	.005
Lactic acid on arrival, mmol/L	2.4 ± 1.5	5.6 ± 2.9	3.8 ± 2.7	.030
WBC count on arrival, $\times 10^9$/L	11.2 ± 4.4	13.8 ± 7.7	12.2 ± 5.9	.28
Hemoglobin on arrival, g/dL	13.1 ± 1.5	11.0 ± 2.9	12.3 ± 2.3	.018
Mangled extremity severity score	4 ± 1	8 ± 3	5 ± 3	<.001
Limb ischemia				
Sensorimotor deficit on arrival (n = 33)	6 (27)	7 (64)	13 (39)	.044
Absence of initial palpable pedal pulse (n = 41)	8 (31)	13 (87)	21 (51)	.001
Absence of initial pedal Doppler signals (n = 33)	0 (0)	11 (92)	11 (33)	<.001
Musculoskeletal injury				
Associated orthopedic injury	24 (89)	14 (93)	38 (90)	.64
Gustilo scale				
No open fracture	12 (50)	3 (21)	15 (40)	.007
I (clean wound <1 cm)	5 (21)	1 (7)	6 (16)	
II (wound 1-10 cm without extensive tissue damage)	2 (8)	0 (0)	2 (5)	
IIIa (wound >10 cm; adequate periosteal coverage)	2 (8)	0 (0)	2 (5)	
IIIb (wound >10 cm; massive contamination)	2 (8)	2 (14)	4 (10)	
IIIc (wound >10 cm; associated with arterial injury requiring repair)	1 (4)	8 (57)	9 (24)	
Knee dislocation				.97
None	18 (67)	10 (67)	28 (67)	
Yes, closed	6 (22)	3 (20)	9 (21)	
Yes, open	3 (11)	2 (13)	5 (12)	
POPSAVEIT score	2 ± 1	4 ± 1	2 ± 1	<.001

NA, Not applicable; *OR,* operating room; *P1,* proximal segment from adductor canal to upper border of patella; *P2,* middle segment from upper border of patella to the joint line; *P3,* distal segment from joint line to the bifurcation of the anterior tibial artery and tibioperoneal trunk; *POPSAVEIT,* popliteal scoring assessment for vascular extremity injuries in trauma; *SBP,* systolic blood pressure; *WBC,* white blood cell.
Data presented as mean ± standard deviation or number (%).