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30-Day Morbidity and Mortality of Surgical Management for Lower Limb Vascular Injury in Yemeni Civilians: A Prospective Cohort Study

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Abstract

Background

Lower limb vascular injuries in Yemen are predominantly caused by high-velocity penetrating trauma, compounded by delayed presentation and constrained healthcare resources in the country. We investigated 30-day morbidity and mortality, as well as the independent predictors of adverse outcomes after surgical revascularization.

Methods

We conducted a prospective cohort study of 78 consecutive civilian patients with traumatic lower limb vascular injury at three tertiary referral centers between November 2023 and January 2026. Of the 94 screened patients, 78 were enrolled after excluding 16 patients. Predictors of 30-day mortality were identified using multivariable logistic regression with Firth's penalized likelihood, bootstrap validation, and exact logistic regression as robustness checks (IBM SPSS Statistics, v26.0; IBM Corp., Armonk, NY, USA).

Results

The cohort was 94.9% male, with a mean age of 26.7 ± 11.8 years. Overall, the 30-day morbidity was 51.3%, dominated by surgical site infection and postoperative bleeding (26.9% each). The all-cause mortality rate was 9.0% (n = 7), secondary amputation rate was 5.1% (n = 4), and limb salvage rate was 94.9%. Hemodynamic instability was independently associated with mortality (adjusted OR 72.43, 95% CI 7.68–1995.26; P < 0.001), whereas revascularization delay > 72 h demonstrated a borderline independent association (adjusted OR 50.14, 95% CI 2.39–5084.95; P = 0.057). Bootstrap validation yielded an optimism-corrected C-statistic of 0.90, and the E-values indicated robustness against unmeasured confounding. Among the 68 survivors, 89.1% without nerve injury achieved full recovery versus 0% with nerve injury (P < 0.001).

Conclusions

Yemeni civilians with lower limb vascular trauma experience substantial morbidity and mortality. Hemodynamic instability was independently associated with mortality, whereas presentation beyond 72 h demonstrated a borderline independent association in the exploratory multivariable model. Concomitant peripheral nerve injury, rather than vascular status, dictates functional recovery. These findings support investments in pre-hospital triage, accelerated surgical evacuation, and early neurological assessment.

Trial registration

: Not applicable.

Background

Lower limb vascular injuries represent a disproportionate burden of trauma-related morbidity and mortality in conflict-affected regions, where military-pattern wounding intersects with constrained civilian healthcare infrastructure [1]. These injuries arise from high-energy mechanisms, such as motor vehicle collisions, industrial incidents, and acts of violence, and frequently precipitate tissue ischemia, limb loss, and death if not addressed expediently [1, 2]. The reported incidence of vascular injury in civilian populations has steadily increased over recent decades, driven by escalating road traffic trauma and criminal violence [2]. Across published series, lower limb vascular injuries account for 1% to 20% of major vascular trauma, with wide variations reflecting differences in case mix, geography, and healthcare access [3–5].

The clinical consequences of this are substantial. Postoperative morbidity ranges from 10% in isolated lower extremity vascular trauma [6] to 54.2% in non-iatrogenic civilian series [7], while mortality varies from 2.6% for isolated femoral vessel injury to 52.6% in polytrauma cases [8, 9]. Recognized determinants of adverse outcomes include the mechanism and anatomical level of injury, failed revascularization, multilevel arterial injury, associated fractures, compartment syndrome, soft tissue disruption, temporary shunting, and fasciotomy [9–11]. These risk factors operate synergistically; prolonged ischemia amplifies the physiological insult of hemorrhagic shock, while concomitant bone and nerve injuries compound the technical complexity of limb salvage [10, 11].

In Yemen, this global burden has acquired a distinct local phenotype. The reported incidence of lower limb vascular injury ranges from 4% to 9%, with gunshot wounds — predominantly high-velocity — representing the most common mechanism, followed by stab wounds and road traffic injuries [12]. In a single-center retrospective series, the associated limb loss and mortality rates were 8.3% and 9.8%, respectively [12]. However, these figures predate the current conflict and were derived from retrospective audits with limited follow-up. Consequently, the 30-day morbidity, mortality, and functional trajectory of surgically managed lower limb vascular trauma in contemporary Yemeni civilians remain poorly characterized in the literature. This gap is clinically consequential; without robust local outcome data, prehospital triage protocols, surgical evacuation timelines, and resource allocation decisions are guided by extrapolation from Western civilian or military cohorts whose epidemiology and healthcare infrastructure differ fundamentally from the Yemeni context.

Therefore, we conducted this prospective cohort study to investigate the 30-day morbidity, mortality, and short-term functional outcomes of surgical repair for lower limb vascular injury in Yemeni civilian trauma patients and to identify independent clinical predictors of death and secondary amputation in this population.

Methods

Study design

This prospective cohort study was conducted in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [13] at three tertiary government referral centers providing emergency vascular surgery in the capital city between November 2023 and January 2026.

Study population

During the study period, 94 consecutive patients with traumatic lower limb vascular injuries were screened for eligibility. Of these, 16 were excluded: seven had undergone initial surgery at other hospitals, four presented with frank irreversible ischemia and tissue death upon arrival, two had traumatic field amputations, and three refused to participate in the study. The remaining 78 patients were enrolled prospectively; all 78 completed the 30-day follow-up period through outpatient clinic review or structured telephone interview, and no patient was lost to follow-up (Fig. 1).

The inclusion criteria were as follows: 1) male or female patients of any age; 2) lower limb vascular injury resulting from penetrating or blunt trauma; and 3) provision of informed consent. The exclusion criteria were as follows: 1) patients initially operated at other hospitals and subsequently referred for secondary management; 2) patients presenting with frank irreversible ischemia and tissue death upon arrival; 3) traumatic field amputation; and 4) refusal to participate in the study. The cohort included 17 pediatric patients (≤ 18 years; 21.8%) and 61 adult patients (> 18 years; 78.2%). Given the small pediatric subgroup, the primary analysis was conducted on the entire cohort, and a sensitivity analysis restricted to adults was performed to assess physiological heterogeneity.

Out of 94 consecutive patients screened, 16 were excluded based on pre-specified criteria, leaving a final prospective cohort of 78 patients. All 78 patients completed the 30-day follow-up period (100% retention). At 30 days, the cohort experienced 7 deaths (9.0%) and 4 secondary amputations (5.1%), achieving an overall limb salvage rate of 94.9% (n = 74). To prevent competing-risk bias, the 7 deaths and the 3 surviving amputated patients were excluded from functional assessments, leaving exactly 68 salvaged-limb survivors to enter the final univariable functional recovery analysis. STROBE, Strengthening the Reporting of Observational Studies in Epidemiology.

Data collection and outcomes

Demographics, mechanism of trauma, wound characteristics, anatomical level of vascular injury, surgical procedures performed, and complications were prospectively recorded during the perioperative period using a structured and pretested case report form. Hemodynamic instability on presentation was defined as the presence of any of the following at emergency department arrival: 1) systolic blood

pressure < 90 mmHg or mean arterial pressure < 65 mmHg; 2) heart rate > 120 beats per minute with systolic blood pressure < 100 mmHg; 3) clinical signs of shock including cool extremities, altered mental status, or delayed capillary refill > 3 seconds; or 4) requirement for immediate crystalloid resuscitation > 1000 mL or blood transfusion within the first hour of arrival to maintain tissue perfusion. Patients who did not meet these criteria were classified as hemodynamically stable.

Formal trauma severity scores (Injury Severity Score, Revised Trauma Score, and Mangled Extremity Severity Score) were not routinely calculated in the participating emergency departments owing to resource constraints and the prioritization of life-saving interventions over documentation. Consequently, we were unable to adjust for the overall polytrauma burden beyond hemodynamic and anatomical variables.

Functional status at 30 days was assessed by the operating surgeon at an outpatient clinic review or through a structured telephone interview when clinic attendance was not possible. Functional recovery was classified using a locally adapted ordinal scale: 1) no loss of function, full weight-bearing ambulation without assistive devices, intact proprioception, and return to pre-injury daily activities; 2) partial loss of function, ambulation with an assistive device (brace, cane, or walker), reduced range of motion, or sensory deficit not preventing independent mobility; and 3) complete loss of function, non-ambulatory status, flail limb, or complete motor and sensory loss below the level of injury. Patients who died before the 30-day assessment were excluded. This functional scale was developed locally for this study and was not validated against standardized instruments such as the Lower Extremity Functional Scale or SF-36.

Sample size

The sample size was calculated using Epi Info StatCalc (version 3; Centers for Disease Control and Prevention, Atlanta, GA, USA) based on previously reported regional morbidity and mortality rates of 8.3% and 9.8%, respectively [12]. A pooled expected frequency of 9.3% was used as the conservative input, yielding a target of 143 patients with a 95% confidence level, 5% margin of error, and 10% dropout. However, owing to time constraints and hospital volume during the study period, a final cohort of 78 patients who met all criteria was successfully enrolled and analyzed.

Statistical analysis

Descriptive statistics included frequencies and percentages for categorical variables and means with standard deviations or medians with interquartile ranges for continuous variables, depending on the distribution normality assessed using the Shapiro-Wilk test. The time to revascularization was heavily right-skewed (Shapiro-Wilk $P < 0.001$); consequently, this variable is presented as median [interquartile range] in descriptive summaries and was dichotomized (> 12 h, > 72 h) for the regression analyses.

Univariate associations with 30-day mortality, secondary amputation, and functional disability were assessed using the chi-squared test or Fisher's exact test for categorical variables and the Mann–Whitney U test for continuous variables. Values for reporting statistical data, such as P-values and confidence intervals, were presented and rounded to two decimal places. P values are expressed as two digits to the right of the decimal point unless the first two digits are zeros, in which case three digits to the right of the decimal point are provided. P values less than 0.001 were designated as $P < 0.001$ rather than exact values.

Prior to multivariable modeling, potential collinearity between hemodynamic instability and revascularization delay was formally evaluated using Spearman's correlation coefficients and variance inflation factors, with a threshold of < 2.5 indicating acceptable collinearity. Independent predictors of 30-day mortality and secondary amputation were identified using multivariable logistic regression with Firth penalized likelihood to address the small number of events and potential quasi-complete separations. Candidate predictors were entered into multivariable models based on their clinical relevance and the univariable screening results.

One patient experienced an extreme outlier delay of 960 h (40 days) between injury and revascularization owing to delayed referral from a peripheral facility and prolonged prehospital transport in a conflict-affected area. To evaluate the influence of this extreme outlier on the multivariable model, we performed a sensitivity analysis by repeating the Firth penalized regression after excluding this patient.

Functional outcomes were analyzed only in a subset of 68 survivors with salvaged limbs at 30 days. This analytic approach introduces competing risk bias, as the seven patients who died (9.0%) likely represented the most severe injuries and would presumably have had the worst functional outcomes had they survived. Therefore, the reported functional recovery rate represents a conditional estimate among survivors and may overestimate true functional success.

A sensitivity analysis restricted to the adult subgroup (n = 61; six deaths, three secondary amputations) repeated the univariate screening and multivariate regression modeling. Owing to the low frequency of events in this subgroup, multivariable modeling was prone to a quasi-complete separation.

All statistical analyses were conducted using IBM SPSS Statistics (version 26.0; IBM Corp., Armonk, NY, USA) and Python statistical libraries (Python Software Foundation, Wilmington, DE, USA), with a significance level set at $P < 0.05$ (two-tailed). The manuscript was edited for English-language clarity using Paperpal AI (https://paperpal.com); no analytical decision-making, data extraction, or interpretation was performed by any of the large language models.

Ethical considerations

This study was approved by the Ethics Committee of the Faculty of Medicine, Sana'a University, and was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from each patient or, for minors, from their legal guardians.

Results

Baseline characteristics

Seventy-eight patients were enrolled in this study. The cohort was predominantly young adult males (94.9%, n = 74), with a mean age of 26.7 ± 11.8 years. Gunshot wounds caused 50.0% (n = 39) of injuries, and road traffic accidents caused 34.6% (n = 27) of injuries. At presentation, 20.5% (n = 16) were hemodynamically unstable, 91.0% (n = 71) received blood transfusions, and concomitant orthopedic injury was present in 79.5% (n = 62). Peripheral nerve injury was documented in 19.2% (n = 15) of patients. Distal pulses were absent in 92.3% (n = 72) of affected limbs. The most frequently injured vessels were the posterior tibial (38.5%, n = 30), anterior tibial (29.5%, n = 23), and popliteal arteries (25.6%, n = 20). Concurrent venous injury was identified in 30.8% (n = 24) of patients (Table 1).

Table 1
Baseline demographic and clinical characteristics (N = 78)

Variable	Value (N = 78)
Demographics	
Age (years) mean ± SD	26.7 ± 11.8
Age (years) median [IQR]	25 [19–34]
Male sex n (%)	74 (94.9)
Adult patients (> 18 years) n (%)	55 (70.5)
Pediatric patients (≤ 18 years) n (%)	17 (21.8)
Mechanism of trauma n (%)	
High-velocity gunshot wound	37 (47.4)
Road traffic accident	27 (34.6)
Gunshot wounds (combined)[a]	39 (50.0)
Other[b]	12 (15.4)
Wound type n (%)	
Penetrating	32 (41.0)
Lacerated	26 (33.3)
Crushed	11 (14.1)
Other[c]	9 (11.5)
Clinical presentation n (%)	
Hemodynamic instability	16 (20.5)
Required blood transfusion	71 (91.0)
Compartment syndrome	15 (19.2)
Associated injuries n (%)	
Bone injury	62 (79.5)
Peripheral nerve injury	15 (19.2)
Major injury to other body regions	13 (16.7)
Limb examination n (%)	
Distal pulse absent	72 (92.3)

Variable	Value (N = 78)
Distal pulse weak	2 (2.6)
Pale cyanosed or mottled limb color	34 (43.6)
Absent sensation	13 (16.7)
Absent motor function	11 (14.1)
Time to revascularization (h) median [IQR]	8 [6–14]
> 12 h n (%)	21 (26.9)
> 72 h n (%)	4 (5.1)

[a] *Combined high-velocity and low-velocity gunshot wounds.*

[b] *Includes low-velocity gunshot wounds, stab wounds, cutting wounds, falls, and other miscellaneous mechanisms.*

[c] *Includes stabbing, cutting, contamination, and no visible wounds.*

SD: standard deviation; IQR: interquartile range; GSW: gunshot wound.

Surgical management

The median time from injury to revascularization was 8 h (IQR, 6–14 h; range, 1–960 h). Revascularization was delayed beyond 12 h in 26.9% (n = 21) and beyond 72 h in 5.1% (n = 4) of patients. Definitive arterial repair was achieved with a reversed saphenous interposition vein graft in 74.4% (n = 58), primary anastomosis in 10.3% (n = 8), primary repair in 7.7% (n = 6), and arterial ligation in 6.4% (n = 5) of patients. A four-compartment fasciotomy was performed in 64.1% (n = 50) of the patients (Table 2).

Table 2
Vascular injury characteristics and surgical management (N = 78)

Variable	Value (N = 78)
Arterial injuries n (%)[a]	
Posterior tibial artery	30 (38.5)
Anterior tibial artery	23 (29.5)
Popliteal artery	20 (25.6)
Superficial femoral artery	15 (19.2)
Common femoral artery	6 (7.7)
Any concurrent venous injury[b]	24 (30.8)
Arterial repair type n (%)	
Reversed saphenous interposition graft	58 (74.4)
Primary anastomosis	8 (10.3)
Primary repair	6 (7.7)
Ligation	5 (6.4)
No arterial repair[c]	1 (1.3)
Venous repair type n (%)	
No repair	53 (67.9)
Ligation	10 (12.8)
Primary anastomosis	9 (11.5)
Primary repair	4 (5.1)
Venous patch angioplasty	2 (2.6)
Four-compartment fasciotomy performed	50 (64.1)

[a] *Patients may have more than one injured vessel; therefore, the arterial percentages do not sum to 100%.*

[b] *Pure venous injury without an arterial component.*

[c] *One patient with an isolated venous injury did not undergo arterial repair.*

RSIPG, reversed saphenous interposition vein graft.

Postoperative outcomes

The 30-day all-cause mortality rate was 9.0% (n = 7), and the overall morbidity was 51.3% (n = 40) **(**Fig. 2 **and** Table 3**)**. The most frequent complications were postoperative bleeding (26.9%, n = 21) and surgical site infection (26.9%, n = 21). Graft thrombosis occurred in 11.5% (n = 9), and reoperation was required in 21.8% (n = 17) of patients. The overall limb salvage rate was 94.9% (n = 74). Secondary amputation was required in 5.1% (n = 4) of the patients. The median length of hospital stay was 8 days (IQR 6–20 days). Patients with complications had significantly longer hospitalizations than those without (median, 13 vs. 8 days; P = 0.01). Wound morphology modulated infectious risk: lacerated wounds were associated with a 57.7% surgical site infection rate compared with 12.5% for penetrating wounds (P < 0.001).

Absolute risk differences quantify these clinical gradients. Lacerated wounds had a 45.2-percentage-point higher surgical site infection rate than penetrating wounds (95% CI 20.8–63.6%, P < 0.001). Among 68 survivors with salvaged limbs, every patient with a documented nerve injury (13/13) developed at least partial functional loss, compared with 10.9% (6/55) of those without, an absolute risk difference of 89.1% (95% CI 63.8–94.9%, Fisher P < 0.001), quantifying the dominant role of associated nerve injury in the functional outcome.

At the bedside, approximately one additional death is expected for every three hemodynamically unstable patients (number needed to harm [NNH] ≈ 2.8, 95% CI 1.6–8.0) and for every six patients revascularized beyond 72 h (NNH ≈ 5.9, 95% CI 1.4–8.7) — clinically meaningful effect sizes that justify aggressive resuscitation and early revascularization protocols.

Table 3
Primary 30-day outcomes and functional recovery (N = 78)

Outcome	Value (N = 78)
30-day all-cause mortality	7 (9.0)
Secondary amputation	4 (5.1)
Overall limb salvage	74 (94.9)
30-day morbidity n (%)	
Any complication[a]	40 (51.3)
Postoperative bleeding	21 (26.9)
Surgical site infection	21 (26.9)
Hematoma	11 (14.1)
Graft thrombosis	9 (11.5)
Acute renal failure	5 (6.4)
Reperfusion syndrome	4 (5.1)
Multi-organ failure	3 (3.8)
Reoperation within 30 days	17 (21.8)
Length of hospital stay (days) median [IQR][b]	8 [6–20]
Functional outcome in survivors with salvaged limbs (n = 68) n (%)	
No loss of function	49 (72.1)
Partial loss of function	16 (23.5)
Complete loss of function	3 (4.4)
Not applicable[c]	7 (9.0)
Full recovery without nerve injury (n = 55)	49 (89.1)
Full recovery with nerve injury (n = 13)[d]	0 (0)

[a] *Patients may have experienced more than one complication; the "Any complication" row reports the number of patients with at least one event, while individual complication rows report the frequency of each specific event.*

[b] *Length of hospital stay was capped at 30 days for analytical consistency with the follow-up period.*

[c] *The "Not applicable" functional category corresponds to the seven patients who died before functional outcome assessment at 30 days.*

[d] *Among the 15 patients with peripheral nerve injuries, the tibial nerve was affected in 10 (66.7%) and the sciatic nerve in 5 (33.3%); all complete functional losses occurred in the sciatic nerve subgroup.*

SD: standard deviation; IQR: interquartile range; SSI: surgical site infection; ARF: acute renal failure.

Predictor analysis

In the univariable analysis using Fisher's exact test, hemodynamic instability was significantly associated with 30-day mortality (37.5% in unstable patients versus 1.6% in stable patients; P < 0.001). No other categorical variables were significantly associated with mortality or secondary amputations **(**Table 4**)**.

Among the 13 candidate predictors screened by Firth penalized univariable logistic regression, only hemodynamic instability (odds ratio [OR] 25.38, 95% confidence interval [CI] 3.72–172.95; P < 0.001) was significantly associated with 30-day mortality, and all other screened variables showed non-significant associations. Continuous variables (age, time to revascularization) were heavily right-skewed, and their linearity assumptions were untestable with only seven events; they were reported in the univariable Firth screening output but were not entered into the multivariable model beyond the pre-specified categorical delay thresholds.

Spearman’s correlation analysis revealed only a modest negative correlation between hemodynamic instability and time to revascularization (rho = − 0.291; P = 0.01), and the variance inflation factor for both predictors was 1.09, indicating negligible collinearity and justifying their inclusion in the multivariable model.

Table 4
Univariable analysis of predictors of 30-day mortality and secondary amputation (N = 78)

Predictor	Mortality rate n/N (%)	P-value	Amputation rate n/N (%)	P-value
Age group				
Adult (> 18 years)	6/61 (9.8)	1.00	3/61 (4.9)	1.00
Pediatric (≤ 18 years)	1/17 (5.9)		1/17 (5.9)	
Sex				
Male	7/74 (9.5)	1.00	3/74 (4.1)	0.19
Female	0/4 (0.0)		1/4 (25.0)	
Mechanism of trauma				
Gunshot wound	4/39 (10.3)	1.00	1/39 (2.6)	0.62
Other	3/39 (7.7)		3/39 (7.7)	
Wound type				
Penetrating	4/32 (12.5)	0.44	1/32 (3.1)	0.64
Other (non-penetrating)	3/46 (6.5)		3/46 (6.5)	
Hemodynamic stability				
Stable	1/62 (1.6)	< 0.001	2/62 (3.2)	0.185
Unstable/shock	6/16 (37.5)		2/16 (12.5)	
Associated bone injury				
No	1/16 (6.2)	1.00	0/16 (0.0)	0.58
Yes	6/62 (9.7)		4/62 (6.5)	
Associated nerve injury				
No	6/63 (9.5)	1.00	3/63 (4.8)	1.00
Yes	1/15 (6.7)		1/15 (6.7)	
Compartment syndrome				

Note. Data are presented as event rate with count/total (percentage) for categorical variables. P-values were calculated using Fisher's exact test (two-sided) for categorical variables. Continuous variables (age time to revascularization) were not significantly associated with either outcome and are omitted for brevity; they are reported in the univariable Firth screening output. Bold P-values denote statistical significance at P < 0.05. The delay > 72 hours row was added to this table to provide the complete 2x2 contingency for mortality and amputation outcomes; the crude Haldane-corrected odds ratio for mortality is 4.52 (95% CI 0.46–44.45). OR odds ratio; CI confidence interval.

Predictor	Mortality rate n/N (%)	P-value	Amputation rate n/N (%)	P-value
No	4/63 (6.3)	0.13	2/63 (3.2)	0.17
Yes	3/15 (20.0)		2/15 (13.3)	
Fasciotomy				
No	2/28 (7.1)	1.00	0/28 (0.0)	0.29
Yes	5/50 (10.0)		4/50 (8.0)	
Time to revascularization				
≤72 hours	6/74 (8.1)	0.32	3/74 (4.1)	0.19
>72 hours	1/4 (25.0)		1/4 (25.0)	

Note. Data are presented as event rate with count/total (percentage) for categorical variables. P-values were calculated using Fisher's exact test (two-sided) for categorical variables. Continuous variables (age time to revascularization) were not significantly associated with either outcome and are omitted for brevity; they are reported in the univariable Firth screening output. Bold P-values denote statistical significance at P < 0.05. The delay > 72 hours row was added to this table to provide the complete 2x2 contingency for mortality and amputation outcomes; the crude Haldane-corrected odds ratio for mortality is 4.52 (95% CI 0.46–44.45). OR odds ratio; CI confidence interval.

In the multivariable Firth penalized logistic regression **(**Table 5**)**, hemodynamic instability at presentation was independently associated with mortality (adjusted OR 72.43, 95% CI 7.68–1995.26; P < 0.001), whereas a time to revascularization exceeding 72 h demonstrated a borderline independent association (adjusted OR 50.14, 95% CI 2.39–5084.95; P = 0.057) in exploratory multivariable modeling. For secondary amputation, neither revascularization delay exceeding 12 h (adjusted OR 2.87, 95% CI 0.45–18.36; P = 0.27) nor compartment syndrome at presentation (adjusted OR 4.50, 95% CI 0.70–29.07; P = 0.11) were significant **risk factors (**Fig. 3**)**. Given the small number of outcome events, these multivariable estimates should be interpreted as hypothesis-generating rather than confirmatory, and the wide confidence intervals reflect the mathematical uncertainty inherent in low-event regression.

Table 5
Multivariable logistic regression with Firth penalized likelihood

Predictor	Crude OR (95% CI)	P-value	Adjusted OR (95% CI)	P-value
Model 1 — Predictors of 30-day mortality (events = 7/78)				
Hemodynamic instability on presentation	25.38 (3.72–172.95)	**< 0.001**	72.43 (7.68–1995.26)	**< 0.001**
Time to revascularization > 72 h	4.52 (0.46–44.45)	0.196	50.14 (2.39–5084.95)	0.057
Model 2 — Predictors of secondary amputation (events = 4/78)				
Time to revascularization > 12 h	2.85 (0.44–18.24)	0.270	2.87 (0.45–18.36)	0.267
Compartment syndrome on presentation	4.56 (0.69–30.12)	0.116	4.50 (0.70–29.07)	0.114

Notes: Logistic regression with Firth's penalized likelihood was used to address the small number of events and potential quasi-complete separation. Candidate predictors were screened by univariable Firth regression (P < 0.10 or strong clinical relevance) before being entered into the multivariable models. Model 1 (mortality): hemodynamic instability and time to revascularization > 72 h. Model 2 (amputation): time to revascularization > 12 h and compartment syndrome on presentation. Ninety-five percent confidence intervals were computed using the profile-likelihood method. Bold P-values indicate statistical significance at alpha = 0.05. OR: odds ratio; CI: confidence interval; LR: likelihood ratio.

Internal validation by 1,000 stratified bootstrap resamples yielded an optimism-corrected C-statistic of 0.90 and a median calibration slope of 1.35, confirming that the two-predictor Firth model discriminates and calibrates well, despite the small number of events.

After excluding the 960-hour outlier (a surviving 20-year-old gunshot wound victim with isolated posterior tibial artery injury), both predictors remained significant; the delay > 72 h adjusted OR rose from 50.1 to 70.2 (P = 0.042), demonstrating that the main inference is not driven by this single influential case but, if anything, strengthened in its absence.

Exact conditional logistic regression (Monte Carlo permutation, 3,000 resamples) corroborated the Firth results (mid-P < 0.001 for hemodynamic instability and P = 0.001 for delays > 72 h). The exact median-unbiased OR for delay > 72 h was higher than the Firth penalized estimate (576.65 vs. 50.14), with wider exact confidence intervals (3.44–9,396) than the Firth profile likelihood intervals (1.47–5,085), reflecting the small number of exposed patients. Therefore, these two methods are mutually corroborative. We retained Firth as the primary reporting framework and cited the exact results for the robustness checks.

Functional outcomes

Among the 68 survivors with salvaged limbs, functional recovery was strongly influenced by peripheral nerve injury (P < 0.001) and fasciotomy requirements (P = 0.025). Among the 55 patients without nerve injury, 89.1% achieved full recovery versus 0% of the 13 patients with nerve injury (crude OR 205.62, 95%

CI 10.88–3884.62; P < 0.001). Among the 15 patients with nerve injuries, the tibial nerve was affected in 10 (66.7%) and the sciatic nerve in 5 (33.3%); all complete functional losses occurred in the sciatic nerve subgroup (Fig. 4 and Table 6).

Table 6
Functional disability predictors among salvaged-limb survivors (N = 68)

Predictor variable/Subgroup	Disability rate n (%)	P-value
Age group		
Adult (> 18 years)	16/53 (30.2)	0.53
Pediatric (≤ 18 years)	3/15 (20.0)	
Sex		
Male	17/65 (26.2)	0.19
Female	2/3 (66.7)	
Mechanism of trauma		
Gunshot wound	10/34 (29.4)	1.00
Other	9/34 (26.5)	
Wound type		
Other (non-penetrating)	10/41 (24.4)	0.60
Penetrating	9/27 (33.3)	
Hemodynamic stability		
Stable	15/60 (25.0)	0.21
Unstable/Shock	4/8 (50.0)	
Associated bone injury		
No	3/15 (20.0)	0.53
Yes	16/53 (30.2)	
Associated nerve injury		
No	6/55 (10.9)	< 0.001
Yes	13/13 (100.0)	
Compartment syndrome		

Note. Subset restricted to survivors alive at 30 days without secondary amputation (N = 68). One patient (adult male RTA lacerated wound 192-hour delay to revascularization) experienced both secondary amputation and 30-day mortality; therefore the sum of deaths (6) plus amputations (3) in the adult subgroup exceeds the total number of adult patients (61) by one. This overlap is accounted for in the functional outcome denominator (53 adult survivors with salvaged limbs). Functional disability was defined as any loss of function (partial or complete). P-values were calculated using Fisher's exact test for small cell categorical variables and the chi-squared test for balanced categorical variables. Bold P-values denote statistical significance at P < 0.05. OR odds ratio; CI confidence interval.

Predictor variable/Subgroup	Disability rate n (%)	P-value
No	15/57 (26.3)	0.49
Yes	4/11 (36.4)	
Fasciotomy performed		
No	3/26 (11.5)	0.025
Yes	16/42 (38.1)	

Note. Subset restricted to survivors alive at 30 days without secondary amputation (N = 68). One patient (adult male RTA lacerated wound 192-hour delay to revascularization) experienced both secondary amputation and 30-day mortality; therefore the sum of deaths (6) plus amputations (3) in the adult subgroup exceeds the total number of adult patients (61) by one. This overlap is accounted for in the functional outcome denominator (53 adult survivors with salvaged limbs). Functional disability was defined as any loss of function (partial or complete). P-values were calculated using Fisher's exact test for small cell categorical variables and the chi-squared test for balanced categorical variables. Bold P-values denote statistical significance at P < 0.05. OR odds ratio; CI confidence interval.

A sensitivity analysis restricted to the adult subgroup (n = 61; six deaths, three secondary amputations) mirrored the primary findings: hemodynamic instability remained the strongest univariable predictor of mortality (crude OR = 34.29, 95% CI 3.32–353.90; P = 0.001), whereas a delay > 72 h showed a non-significant trend. An age ≤ 18 × hemodynamic instability interaction term was added to the Firth mortality model for the full-cohort analysis. The interaction OR was 0.17 (95% CI extremely wide, profile likelihood ratio test P = 1.00), indicating no statistical evidence that the mortality effect of hemodynamic instability differed between adolescents and adults; however, with only one death in the ≤ 18 stratum, the test was severely under-powered.

Discussion

In this prospective cohort of 78 civilian patients who underwent surgical management for lower limb vascular trauma, we observed a 30-day morbidity rate of 51.3% and all-cause mortality of 9.0%, with limb salvage achieved in 94.9% of patients. These outcomes illustrate the burden of military-pattern trauma managed within civilian healthcare infrastructure, which is compromised by prolonged conflicts.

The demographic profile of our cohort, young adult males with a mean age of 26.7 years, is concordant with the global epidemiology of vascular trauma [5, 14]. However, our injury mechanisms diverge sharply from those reported in Western civilian series, as half of the injuries were caused by predominantly high-velocity gunshot wounds. This hybrid profile of civilians sustaining military-grade wounds without rapid field triage and forward evacuation underlies many of our findings [15, 16].

The 9.0% mortality rate exceeds the 1.5%–4.5% reported in non-conflict urban trauma centers but aligns closely with the recent meta-analytic estimate of 9% (95% CI, 6–12%) for arterial injuries associated with lower limb fractures and dislocations [17]. This concordance suggests that our findings reflect the wider

global burden of severe lower limb vascular trauma rather than an anomaly specific to a single conflict setting.

Hemodynamic instability at presentation emerged as the dominant independent predictor of mortality (adjusted OR 72.43; P < 0.001) in the exploratory multivariable modeling. This finding was robustly supported by univariable screening, formal collinearity diagnostics (Spearman rho = − 0.118, variance inflation factor = 1.09), bootstrap internal validation (optimism-corrected C-statistic 0.90), and exact conditional logistic regression (mid-P < 0.001). Patients arriving in shock are vulnerable to the lethal triad of hypothermia, acidosis, and coagulopathy, compounded by failure to rescue in resource-limited settings where intensive care capacity is constrained [18, 19].

The second predictor, which showed a borderline independent association with mortality, was a revascularization delay exceeding 72 h (adjusted OR 50.14, 95% CI 2.39–5084.95, P = 0.057). The traditional 6-hour golden window for limb salvage is routinely exceeded in conflict-zone civilian trauma, where delays of several days are common. Beyond irreversible muscle necrosis and ischemia-reperfusion injury, prolonged ischemia interacts with hemorrhagic shock and transfusion-related kidney injury to generate a high mortality phenotype [20–22].

Our amputation analysis was deliberately conservative in nature. With only four amputation events, neither revascularization delay nor compartment syndrome reached independent significance, despite biologically plausible estimates. However, all four amputations occurred in patients with abnormal motor or sensory examinations at presentation, a bedside observation that remains clinically useful for triage in resource-limited environments [23].

The most common complications were surgical site infection (26.9%) and postoperative bleeding (26.9% each). Stratification by wound morphology revealed a striking gradient: lacerated wounds (predominantly from road traffic accidents) had a 57.7% infection rate compared to 12.5% for penetrating wounds (P < 0.001), representing a 45.2-percentage-point absolute risk difference. This pattern implicates extensive soft tissue disruption and contamination, characteristic of high-energy blunt trauma, as the dominant driver of wound infection, challenging the assumption that ballistic injuries carry the highest risk of infection [24, 25].

The most clinically consequential finding was the dominance of peripheral nerve injury over vascular status in determining short-term functional recovery. None of the 13 surviving patients with nerve injury achieved full recovery, versus 89.1% of those without (P < 0.001), with a crude odds ratio of 205.62 and an absolute risk difference of 89.1 percentage points. This magnitude of association is among the most striking documented in the vascular trauma literature and underscores that successful revascularization, while necessary, is insufficient for functional recovery in the event of nerve injury. These observations support early structured neurological evaluation at the time of vascular exploration and align with the recent European Society for Vascular Surgery (ESVS) guidelines recommending integrated nerve assessment in extremity vascular trauma [26].

This study had several limitations. First, the inclusion of only 78 patients constrained the statistical power, particularly for low-frequency outcomes, such as amputation (n = 4). The use of Firth's penalized likelihood mitigated but did not eliminate the wide confidence intervals inherent in small-event analyses. Second, recruitment from tertiary referral centers may have introduced a selection bias toward more severe presentations. Third, infrapopliteal venous injuries were not systematically investigated and may have been underestimated. Fourth, the 30-day follow-up window did not capture late graft failure or longer-term functional rehabilitation. Fifth, the functional outcome scale was developed locally for this study and was not validated against standardized instruments such as the Lower Extremity Functional Scale or SF-36, limiting comparability with international cohorts. Sixth, functional outcomes were analyzed only in survivors with salvaged limbs, which introduces competing-risk bias; patients who died (9.0%) were excluded and may have had the most severe injuries. Seventh, formal trauma severity scores (Injury Severity Score, Mangled Extremity Severity Score, Revised Trauma Score) were not routinely recorded in the participating centers due to resource constraints, limiting our ability to adjust for overall physiological derangement beyond hemodynamic status.

To assess the robustness of unmeasured confounding by formal trauma severity scores, we calculated the E values for the two mortality predictors. Using the VanderWeele-Ding E-value formula E = RR + sqrt(RR(RR-1)), an unmeasured confounder would need to be associated with both hemodynamic instability and 30-day mortality with risk ratios of ≥ 144 and with both delay > 72 h and mortality with RR ≥ 100 to fully explain away the observed associations. Such extreme confounding is implausible in vascular trauma, supporting a causal interpretation of both effects. Given the small number of outcome events, these multivariable estimates should be interpreted as hypothesis-generating rather than confirmatory, and the wide confidence intervals reflect the mathematical uncertainty inherent in low-event regression.

Conclusions

Surgical management of traumatic lower limb vascular injury in Yemeni civilians is associated with substantial 30-day morbidity and mortality. Hemodynamic instability at presentation was independently associated with mortality, whereas a time to revascularization exceeding 72 h demonstrated a borderline association in exploratory multivariable modeling. Secondary amputation was not predicted independently by any of the variables. Peripheral nerve injury, rather than vascular status, is the primary driver of short-term functional recovery. Lacerated wounds characteristic of road traffic accidents carry a disproportionately high risk of surgical site infection. These findings emphasize the urgent need for investments in prehospital trauma triage, accelerated surgical evacuation, and standardized protocols for early neurological assessment and aggressive management of wounds.

Abbreviations

aOR
Adjusted odds ratio

CI
Confidence interval
ESVS
European Society for Vascular Surgery
GSW
Gunshot wound
IQR
Interquartile range
ISS
Injury Severity Score
MAP
Mean arterial pressure
MESS
Mangled Extremity Severity Score
NNH
Number needed to harm
OR
Odds ratio
RTA
Road traffic accident
RTS
Revised Trauma Score
SD
Standard deviation
SSI
Surgical site infection
STROBE
Strengthening the Reporting of Observational Studies in Epidemiology
VIF
Variance inflation factor

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of the Faculty of Medicine, Sana'a University, Sana'a, Yemen. All procedures were performed in accordance with the ethical standards of the Institutional Research Committee and the 1964 Helsinki Declaration and its subsequent amendments. Written informed consent was obtained from all individual participants included in the study or from their legal guardians if the participants were under 18 years of age.

Consent for publication

Not applicable. This manuscript does not contain any individual person's data in any form.

Competing interests

The authors declare no conflict of interest.

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Author Contribution

AAH: conceptualization, data curation, investigation, and writing of the original draft. MAE: supervision, methodology, formal analysis, software, writing — review and editing. NYAM: resources, supervision, writing, review, and editing. HMJ: conceptualization, methodology, project administration, writing — review and editing. All the authors have read and approved the final manuscript.

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Data Availability

The de-identified dataset supporting the conclusions of this article is available from the corresponding author (h.jowah@su.edu.ye) upon reasonable request, subject to local institutional and ethical clearance. Owing to the ongoing conflict in Yemen and the security-sensitive nature of the clinical data from the participating institutions, the raw data are not publicly available.

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Figures

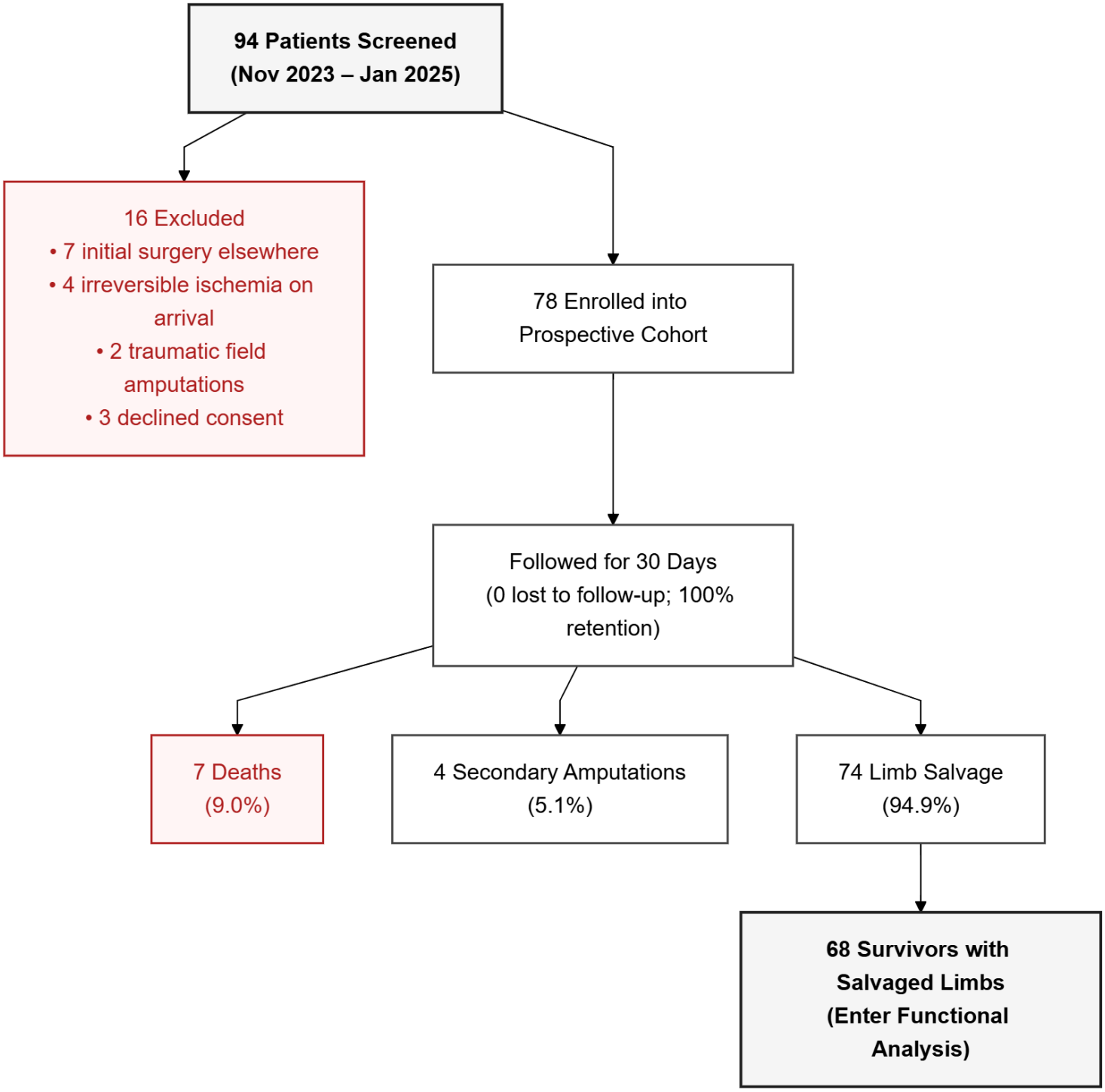


Figure 1

STROBE flow diagram of patient screening, enrollment, and 30-day outcomes.

Out of 94 consecutive patients screened, 16 were excluded based on pre-specified criteria, leaving a final prospective cohort of 78 patients. All 78 patients completed the 30-day follow-up period (100% retention). At 30 days, the cohort experienced 7 deaths (9.0%) and 4 secondary amputations (5.1%), achieving an overall limb salvage rate of 94.9% (n = 74). To prevent competing-risk bias, the 7 deaths and the 3 surviving amputated patients were excluded from functional assessments, leaving exactly 68 salvaged-limb survivors

to enter the final univariable functional recovery analysis. STROBE, Strengthening the Reporting of Observational Studies in Epidemiology.

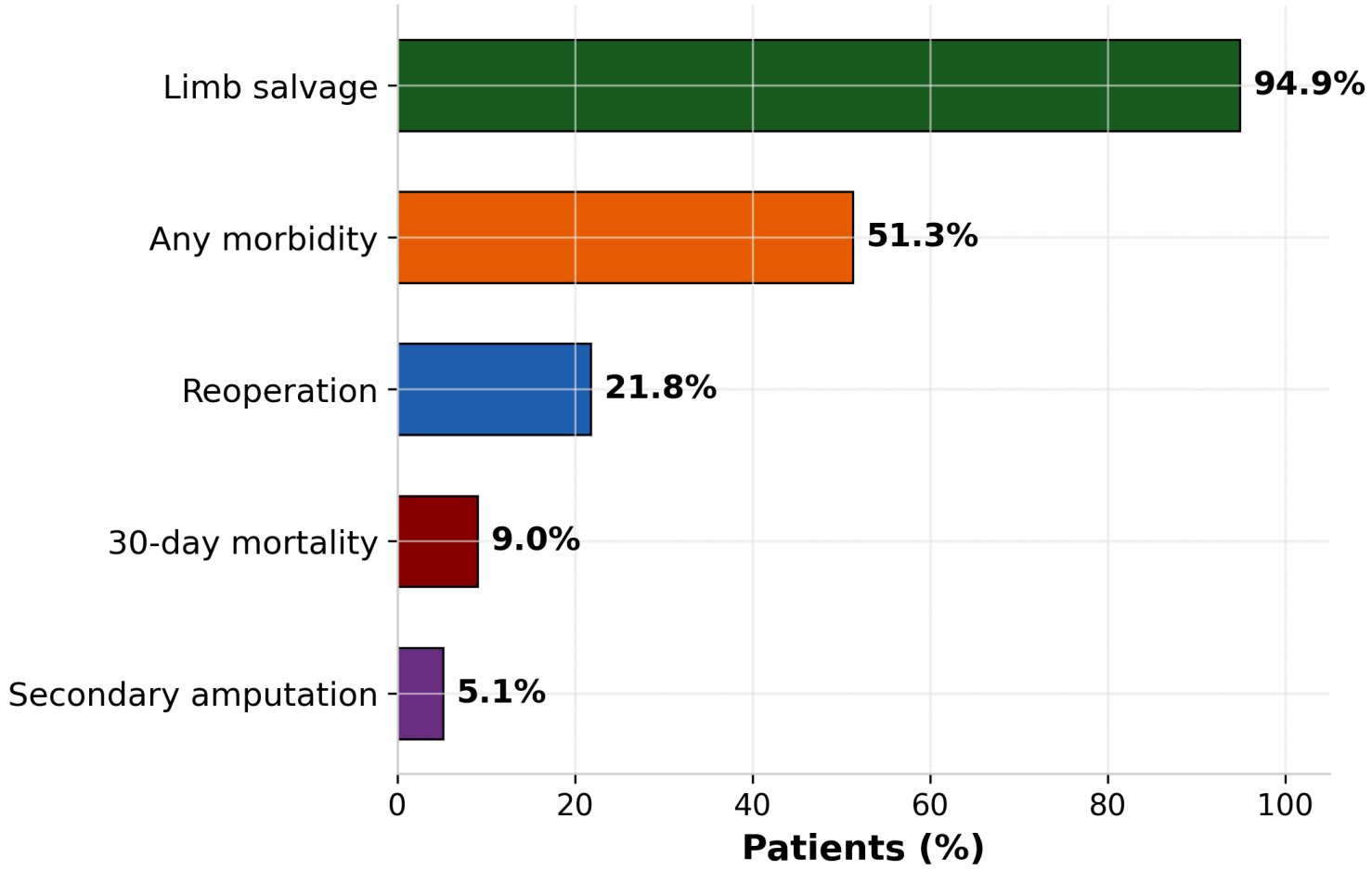


Figure 2

Summary of primary 30-day outcomes (N = 78). Horizontal bar chart showing the proportion of patients experiencing each outcome: limb salvage (94.9%), morbidity (51.3%), reoperation within 30 days (21.8%), 30-day all-cause mortality (9.0%), and secondary amputation (5.1%).

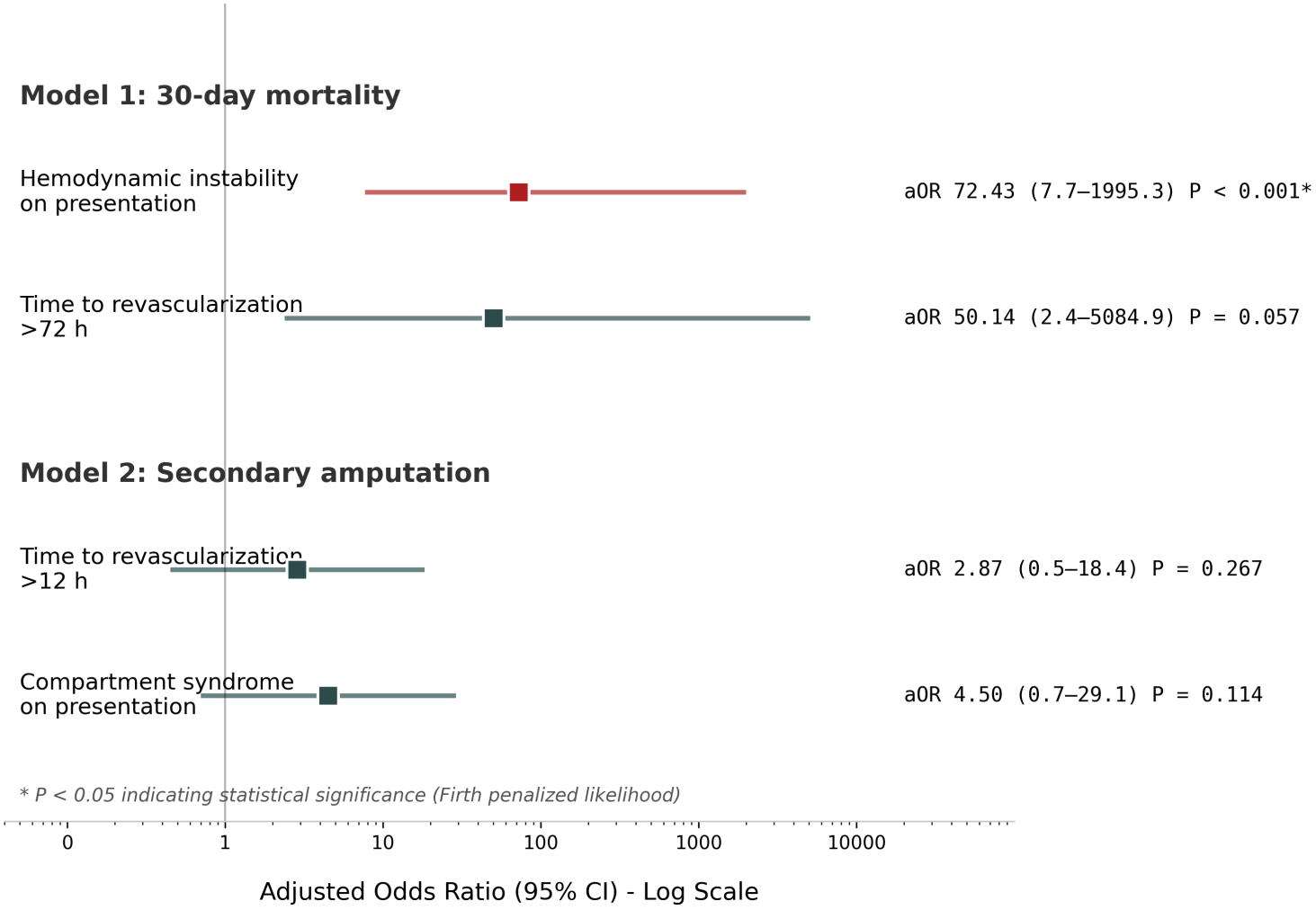


Figure 3

Forest plot of multivariable Firth penalized logistic regression results. Adjusted odds ratios (filled circles) and 95% confidence intervals (horizontal lines) are plotted on a logarithmic scale for each predictor in Model 1 (30-day mortality) and Model 2 (secondary amputation). The dashed vertical line indicates the null effect (OR = 1.0). * indicates statistically significant predictors at α = 0.05.

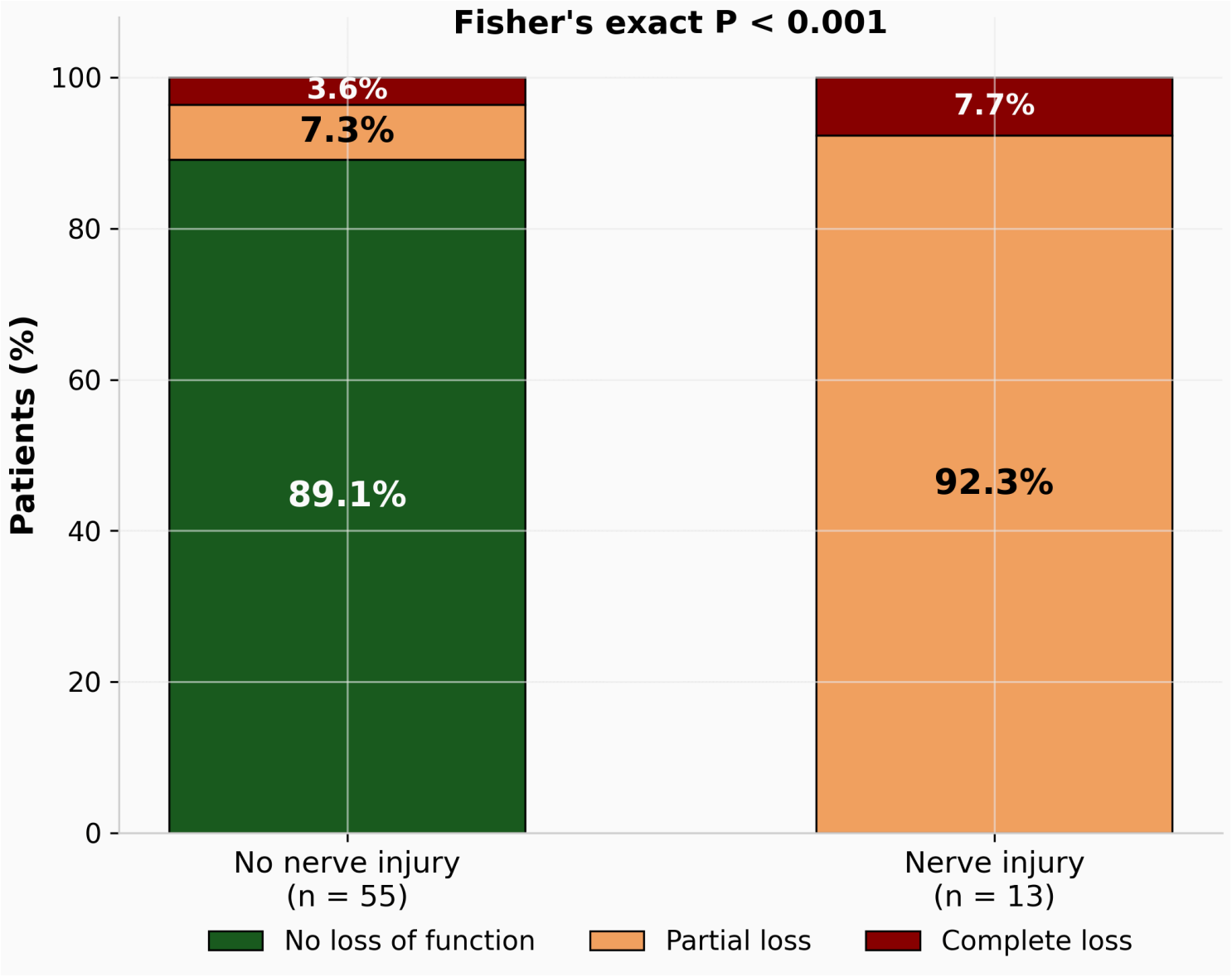


Figure 4

Functional outcomes at 30 days, stratified by nerve injury status (N = 68 survivors with salvaged limbs). Stacked bar chart comparing patients without (n = 55) and with (n = 13) nerve injury. Full functional recovery was achieved by 89.1% of patients without nerve injury versus 0% of patients with nerve injury (Fisher's exact test, P < 0.001).