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Penetrating Femoropopliteal Vascular Injuries during Wartime in Yemen: Early Management Outcomes and Risk Factors for Limb Loss and Mortality

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ABSTRACT

Background: This study aimed to determine early management outcomes and to identify the risk factors associated with limb loss and mortality for penetrating femoropopliteal vascular injury during war in Yemen. **Methods:** This prospective study was conducted at the 48 Model Hospital, a military referral center in Sana'a, Yemen, from January 2020 to October 2023. This study focused on patients with penetrating femoropopliteal vascular injuries resulting from war-related trauma. Patients who experienced blunt trauma, primary traumatic amputation, or were treated outside the hospital were excluded. The study employed a structured questionnaire to collect data during the perioperative period and hospital stay, including patient demographics, pattern of injury, surgical repair methods, and early management outcomes. **Results:** We analyzed 65 cases of wartime femoropopliteal injuries and found that high-velocity gunshot wounds were the main cause (47.7%). Most patients were young males, with a median age of 25. Associated soft tissue injuries were present in 92.3% of cases, with severe crush injuries in 46.7%. Arterial injuries occurred in 90.8% of patients, predominantly affecting the popliteal artery (57.6%), while venous injuries occurred in 73.8% of patients, mostly involving partial transection of the popliteal vein. Nerve injuries were observed in 13.8% of cases and bone injuries in 21.5%. The primary arterial repair methods were reverse saphenous interposition graft (n=35) and primary reconstruction (n=18), whereas venorrhaphy and saphenous interposition graft were the most common venous repair methods. Intraoperative complications were seen in 7.7% of cases, and postoperative complications in 35.4%, with wound infection being the most frequent. The median hospital stay was 17 days, and secondary amputations were required in 4.6% of cases. The mortality rate was 3.4%. Limb salvage was achieved in 62 patients, with the majority (80%) achieving functional independence in ambulation. Predictors of secondary amputation included intraoperative complications,

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associated bone fracture injury, systolic blood pressure, hemodynamic instability, intraoperative ankle stiffness, and pulse rate. Predictors of mortality included systolic blood pressure, hemodynamic instability, postoperative ischemia-reperfusion injury, venous ligation, multiorgan failure, sepsis, and septic shock. **Conclusions:** Penetrating femoropopliteal vascular injuries during wartime in Yemen are challenging. We advocate for individualized treatment based on muscle viability and hemodynamic stability instead of ischemic time alone, and we emphasize the importance of shock, ankle rigidity, and IRI as crucial risk factors for amputation and mortality. We also recommend prioritizing venous repair over ligation and determining the sequence of surgical interventions based on intraoperative evaluations. We recommend further research to validate our findings.

Keywords: Penetrating Femoropopliteal Vascular Injuries, Wartime, Surgical Management Outcomes, Risk Factors, Ankle Stiffness, Ischemic Reperfusion Injury, Limb Loss, Mortality.

LIST OF ABBREVIATIONS

PFPVI: Penetrating Femoropopliteal Vascular Injury; AKI: Acute Kidney Injury; IRI : Ischemic Reperfusion Injury; TIVS: Temporary Intravascular Shunt; ATLS: Advance Trauma Life Support; RIPSG: Reverse Interposition Saphenous Graft; SIPG: Saphenous Interposition Graft; SD: Standard Deviation; SPSS: Statistical Package for the Social Sciences; ARDS: Acute Respiratory Distress Syndrome.

INTRODUCTION

Femoropopliteal vascular injuries, which occur in the thigh and knee regions, can have severe consequences as they supply blood to the lower extremities. In combat situations, these injuries often lead to amputation due to complications like blood loss, infection, and delayed medical intervention. Studies have reported complication rates between 14.2% and 36.4%, with amputation rates ranging from 4.3% to 13.0% [1].

In wartime, the complexity of these injuries is exacerbated by limited medical resources and immediate battlefield needs [2]. Various factors influence the amputation rate, including the mechanism of injury, time between injury and surgery, associated injuries, preoperative hypotension, and the availability of medical expertise and resources [3-6].

Historical data from conflicts like the Vietnam War and recent operations in Iraq and Afghanistan show fluctuating amputation rates due to advancements in military medical care [7-12]. However, recent literature still reports amputation rates of 10%–30% for penetrating femoropopliteal injuries [13,14].

In Yemen, during wartime, penetrating popliteal vascular injuries have been studied, with amputation rates ranging from 5.2% to 11.5% and mortality rates from 1.9% to 9.8% [15-17]. However, there is a lack of comprehensive research on early management outcomes for penetrating femoropopliteal injuries in Sana'a, Yemen.

Therefore, this study aims to address this gap by determining early surgical management outcomes and identifying risk factors associated with limb loss and mortality for penetrating femoropopliteal injuries during the war in Yemen.

MATERIAL AND METHODS

Study Design and setting

This prospective study evaluated early surgical management outcomes for patients with penetrating femoropopliteal vascular injuries during the war in Sana'a, Yemen, from January 2020 to October 2023. Conducted at the 48 Model Hospital, this study focused on patients who experienced these injuries after penetrating trauma and underwent surgical repair at our institution. Patients with blunt trauma, primary traumatic amputation, or who were treated outside the hospital were excluded.

Data Collection

Data were collected using a structured questionnaire during the perioperative period and hospital stay to gather information on patient demographics, pattern of injury, surgical repair methods, and early management outcomes.

Outcomes Measures and Definitions

The primary objective of this study was to evaluate early management outcomes in terms of intraoperative and postoperative complication rates, secondary amputation, mortality, and functional outcome of salvaged limbs. The secondary objective was to identify the factors associated with secondary amputation and mortality by exploring demographic data, clinical patterns, surgical repair methods, and intraoperative and postoperative complications.

Secondary amputation was defined as failed salvage of the limb after any trail of revascularization, including patients who underwent reperfusion using a temporary shunt. All amputations in our study were secondary. Intraoperative ischemic reperfusion injury was defined as the immediate appearance of one or more of the following clinical manifestations during reperfusion trail of limb with prolonged ischemia, such as persistence of hypotension, cardiac arrhythmia (ECG change with peaked T waves), and persistent hypoxemia. In contrast, postoperative IRI was defined as the occurrence of postoperative clinical manifestations within the first 24 h after revascularization, such as lower limb pain, swelling, and organ dysfunction (e.g., acute kidney injury (AKI), hyperkalemia, acute respiratory distress syndrome, pulmonary edema, septic shock, or multiorgan dysfunction) [18].

Using the locomotion component of the modified FIM score to assess disability in survivors discharged from the hospital [19]. The score ranges from 1 (require full assistance) to 4 (walk without any assistance), with 2 requiring assistive devices (e.g., crutches, walker, cane) and 3 indicating the need for some assistance or support from another person.

Management Approach

On arrival at the ER, patients were primarily surveyed and resuscitated if shocked (SBP≤ 90 mmHg) according to the ATLS protocol, followed by detailed clinical examination [20]. Patients with hard signs of vascular injury (active bleeding, pulsating mass, audible bruit or thrill, expanding hematoma, or signs of distal ischemia) [21] underwent immediate surgical exploration. Patients with soft signs of vascular injury (proximity injury, large nonpulsatile hematoma) [3] were either radiologically evaluated using computed tomography angiography (CTA) if available or surgically explored because interpreting soft signs, particularly through pulse examination and continuous wave Doppler assessment, can be challenging in the context of war [22]. In hemodynamically stable patients who presented with multiple penetrating level injuries and exhibited hard signs of vascular injury, CTA was requested to precisely identify and locate the injury site to avoid extended exploration and decrease surgical time [23].

Patients with a high suspicion or confirmation of vascular injury, following appropriate assessment and resuscitation, underwent surgical exploration by a vascular surgeon.

Fasciotomy: We used fasciotomy liberally, especially in high-risk patients [24]. This was performed by opening the four compartments through medial and lateral incisions. In high-risk patients and those with prolonged ischemia or tense calf muscles, preoperative fasciotomy was performed under local anesthesia in the ER. Intraoperatively, fasciotomy was performed when limb viability was questionable, or ankle rigidity was observed. Prophylactic fasciotomy was performed for patients with combined arteriovenous injuries or multilevel injuries. Muscle viability was assessed based on visual cues such as color, bleeding, contractility, capillary refill, and consistency. Healthy muscle exhibited a pinkish-red color, good bleeding, contractility, and prompt capillary refill. Questionable muscles displayed pale or dusky colors, altered textures, reduced bleeding, and delayed capillary refill. The ischemic muscle appeared dark or black, had a soft texture, no bleeding or contractility, and no capillary refill.

Limb salvage vs. amputation: The decision between limb salvage and amputation in patients with advanced ischemia was determined by gradual reperfusion [18] of the limb using a temporary shunt and subsequent assessment of muscle viability. If a patient showed any clinical manifestations of IRI that did not respond to medical treatment, the limb was considered unsalvageable and amputated. However, if there were no signs of IRI, preceded with a definitive repair with reevaluation of muscle viability for 24–48 hrs postoperatively, with successful outcomes usually occurring within 48 h. Patients were closely monitored in the ICU for any potential postoperative IRI signs. Medical management was used to treat postoperative IRI, along with frequent debridement and necrotomy of the necrotic muscle groups.

Arterial Repair: The injured limb was explored using standard approaches with proximal and distal vessel control. Systemic heparin was administered before vessel clamping. Arterial repair methods varied based on the type of injury: partial injury without intimal damage underwent resection and end-to-end anastomosis, whereas complete transaction or intimal injury involved bypass using the contralateral great saphenous vein. For arteriovenous fistula repair, the method depended on the presence of the arterial wall defect and intimal injury.

Venous Repair: All venous injuries were repaired in any location if the patient's hemodynamic status was stable. We repaired partial injuries by lateral suturing (venoraphy) or resection with primary reconstruction. Primary repair of complete injuries with small defects was performed, whereas defects larger than 3 cm were repaired using saphenous interposition vein grafts (SIPGs).

Adjacent bone injury or nerve injury: In cases of associated bone injury, the priority of bone fixation or vascular repair depended on the viability of the muscle group after proper fasciotomy. If the muscles were healthy, fracture fixation occurred before limb revascularization. However, if muscle group viability was questionable, reperfusion occurred first after bone fixation. For nerve injuries, complete transection injuries were marked for delayed repair (especially for firearm-related injuries), whereas partial nerve injuries were conservatively managed.

Wounds and soft tissue debridement: The injury region was carefully assessed, and the trajectory of injury was explored, with good irrigation by normal saline and proper debridement of tissue with questionable viability.

Closure: Following complete repair and good hemostasis, the wounds at the injury site were initially left open, and only two stitches were used to approximate and cover the bypass site. A second look was conducted after 24–48 h to assess the wound and soft tissue. Appropriate antibiotic therapy was administered along with anticoagulation treatment, and intravenous fluid infusion was maintained to preserve inflow and outflow in the repaired vessels.

Postoperative follow-up: Repaired vessels were assessed clinically through palpable pulses at the ankle level and through Doppler ultrasound. Postoperative complications and limb functionality were monitored through daily follow-up while in the hospital.

Statistical analysis

Data analysis: IBM SPSS Statistics version 26.0 was employed, with the normality of continuous variables tested using the Kolmogorov– Smirnov test. Depending on data distribution, results were presented as median and range or means and standard deviation. Chi-squared and Fisher's exact tests were used for categorical variables, independent t- tests for normally distributed data, and the Mann– Whitney U test for nonparametric groups. Statistical significance was set at a two-sided P-value of 0.05.

RESULTS

The study involved 65 patients with a median age of 25 years; most were male (n = 64, 98.5%). The median time from injury to presentation was 12 h. Most patients had stable hemodynamic status (n = 50, 76.9%), whereas 15 patients (23%) were hemodynamically unstable. Common injury mechanisms included high-velocity gunshot wounds (47.7%) and blast injuries (46.2%). Most patients had no associated body injuries (81.5%), whereas 92.3% exhibited associated soft tissue injuries ranging from minimal to severe crush injuries (Table 1).

Table 1. Demographic data of the study population

Variables	*N*	%
Age	25 ± 7.46	-
Gender		
Male	64	98.5
Female	1	1.5
Time from injury until presentation (hrs.)	12(1-168)	
SBP (mmHg)	107 ± 17.5	
Pulse Rate(bpm)	95 ± 18.4	
R rate (cycle/min)	20 ± 3.2	
Hemodynamic status		
Stable	50	77
Unstable	15	23
Mechanism of injury		
GSW of High Velocity	31	48
Blast injury	30	46
GSW of Low Velocity	2	3
Shrapnel Injuries	2	3
Associated body injury		
No associated injury	53	81.5
Chest injury	7	11
Abdomen injury	6	9
Head and neck injury	3	5
Associated soft tissue injury	60	92
Extent of soft tissue injury		
Minimal or no crush injury	12	20
Moderate crush injury	20	33
Severe crush injury	28	47
Hard Signs		
Present	49	75
Absent	16	25
Compartment syndrome	19	29

Regarding early management outcomes, intraoperative complications (n= 5, 7.7%) included IRS (4 patients) and bleeding (one patient), whereas postoperative complications (n= 23, 35.4%) included wound infection (47.8%), hematoma collection (26.1%), and IRI (21.7%). Graft-related complications, such as graft thrombosis (13.0%) and graft infection (8.7%), were also observed. The median hospital stay was 17 days, with 4.6% of patients (3 patients) having secondary amputations due to intraoperative IRI resistant to management and 3.4% (2 patients) of the deaths recorded, primarily due to postoperative IRI. Despite these risks, 95.4% of patients achieved successful limb salvage, and 80% experienced satisfactory functional outcomes (Table 2).

Table 2. Early Management Outcomes

Variables	*N*	%
Operative complication:	5	7.7
Ischemic reperfusion injury	4	6.2
bleeding	1	1.5
Postop Complications	23	35.4
Ischemic reperfusion injury	5	7.7
Acute kidney injury	5	7.7
Sepsis	1	1.5
Septic shock	1	1.5
Myocardial infarction	1	1.5
Multiorgan failure	1	1.5
Hematoma collection	6	9.2
Wound infection	11	16.9
Graft thrombosis	3	4.6
Graft infection	2	3.1
Rupture and ligation graft	1	1.5
Significant limb swelling	4	6.2
Postoperative Outcomes		
LOS (days)	17 (2-100)	-
LO ICU stay (days)	4(0-40)	-
Secondary amputation	3	4.6
Limb salvage	62	95
Functional outcomes		
Independent	43	70
Modified independence (e.g., crutches, walker, cane).	7	10
Assistance required	9	15
Dependent	3	5
Mortality		
Died	2	3.4
Survived	63	96.9

Regarding the pattern of vascular injuries, the most common injury level was the popliteal level (49.2%), followed by the femoral level (41.5%). Arterial injuries were observed in 90.8% of patients, with the popliteal artery being the most affected artery (n= 34, 57.6%). Venous injuries occurred in 73.8% of patients and mostly involved partial transections of the popliteal vein. Associated nerve injuries occurred in 13.8% of patients, and bone injuries occurred in 21.5% of patients (Table 3).

Table 3. Patterns of vascular injury

Variables	*N*	%
level of vascular injury		
Femoral level	27	41.5
Popliteal level	32	49
Muti-level	6	9
Arterial injury (F, %)	59	90.8
SFA	23	39
PA	34	57.6
DFA	8	13.6
CFA	6	10
Type of arterial injury		
Intimal injury or contusion	12	20
Partial transection	13	22
complete with hemorrhage or occlusion	17	29
complete wall defects with pseudo aneurysms or hemorrhage	4	7
arteriovenous fistulas	7	12
pseudoaneurysm fistula	6	10
Associated venous injury (F, %)	48	73.8
Popliteal Vein	28	58.3
SFV	21	43.8
CFV	8	16.7
DFV	5	10.4
Type of venous injury		
Intimal injury or contusion	1	2.1
Partial transection	28	58.3
complete transection	15	31.3
pseudoaneurysm	4	8.3
Associated nerve injury	9	13.8
sciatic nerve	4	44.4
tibial nerve	5	55.6
Associated bone injury	14	21.5

In terms of surgical repair methods, the median ischemic time for revascularization after injury was 22 h. The most common arterial repair method was reverse saphenous interposition graft (53.8%), followed by primary reconstruction (27.7%). Venous repair methods varied, with venorrhaphy being the most common (21.5%). Fasciotomy was performed in 50.8% of patients, primarily for accurate muscle assessment. Approximately 18.5% of the patients had combined arterial and venous injuries, and 15.4% had undergone prophylactic procedures. Ankle stiffness and multilevel limb injuries were also observed in some patients (Table 4).

Table 4. Methods of Surgical Repair

Variables	*N*	*%*
Time from injury to revascularization (hrs)	22(6-168)	
Type of arterial repair		
RSIPG	35	53.8
Primary reconstruction	18	27.7
Temporary shunt	4	6.2
Arteriorrhaphy	3	4.6
ligation	2	3.1
synthetic graft	1	1.5
Type of venous repair		
ligation	10	15.4
Venorrhaphy	14	21.5
Primary reconstruction	11	16.9
SIPG	12	18.5
conservative	1	1.5
venous patch	1	1.5
Fasciotomy procedure	33	50.8
Fasciotomy Indications		
for accurate assessment of muscle	30	46.2
Prolonged ischemia > 6 hrS	20	30.8
Compartment syndrome on presentation	18	27.7
Combined arterial and venous injuries	12	18.5
Prophylactic	10	15.4
Ankle stiffness on presentation	8	12.3
multilevel limb injuries	6	9.2
ankle stiffness in O. T	3	4.6

Several risk factors for secondary amputation were identified, including intraoperative complications, hemodynamic instability, systolic blood pressure, associated bone fractures, pulse rate, and ankle stiffness.

In terms of mortality, hemodynamic instability and systolic blood pressure are key predictors of sepsis, as are venous ligation, postoperative IRI, multiorgan failure, sepsis, and septic shock (Table 5).

Table 5. Risk Factors for Secondary Amputation and Mortality

Variables	Secondary Amputation			P	Mortality			P
	Yes N = 3	NO N=62	Total N=65		Yes N=2	No N=63	Total N=65	
Hemodynamic instability	3(100%)	12(19%)	15(23%)	.010**	2(100%)	13(21%)	15(23%)	.017*
SBP in mmHg (median+ range)	80(80-90)	110(40-140)	-	.007†	55(40-70)	110(70-140)	-	.001†
Pulse Rate(bpm)	116 ± 12	94 ± 18	-	.019†	74 ± 79.1	95 ± 15.4	-	0.951
Associated bone fracture injury	3(100%)	11(18%)	14(21%)	.008**	0	14(22%)	14(21%)	0.452
Intraop ankle stiffness	2(67%)	1(3%)	3(9%)	.017**	0	3(10%)	3(9%)	0.645
Intraoperative complication	3(100%)	2(3%)	5(8%)	.000**	1(50%)	4(6.3%)	5(8%)	0.149
postop IRI	0	5(24%)	5(22%)	1	2(100%)	3(14%)	5(22%)	.040*
Multiorgan Failure	0	1(5%)	1(4.5%)	1	1(100%)	0	1(4.5%)	.045**
Sepsis	0	1(5%)	1(4.5%)	1	1(100%)	0	1(4.5%)	.045**
Septic shock	0	1(5%)	1(4.5%)	1	1(100%)	0	1(4.5%)	.045**
Venous ligation	1(33%)	9(20%)	10(21%)	0.512	2(100%)	8(17%)	10(21%)	.040**

*Footnote 5: Data are presented as mean ± Sd or median (range). Information in the parentheses indicates the percentages. *Significant p-value (person correction), **Fisher's exact test, †The Mann-Whitney U test*

DISCUSSION

This study aimed to evaluate early management outcomes, major risk factors for secondary amputation, and mortality in individuals with penetrating femoropopliteal vascular injuries during wartime.

The fasciotomy procedure was liberally and successfully used in more than half of our patients (n = 33, 51%), aligning with the rates reported in other studies [3,25]. It was indicated for accurate muscle assessment in 46.2%, prolonged ischemia > 6 h in 31%, compartment syndrome at presentation in 28%, combined arterial and venous injuries in 18.5%, and prophylactically in 15%. Various studies have emphasized the significant role of fasciotomy in the management of such indications [26-29]. Prophylactic fasciotomy has been shown to be crucial in high-risk limb profiles, where continuous monitoring for compartment syndrome is challenging, and it can effectively reduce limb loss [30,31].

On the basis of our approach regarding the decision to perform limb salvage vs. amputation, which was explained previously in the methodology section, secondary amputations were performed in 4.6% (3 out of 65) of the patients, all of whom underwent above-knee amputation. Successful limb salvage was achieved in most patients (95.4%, n=62), indicating a superior result compared with that of other studies [7,32,33]. Similarly, during wartime in Yemen, two studies reported a limb salvage rate of 94.2%, with early limb loss occurring in 5.8% of patients following penetrating popliteal injuries [15,16].

In our study, intraoperative complications were observed in 5 patients, including IRI in 4 and bleeding in one patient. Of the 4 patients who exhibited intraoperative IRI, 3 were resistant to medical management and subsequently underwent amputation, which was the main cause of secondary amputation in our study. Postoperative complications occurred in 23 patients (35.4%), with wound infection being the most common complication (47.8%), followed by hematoma collection (26.1%) and postoperative IRI (21.7%). Graft-related complications, including graft thrombosis (13.0%) and graft infection (8.7%), were also identified. Our overall complication rate aligns with that of previous studies [7,16,31,34,35], but our rate of postoperative IRI was superior to that of a previous study [36].

We recorded an overall mortality rate of 3.4% (2 patients). Both patients died because of the sequelae of postoperative IRI manifested as acute respiratory distress syndrome (ARDS) in one patient and septic shock with multiorgan failure in the other. Our findings align with the range of reported mortality rates in previous studies [37,38].

It is worth noting that despite the lack of reports on the incidence of intraoperative IRI in the literature, our study provides valuable baseline insight into the rate of this complication among war injuries, highlighting its significant role in management outcome decision making.

Our study found an encouraging rate of functional independence in ambulation among the majority of patients with salvaged limbs at discharge. These findings align with previous studies by Urrechaga et al. (2022) and Padberg Jr. et al. (1992), which reported similar outcomes in patients with comparable injuries [39,40]. The timely and effective management of these injuries plays a crucial role in maximizing functional outcomes. Pourzand et al. (2010) also supports our findings, emphasizing the potential for patients to regain strength and mobility for ambulation after treatment [41]. Our results contribute to the existing knowledge on the management of wartime vascular injuries, highlighting the importance of early surgical intervention and the complexities associated with risk factors for limb loss discussed by Davidovic et al. (2005) [42]. Although these studies may differ in their context among civilians, the common theme of achieving favorable functional outcomes through early and appropriate care is evident. Our study not only supports these findings but also provides unique insights into the challenges and successes encountered in a wartime setting, thus enhancing our understanding of vascular injury management and rehabilitation.

Several risk factors were found to be correlated with secondary amputation and mortality. Crucially, our study identified hemodynamic instability and systolic blood pressure as significant risk factors for both secondary amputation (p =.010, p=.007) and mortality (p =.017, p =.001). This significant difference was attributed to the fact that all patients who underwent secondary amputation or died during our study presented with hypovolemic shock. Our findings agree with previous research demonstrating that patients with preoperative hypotension and greater degrees of shock were more likely to undergo leg amputation and have increased mortality rates than those without such risk factors [35,43-45]. The Lebanese War experience also indicated that shock, among other factors, had a significant effect on limb salvage, and timely management was crucial in cases of penetrating trauma near major limb blood vessels [46]. Asensio et al. (2015) reported that shock in patients with penetrating lower limb vascular injuries can complicate management and impact outcomes, highlighting the importance of prompt and appropriate treatment protocols [47].

Thus, we recommend prompt management of vascular injuries, including rapid and proper resuscitation from shock and restoration of blood flow starting in the battel field, and we highlight its critical role in improving outcomes and limb salvage rates.

In terms of associated bone injury, in our study, 14 of 65 patients (21.5%) had concomitant bone fracture, which was significantly correlated with secondary amputation (p=.008). Our findings are in accordance with those of previous studies reporting that concomitant bone injury increases the likelihood of subsequent amputation [11,34,43,48,49].

The issue of which injury should be treated first during repair in such scenarios remains a matter of debate. Prior skeletal fixation has been advocated by some authors [50-52]; however, more recent studies have recommended that vascular repair be prioritized before any fixation to decrease the duration of ischemia in the lower limb [52-54]. In our practice, the priority of bone fixation or vascular repair solely depended on the viability of muscle groups intraoperatively after proper fasciotomy.

The importance of venous repair in managing penetrating lower limb vascular injuries cannot be overstated. Our study revealed that venous ligation was a significant risk factor for mortality (p =.040). In our practice, we prioritized venous repair over ligation whenever possible, if patients were hemodynamically stable. Previous studies have reported controversy regarding the choice between vein repair and ligation for traumatic venous injuries [55,56]. However, several studies have indicated the potential benefits of venous repair, including improved venous drainage leading to reduced compartment pressure and a decreased risk of limb loss [57-59]. Additionally, venous repair is associated with lower mortality rates than venous ligation [35], which supports our findings.

The significance of monitoring patients for IRI during procedures to restore blood flow in prolonged ischemic limbs cannot be overlooked. Our study demonstrated a strong correlation between intraoperative complications, particularly IRI, and secondary amputation (p=.000). These findings merit serious attention because 3 of 4 patients who suffered from IRI and were resistant to medical management ultimately underwent secondary amputation. It is crucial to recognize that there is a lack of clear diagnostic criteria for IRI, especially when it occurs promptly during limb revascularization. However, despite our approach in identifying intraoperative IRI, there remains a substantial gap in the literature on this complication. Thus, we emphasize the need for vigilant intraoperative patient monitoring for IRI during critical surgical procedures to improve patient outcomes and minimize the likelihood of secondary amputation.

Moreover, our study presented a compelling argument that postoperative complications, including IRI (p = 040), multiorgan failure (p =.045), sepsis (p =.045), and septic shock (p =.045), are all significant risk factors for mortality in our patients. First, the strong association between postoperative IRI and mortality highlights the need for greater vigilance in identifying and managing this complication postoperatively to avoid preventable death [60]. The fact that only two out of five patients who developed this condition eventually died highlights that with adequate intervention, this risk may be mitigated [61].

Ankle stiffness or rigidity, characterized by a fixed equinovarus deformity of the foot, was observed in 8 of 65 patients upon presentation and in 3 of 33 patients during fasciotomy. Importantly, intraoperative ankle rigidity was correlated with secondary amputation (p =.017). This observation may be attributed to the presence of hemorrhagic shock at presentation because shock reduces the critical ischemic time of the limb to 1 h, according to a previous study [62]. Notably, 3 patients with intraoperative ankle rigidity presented with shock, revealing a significant association between intraoperative ankle stiffness and shock (p =.043).

Since the Vietnam War, multiple authors have emphasized the importance of ankle rigidity as an indicator of negative outcomes in ischemic limbs [63]. Recent research further supports these claims and reinforces their validity in assessing the severity of ischemia. For instance, Ratnayake et al. (2020) proposed immediate amputation for patients presenting with ankle rigidity, particularly in scenarios involving mass casualties or limited resources [64]. Their findings underscore the significance of ankle rigidity as a reliable criterion for making critical decisions during emergencies, potentially saving valuable time and resources. This highlights ankle rigidity as a sign of severe ischemia with irreversible muscle injury, raising the question of whether primary amputation is preferable to revascularization in such cases [65].

These studies contribute to our understanding of ankle stiffness as a late sign of irreversible limb ischemia necessitating amputation. Recognizing this crucial connection can significantly aid in designing appropriate treatment strategies for ischemic limbs and optimizing patient outcomes in emergencies.

In our study, all patients who underwent secondary amputation or died had blast or high-velocity gunshot injuries, as well as associated soft tissue injuries. However, we did not find any statistically significant difference between the mechanisms of injury and associated soft tissue injury in relation to secondary amputation or mortality. These finding contrasts with previous studies that reported a significant association between secondary amputation and mortality and between the mechanism of injury and soft tissue injury [34,43,44]. The small sample size used in our study may explain this inconsistency.

Our study found no significant link between arterial injuries and secondary amputation or mortality. However, popliteal artery (PA) injuries were noted in two amputation cases and both fatalities. Numerous studies confirm that PA injuries are especially challenging, often leading to higher limb loss rates than other vascular injuries [63,66,67]. Therefore, the severe consequences of PA injuries on patient outcomes must be emphasized.

In terms of ischemic duration, the median ischemic duration in our study was 22 h, ranging from 6 to 168 h. Only one patient underwent revascularization within 6 h of injury, whereas 64 patients underwent delayed intervention. Despite findings from other studies that have reported ischemic duration as an independent risk factor for morbidity and mortality [37], our study did not find a significant statistical correlation between ischemic duration and secondary amputation or mortality.

Huynh and colleagues reported that the tolerance period for ischemia varies from person to person, depending on the severity of ischemia and the presence of collateral flow [26]. Another study revealed that the decision between limb salvage and amputation is influenced primarily by the severity of soft tissue and arterial injuries [68]. Furthermore, Garg et al. strongly reported that the decision to reperfuse the affected limb should not only depend on the elapsed time but also consider factors such as muscle viability and neurological status [36].

Thus, the decision to amputate the limb rather than attempt salvage based solely on ischemic time or muscle viability before revascularization should be reconsidered. Accordingly, we recommend revascularization for ischemic limbs that experience prolonged ischemia, followed by muscle viability assessment, if the patient is hemodynamically stable and does not manifest any signs of IRI.

Unfortunately, our study has several limitations that should be acknowledged. First, the relatively small sample size limited our ability to identify potential risk factors associated with these outcomes compared with those of other studies. Consequently, the generalizability of our findings to a broader population may be restricted. In addition, the study was conducted in a single center in Sana'a city, which may limit the applicability of the results to different geographic contexts with varying health care resources and characteristics. Furthermore, relying on the literature for comparison introduced variability in data quality and consistency, as methodologies and definitions across studies differed.

CONCLUSIONS

In conclusion, our study analyzed management outcomes, risk factors, and mortality rates in relation to wartime femoropopliteal vascular injuries in Yemen. Key insights include the importance of individualized treatment, assessment of muscle viability and hemodynamic stability, and impact of popliteal artery injuries on outcomes. In addition, ankle rigidity and intraoperative ischemia-reperfusion injury (IRI) play roles in prognosis and decision making. Venous repair should be prioritized over ligation to reduce mortality risk, and surgical intervention sequences should be based on intraoperative evaluations rather than predetermined protocols. This approach may lead to improved outcomes in individuals with wartime vascular injuries. Further research is suggested to validate the findings and enhance medical personnel training in war zones along with improved healthcare infrastructure for timely treatment and increased limb salvage, as well as patient survival chances.

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ETHICAL ASPECTS

For this investigation, approval was obtained from the 48 Model Hospital administrations. Before surgery, a consent document was signed by each patient. Additionally, we adhered to the principles of the Helsinki Declaration when conducting this study.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work the authors used [Hyper Write / summarization and improve text tools] in order to [summarize different long section of the manuscript and improve text readability]. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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