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Comprehensive Risk and Prognostic Analysis of Femoropopliteal Vascular Damage in Yemen Conflict: Limb Salvage and Mortality Rates

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ABSTRACT

Introduction: The objectives of this study were to ascertain the results of early care and to pinpoint the risk variables linked to death and limb loss in cases of penetrating femoropopliteal vascular damage sustained during Yemeni warfare.

Methods: From January 2020 to October 2023, a prospective study was carried out in the military referral center, 48 Model Hospital, located in Sana'a, Yemen. Patients with penetrating femoropopliteal vascular damage from trauma due to combat were the subject of this investigation. Excluded patients were those with primary traumatic amputation, acute trauma, and out-of-hospital treatment. During the preoperative phase and hospital stay, the study used a standardized questionnaire to gather information on patient demographics, damage patterns, surgical repair techniques, 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, 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.

Conclusion: It is difficult to penetrate femoropopliteal vascular damage in Yemen during hostilities. We stress the significance of shock, ankle rigidity, and IRI as critical risk factors for amputation and mortality, and we recommend for tailored treatment based on hemodynamic stability and muscle viability rather than ischemia duration alone.

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 Graft SD: Standard Deviation; SPSS: Statistical Package for the Social Sciences; ARDS: Acute Respiratory Distress Syndrome.

Introduction

PFPV 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].

Due to the scarcity of medical resources and the pressing needs of the battlefield during a war, these injuries are more complex [2]. The mechanism of damage, length of time between injury and surgery, related injuries, preoperative hypotension, and the accessibility of medical knowledge and resources are some of the variables that affect the amputation rate [3-6].

Amputation rates have fluctuated due to improvements in military medical care, as evidenced by historical statistics from wars such as the Vietnam War and more recent operations in Iraq and Afghanistan [7–12]. Nonetheless, amputation rates for penetrating Femoropopliteal injuries are still reported to be between 10% and 30% in contemporary research [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.

Materials and Methods

Study Design and setting

Between January 2020 and October 2023, a prospective study was conducted to assess the results of early surgical care for patients who had penetrating femoropopliteal vascular injuries during the conflict in Sana'a, Yemen. This study, which was carried out at the 48 Model Hospital, concentrated on individuals who sustained these wounds as a result of penetrating trauma and had surgery at our facility. Excluded patients had initial traumatic amputation, physical trauma, or were receiving treatment outside of a hospital.

Data Collection

During the preoperative period and hospital stay, a standardized questionnaire was used to collect data on patient demographics, damage patterns, surgical repair techniques, 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].

Assessing survivors' disabilities after they are released from the hospital by using the mobility component of the modified FIM score [19]. From 1 (need complete assistance) to 4 (walk without assistance), the score goes from 2 (need assistive equipment, such as crutches, walker, or cane) to 3 (need 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 non pulsatile 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 performed a lot of fasciotomy, especially on individuals who were at high risk [24]. The four compartments were opened by making medial and lateral incisions in order to accomplish this. Preoperative fasciotomy was carried out in the emergency room under local anesthetic in high-risk patients, those with protracted ischemia, and those with stiff calf muscles. When ankle rigidity was noticed or limb viability was doubtful, fasciotomy was done intraoperatively. Patients with multilayer injuries or mixed arteriovenous injuries underwent prophylactic fasciotomy. Visual indicators like color, hemorrhage, contractility, capillary refill, and consistency were used to evaluate the vitality of the muscles. 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: Standard methods were used to examine the injured limb while controlling the proximal and distal vessels. The administration of systemic heparin preceded the vascular clamping. Depending on the type of injury, several procedures were used for arterial repair: end-to-end anastomosis and resection were used for partial injuries without intimal damage, whereas a contralateral great saphenous vein bypass was used for total transactions or intimal injuries. The technique for repairing arteriovenous fistulas was contingent upon the existence of both intimal injury and arterial wall defect.

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: The vitality of the muscle group following appropriate fasciotomy determined whether bone fixation or vascular repair should take precedence in cases of concomitant bone injury. Fracture fixation happened prior to limb revascularization if the muscles were in good condition. However, reperfusion happened after bone fixation if muscle group viability was in doubt. Partial nerve injuries were treated conservatively, but complete nerve injuries (particularly those involving firearms) were designated for delayed healing.

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: The wounds at the damage site were initially left open after complete repair and adequate hemostasis, while the bypass site was just approximated and covered with two sutures. After 24 to 48 hours, a second examination was done to evaluate the soft tissue and incision. Anticoagulation medication was combined with appropriate antimicrobial therapy, and intravenous fluid infusion was continued to maintain the flow of fluid into and out of 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

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).

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%).

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

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

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).

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

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.

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

The purpose of this study was to assess mortality, key risk factors for secondary amputation, and early care results in patients with penetrating femoropopliteal vascular injuries during a period of conflict.

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 noteworthy that our study offers important baseline insight into the rate of this complication among combat injuries, underscoring its critical significance in management outcome decision making, even though there aren't many publications on the incidence of intraoperative IRI in the literature.

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].

As a result, we advise early treatment of vascular injuries, emphasizing its vital role in enhancing outcomes and limb salvage rates. This includes quick and appropriate resuscitation from shock and restoration of blood flow beginning in the battel field.

In our study, 14 out of 65 patients (21.5%) experienced concurrent bone fractures, which were strongly correlated with secondary amputation (p=.008) in terms of associated bone injury. Our results are consistent with earlier research showing that concurrent bone damage raises the risk of 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.

It is crucial to keep an eye out for IRI in patients while undergoing operations to restore blood flow to limbs that have been prolongedly ischemic. Our research showed a significant (p=.000) association between intraoperative complications—specifically, IRI—and secondary amputation. Given that 3 out of 4 patients with IRI who were not amenable to medical therapy ultimately had secondary amputations, these findings deserve careful consideration. 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, defined as a fixed equinovarus deformity of the foot, was noted in 3 out of 33 patients during the fasciotomy procedure and in 8 out of 65 patients at the time of presentation. Significantly, there was a correlation between secondary amputation and intraoperative ankle rigidity (p =.017). This finding could be explained by the presence of hemorrhagic shock upon presentation, as shock shortens the limb's critical ischemia time to one hour, as per a prior study [62]. Significant evidence of a correlation between intraoperative ankle stiffness and shock was seen in three individuals with intraoperative ankle stiffness who also presented with 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 investigations advance our knowledge of ankle stiffness as a delaying indicator of permanent limb ischemia that requires amputation. Understanding this important relationship will greatly help in developing effective treatment plans for ischemia limbs and improving patient outcomes in emergency situations.

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.

There is no conclusive evidence in our study linking arterial damage to mortality or secondary amputation. Nonetheless, two amputation cases—both of which resulted in fatalities—noted popliteal artery (PA) damage. According to a number of studies, PA injuries are particularly difficult and frequently result in a higher rate of limb loss than other vascular injuries [63,66,67]. Consequently, attention needs to be paid to the serious effects PA injuries have on patient outcomes.

In our investigation, the range of ischemia duration was 6 to 168 hours, with a median of 22 hours. Sixty-one patients had delayed intervention, and only one patient had revascularization within six hours of the injury. Our investigation did not discover a significant statistical link between ischemia duration and mortality or subsequent amputation, in contrast to other studies' conclusions [37] that ischemic duration is an independent risk factor for morbidity and 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].

Therefore, based just on ischemic time or muscle viability prior to revascularization, the choice to amputate the limb rather than attempt salvage should be reevaluated. For ischemic limbs that undergo extended ischemia, we thus advise revascularization; if the patient is hemodynamically stable and shows no symptoms of IRI, we then advise evaluating the muscle's survival.

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.

Conclusion

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

The writers summarized several lengthy sections of the paper and enhanced text readability when preparing this work by using [Hyper Write / summary and improve text tools]. Following their use of this tool/service, the writers took full responsibility for the publication's content and reviewed and amended it as necessary.

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