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Original Research Article

Predictors for limb amputation in war vascular trauma: A 20-years retrospective analysis from the Colombian armed conflict

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ABSTRACT

Background: The Latin American military vascular trauma is virtually unknown. The aim of this study was to describe severe war vascular trauma during the last 20 years of the Colombian armed conflict, and to identify predictors of limb amputation.

Methods: Retrospective analysis of a follow-up cohort from 1999 to 2019 of patients with associated severe vascular injuries (ISS >15) in the Colombian armed conflict treated at the Hospital Militar Central.

Results: Out of 5948 patients, 243 had military vascular trauma with 430 vascular injuries. The most frequent trauma mechanisms were gunshot wounds (n = 153; 63%). The most common injured vessels were femoral. 24 (10%) patients required amputations. Mortality was 4.1%. Amputation was associated with arteriovenous lesions (RR 4.82, p = 0.025), compartment syndrome (RR 4.2, p = 0.007), arteriovenous femoropopliteal injuries (RR 3.5, p = 0.0026), multiple arterial injuries (RR 3.35, p = 0.0218), associated fractures (RR 3.1, p = 0.0032).

Conclusions: Concomitant arteriovenous injuries in popliteal and femoropopliteal lesions, multiple arterial lesions, bone fractures, and compartment syndrome are associated with amputation in severe vascular injury.

1. Introduction

The management of military vascular trauma has changed considerably as a result of wars: World War I, World War II, the Korean Conflict, the Vietnam War, and especially the twenty first century wars—the Persian Gulf War and the Iraq and Afghanistan Conflicts. This has led to advances in the diagnosis and treatment of vascular trauma.[1] During World War I, clinical observations were collected, including symptoms and signs of vascular injuries, and detailed descriptions were provided of the sequelae of vascular injuries, including aneurysms, pseudoaneurysms, and arterio-venous fistulas, from the study carried out by Makins.[1,2] In the Second World War, DeBakey and Simeone[3] identified the correlation between the time of surgical intervention and the incidence of amputation on the premise that early restoration of blood flow was a primer, but surgery was still reserved for the treatment of late sequelae of vascular injuries.[3]

During the First World War, the techniques of primary vascular repair already existed; nevertheless, vascular ligation was the main procedure performed during this conflict. It was only during the Korean War that vascular repair was undertaken as the main procedure under the premise that "Primary surgical repair is recommended in all cases of major acute arterial vascular injury if the incidence of amputation wants to be decreased and if a functional and viable limb wants to be obtained".[4] Diagnostic tools such as Doppler and angiography were readily available during the more recent Middle East conflicts, as were advancements in endovascular management.[5,6]

Colombia has been involved since the early 1960's in a non-conventional warfare fueled by the cocaine drug trade and guerrilla groups.[7,8] This internal conflict has yielded a large volume of war injuries inflicted upon the civilian and military populations. A unique feature of this conflict has been the widespread use of antipersonnel landmines by all participating guerrilla factions in rural zones of our

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country. Preliminary collected data from this conflict was reported previously by Asensio et al.[1] in 2015, but the true reality of vascular trauma in Latin America is virtually unknown due to the absence of national trauma databases. Therefore, the aim of this study was to describe and analyze the severe war vascular trauma (defined as an Injury Severity Score [ISS] >15) during the last 20 years of the Colombian armed conflict, and to identify predictors of limb amputation.

2. Methods

2.1. Study design

The study has been reported in line with the STROCSS criteria.[9]

A retrospective longitudinal study was conducted at Hospital Militar Central in Bogota, Colombia; a reference center of the Colombian Military Forces that concentrates the largest number of patients injured in combat in the country. Patients with severe (ISS >15) vascular injuries from January 1999 to January 2019 were included.

2.2. Patient selection and data collection

Inclusion criteria were: military patients with severe vascular trauma caused in combat, defined as an ISS >15, who received medical or surgical treatment by the general surgery and vascular surgery team at our institution. Exclusion criteria were the following: civilian vascular trauma patients, patients under 15 years old and iatrogenic vascular injuries.

The evaluated variables were demographics, trauma mechanism, vascular injury anatomic location, surgical technique, time to surgical repair, need of amputation and outcomes. Limb salvage was defined as the presence of a viable limb at one month after injury, regardless of functional outcome of the corresponding limb. Amputations were defined as any amputation above the ankle for the lower limb and any amputation above the forearm for the upper limb. All amputations were secondarily defined as amputations performed during surgical procedures subsequent to an initial attempt to achieve limb salvage, including repair of limb vascular injury. Multiple organ failure was defined using the modified Marshall scoring system; a score of 2 or more in any organ system indicated organ failure and 2 or more systems with organ failure was considered as a multiple organ failure.

The data were extracted from the electronic records of the institution. All the patients were informed about the nature of the treatment, and their written consent was obtained. Data collection was designed to preserve patient anonymity.

2.3. Statistical analysis

All data were collected using the SPSS. v26 statistics software. Descriptive analysis was performed for numeric parameters using mean ± standard deviation and median with confidence interval (95% CI). A qualitative bivariate analysis was performed. Association between categorical variables and limb amputation was performed using Fisher's exact probability test. Dichotomous outcomes were also compared using the Yates corrected chi-square test. Statistical significance was considered as $p \leq 0.05$.

2.4. Ethical statements

This study was approved by the institution ethics review board. The protocol was implemented in accordance with the Declaration of Helsinki[10] and Good Clinical Practice guidelines.[11] The ethics committee exempted the collection of informed consent, due to the retrospective nature of the study and the minimal risk.

3. Results

A total of 5948 patients presented vascular injuries but only 243 of them presented severe (ISS >15) vascular injuries (Fig. 1). The 100% of the patients were males. The average age was 23.9 years (range: 18–48 years). The 75% of the patients were younger than 25 years. The mean time for surgical intervention was 30.9 h. The 65.4% of patients were referred from other institutions.

The majority of patients (n = 188; 77.4%) required transfusion of blood products, with an average transfusion of 3.1 units of packed red blood cells (PRBCs). Massive transfusion occurred in 52 patients (27.6%). The 95% of patients required admission to the intensive care unit (ICU). More than half of the patients (58%) developed multiple organ failure. The average length of hospital stay was 20 days. The overall mortality was 4.1% (n = 10).

The vascular trauma mechanisms are shown in Table 1. Clinical diagnosis of the vascular injury was performed in 42 (17%) patients, angiography was used in 75 (31%) patients, and the 42% of the patients were diagnosed using Duplex ultrasound scanning. Associated soft-tissue injury was observed in 89 (37%) patients, bone fractures in 86 (35%), and nerve injury in 25 (10%). The anatomic location of vascular injuries is shown in Table 2. Only the 8% of patients had two or more arterial injuries. A total of 187 patients had associated veins injuries. The femoral vein was the most frequent injured vein in the 31% of the cases followed by the popliteal vein in the 23% of the cases, the humeral vein in 14%, and the subclavian vein in 7%. Combined injuries of artery and vein were found in 74 (30.5%) cases, and the areas of greatest body involvement were the extremities (64% lower limbs and 22% upper limbs), followed by the head/neck, thorax and abdomen.

Surgical interventions and complications are shown in Table 3. Fasciotomy was performed in 99 (40.7%) patients with limb vascular injuries. A total of 24 patients (10%) required amputation (23 in the lower limb and 1 in the upper limb). The microorganisms most frequently found in the surgical site infections presented in patients were *Staphylococcus aureus* and *Pseudomonas* spp, followed by *Escherichia coli* and *Klebsiella* spp. The 54% of patients with antipersonnel landmines trauma developed surgical site infections compared with 28% of gunshot wounds patients and 10% blast injuries.

Amputation was associated with combined arterial and vein injuries (RR 4.82; 95% CI 1.16–19.96, p = 0.025), compartment syndrome (RR 4.2; 95% CI 2.1–8.6, p = 0.007), combined femoral artery and vein injuries (RR 3.5; 95% CI 1.58–7.9, p = 0.0026), fasciotomy (RR 3.5; 95% CI 1.5–8.2, p = 0.002), multiple arterial injuries (RR 3.35; 95% CI 1.5–7.6, p = 0.0218), bone fractures (RR 3.1; 95% CI 1.39–6.7, p = 0.0032) and combined popliteal artery and vein injuries (RR 2.72; 95% CI 1.2–6.3, p = 0.51). The trauma mechanism had no significant relationship with the length of hospital stay, transfusion, amputation, other complications as neurologic sequelae, surgical site infection, rhabdomyolysis, osteomyelitis, pseudoaneurysm, ischemia-reperfusion syndrome and death.

4. Discussion

The mechanisms of injury in this study were very similar to those in the United States Civil War, World War I, and Latin American conflict, with a predominance of gunshot wounds. In World War II and the Afghanistan/Iraq conflicts, trauma mechanisms changed due to technological advancement. The most frequent mechanisms in these two conflicts included improvised explosive devices in the 73% of the cases and antipersonnel landmines in less of the 1% of the cases.[12] This study found fewer blast injuries (21%) but more cases of antipersonnel landmines (16%) compared with the Iraq and Afghanistan wars, which are contemporary to the Colombian armed conflict. Blunt trauma has been identified as a risk factor for amputation. As reported by Rozycki et al.[13] the amputation rate with blunt injuries (18%) is at least three times higher that penetrating injuries.[13] In our study the 50% of amputations

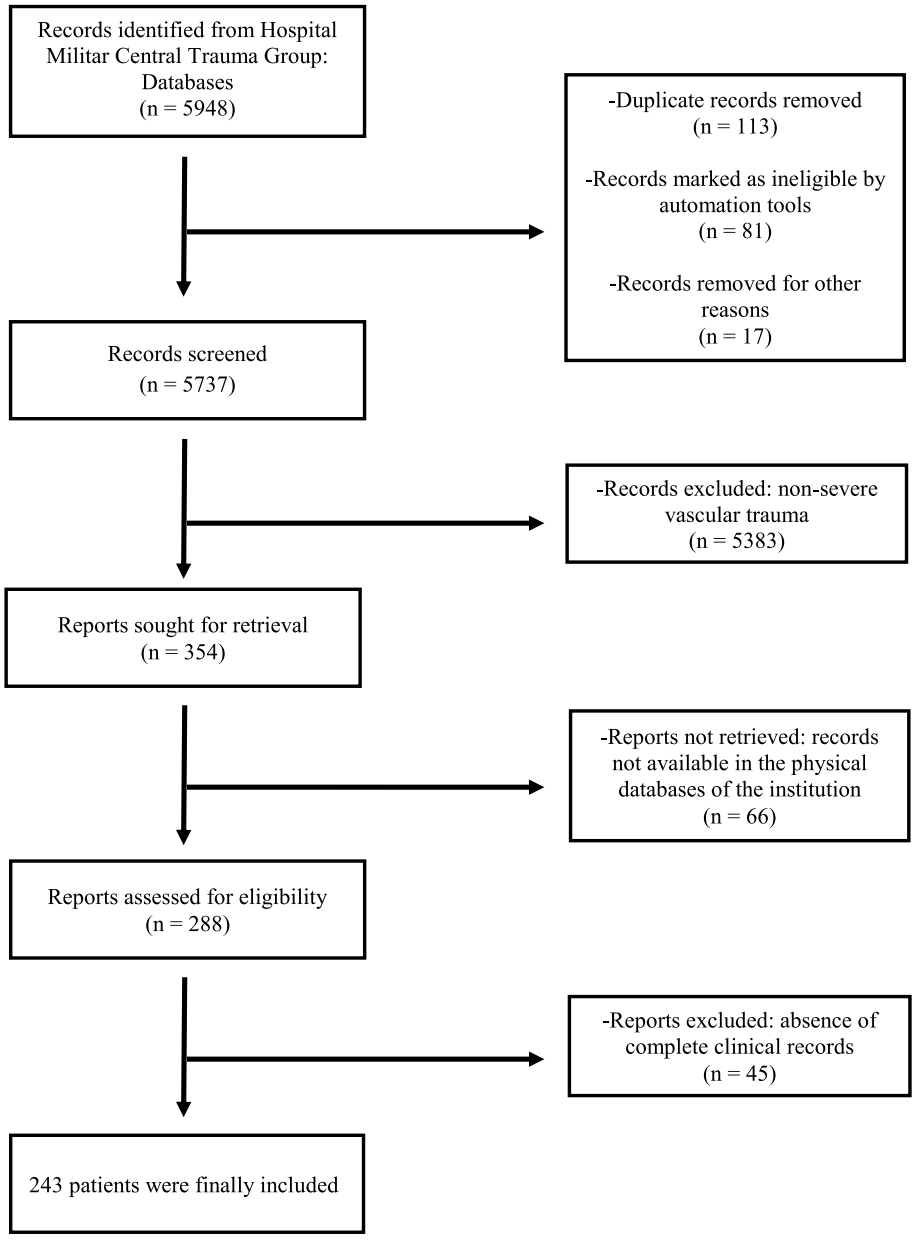

Fig. 1. Study participant flowchart.

Table 1
Comparison between the frequency of injury mechanisms among world wars/conflicts and the Colombian conflict.[12,38]

Conflict/War	WWI	WWII	Afghanistan and Iraq	Colombian armed conflict
	%			
Gunshot wound	65	27	27	63
Blast injuries	35	73	73	21
Antipersonnel landmines	–	–	<1	16

WWI: World War I; WWII: World War II.

were due to gunshot wounds.

The ISS >15 patients were all due to gunshot wounds; this may have been caused by different factors, as blast injuries and antipersonnel landmines are deadlier in the combat zone and patients fail to reach the hospital. Results supported by other studies such as Jahunlu et al.,[14] who

Table 2
Anatomic distribution of traumatic arterial injuries compared among world wars/conflicts and the Colombian conflict.[2,3,12]

Conflict/War	WWI	WWII	Afghanistan and Iraq	Colombian armed conflict
	n (%)			
Head and neck	131 (11)	13 (1)	129 (8)	9 (4)
Lower extremity	367 (31)	1044 (42)	736 (47)	154 (63)
Upper extremity	648 (54)	519 (21)	511 (33)	52 (21)
Torso	45 (4)	24 (1)	51 (3)	19 (8)
Abdomen	11 (1)	871 (35)	143 (9)	9 (4)
Total	**1202**	**2471**	**1570**	**243**

WWI: World War I; WWII: World War II.

Table 3
Arterial and venous surgical procedures performed and complications.

Variable	N (%)
Arterial	
Ligation	130 (53.4)
Saphenous vein graft	51 (21)
Primary repair	27 (11.1)
Endovascular	11 (4.5)
Prosthetic graft material	13 (5.3)
Arteriography	11 (4.5)
Venous	
Ligation	138 (73.8)
Venorrhaphy	31 (16.6)
Primary repair	12 (6.4)
Patch repair	3 (1.6)
Panel venous graft	2 (1.1)
Endovascular	1 (0.5)
Saphenous vein graft	2 (1.1)
Complications	
Neurologic sequelae	69 (35)
Surgical site infection	43 (22)
Compartment syndrome	30 (15)
Amputation	24 (12)
Deep venous thrombosis	11 (6)
Rhabdomyolysis	10 (5)
Osteomyelitis	4 (2)
Prosthetic infection	3 (2)
Pseudoaneurysm	2 (1)
Ischemia-reperfusion syndrome	1 (1)

reported a 36.4% mortality rate for antipersonnel landmines between 1989 and 1999 in Iran, and most fatalities occurred in the prehospital setting.[14] At the same time, this may be explained by the fact that Colombian terrorist groups are groups outside the law that are not governed by International Humanitarian Rights or the North Atlantic Treaty Organization (NATO) and that carry out crimes against humanity with the use of all types of weapons for both military and civilian use in addition to hybrid weapons or improvised explosive devices.[15] Hybrid weapons are weapons that can switch their usual firing mode and operate as a completely different class of weapon with the possibility of generating more serious injuries than those usually found for that type of mechanism.

Antipersonnel landmines came into widespread use in World War II and were initially used to protect antitank mines but then it became a weapon system widely used in the Colombian conflict. Colombia is the second country most affected by antipersonnel landmines in the world after Afghanistan. The Colombian government has reported 11,408 deaths and injuries since 1990, 2006 was the most critical year, as there were 1228 victims, the largest number in Colombian history. The 61% of casualties have been members of the army. During 2019, there were 108 victims.[16,17] In 1997 a treaty was signed in Ottawa by 162 countries promising to cease anti-personnel landmine production or use, among other regulations about war, and the last update of the Mine Ban Treaty was in January 2018. In the first convention, there was a clinical description of anti-personnel landmine-related injuries for the International Committee of the Red Cross describing three patterns and dividing the injuries caused by antipersonnel mines from blast injuries.[18] The antipersonnel mines had a particularly severe pattern injury to the inferior limbs.[19–22] In this study, the rate of amputation was 10% for cases injured by antipersonnel mines and blast trauma but reached 30% of the total amputee patients. However, comparing other types of injury mechanism with amputation, the result was not statistically significant ($p = 0.634$).

Previous studies using multivariate analysis have found that the mechanism of trauma with antipersonnel landmines was associated as a risk factor for infectious complications (odds ratio [OR] 4.0; 95% CI 1.29–12.4, $p = 0.02$). Similar results were found in our study, where 54% of patients with antipersonnel landmines injuries presented infection. Restrepo et al.[23] in 2010 found a similar microbiological profile to the surgical site infections presented in our patients were *Staphylococcus aureus* and *Pseudomonas* spp were the most frequent microorganisms, followed by *Eccheriachia coli* and *Klebsiella* spp.[23] Limb injuries remain the most prevalent anatomic location for vascular trauma; similarly, to World War II and Vietnam, representing 80% of injuries. There is a higher incidence of vascular injuries in the lower limbs.[1,5,24] In our study, 86% of vascular injuries were located in the limbs with 62% in lower limbs. The anatomic locations of vascular injuries in our results were very similar to those reported during World War II and the Afghanistan and Iraq conflicts. The most commonly injured vessels were located in the distal regions of limbs. DeBakey et al.[3] reported that 28% of arterial injuries occurred in distal or minor arteries compared with 33% (518/1570) reported by White et al.[12] Similar results to our study findings with 39% of minor distal arteries injuries. The present study showed a higher incidence of carotid (3%) and aortic (4%) vascular injuries than the reported by DeBakey et al.[3] but similar to the 7% and 3% shown by White et al.[12] in the Afghanistan and Iraq conflicts. This difference can be due to a faster evacuation of injured patients providing an early surgical attention improving the survival rate.[3,12]

Indications for arteriography include the mechanism or extent of injury, abnormal physical examination, reconstructive operative planning, or evaluation of a previous vascular repair. Fox et al.[25] reported a series of 107 vascular injuries; arteriography was performed in 63% of the patients, with abnormal findings in 46% of the cases. The most frequent findings were occlusions of the ulnar, radial, or tibial vessels, pseudoaneurysms and arteriovenous fistulae. The authors suggested a more liberal application of arteriography.[25] In our study, only 9% of the patients were taken to arteriography, and the most frequent findings were pseudoaneurysms and arteriovenous fistulae.

The change from the paradigm of "life over limb'' to the "life and limb" has been made possible by advances in casualties evacuation, bleeding control, and wound care with damage control strategies.[26,27] The use of damage control protocols is very frequent in our patients due to the difficult evacuation of casualties secondary to a 40% of mountainous national geography, long distances from the rural combat zone to our institution and a limited system of evacuation. These issues explain the findings of our study with an average interval from trauma to treatment of 30.9 h. In World War II, DeBakey et al.[3] reported the use of ligation in 2390 cases corresponding to 97.7% of the patients with only 20% of vascular repair cases.[3] In contrast, in the Afghanistan and Iraq conflicts, it was reported that 46% of a series of 1570 patients had some type of vascular repair, and the most often used methods were primary anastomosis or venous interposition graft.[12] These findings were very similar to our study, where vascular repair was performed in the 47% of the patients. Fasciotomy is one of the most important procedures used in vascular injuries with specific indications such as combined arterial and vein injury, ischemia time 4–6 h, mangled limb, and prior arterial or venous ligation, among others. In the present study we found a 3.5-fold association between fasciotomy and amputation (RR 3.5; 95% IC 1.5–8.2, $p = 0.002$).

The first report to describe the full implementation of endovascular approach in vascular war trauma was in the level III Air Force Theater Hospital at Balad Air Base in Iraq. In the period between 2004 and 2007 they treated a total of 9289 patients with a 5.4% of vascular injuries. They demonstrated the safety and feasibility of endovascular procedures in a war and austere environment. Although logistic and skill sets demand a great limitation to endovascular approach becoming a routine practice in wartimes.[28] Only 5% of the patients in our study were treated with endovascular management due to this minimally invasive approach have been implemented in recent years. Historically, ligation of injured veins was the most common surgical treatment modality through the end of World War II. In the Korean and Vietnam Wars, the concept of venous repair appeared and was based on the experience of Rich,[29] who wrote "Venous repair may be important, particularly in popliteal

injuries when repair of the vein may be necessary to prevent limb loss despite successful arterial reconstruction".[29,30] Nevertheless in our study there were not significant finding of vein repair benefit for limb salvage.[30] Quan et al.[31] recommends, for lower limb vein injuries in wartime, repair by lateral suture in the case of minor injuries, interposition saphenous vein graft or end to-end anastomosis in a totally stable patient with isolated injury, and ligation in all patients with multiple injuries or hemodynamic instability.[31] Rich et al.,[32] in a study with 377 veins injuries with 253 ligations and 124 primary repairs, reported a low incidence of complications and emphasized the benefit of these repairs, particularly in lower limb injuries.[32] The Balad Vascular Registry reported 71 vein limb injuries and all early amputations occurred in those with combined arterial and venous injury.[24] A meta-analysis of lower limb vascular injuries conducted in 2015 identified 904 veins injuries associated with arterial injury and a 6-fold lower risk of secondary amputation to the patients that underwent to vein repair compared with ligation (OR 0.17; 95% CI 0.06–0.39, $p < 0.01$).[33] Our study found a 4.8-fold increased risk of amputation in the presence of combined arterial and vein injury (RR 4.82; 95% CI 1.16–19.96, $p = 0.025$).

During World War II amputation rates were 53.2% for femoral artery injuries and 72.5% for popliteal artery injuries.[3] A retrospective study of the National Trauma Data Bank with 1395 popliteal arterial injuries reported a 15% amputation rate for these specific arterial and venous injuries, and they concluded that popliteal vascular injury is associated with significant rates of limb loss, functional disability, and mortality.[34] Case series that have studied popliteal vascular injuries, have reported an amputation rate of 37.1% and identified popliteal artery and vein repair as a significant independent factor associated with improved early limb salvage ($p = 0.05$).[35] The present study showed a 2.7-fold increased risk of amputation in the presence of combined popliteal arterial and vein injury (RR 2.72; 95% CI 1.2–6.3, $p = 0.51$). In a cohort of 513 vascular injuries from the Balad Vascular Registry, Woodward et al.[36] reported 145 femoropopliteal vascular injuries with 86 venous injuries and an amputation rate of 7%, all with combined arterial and venous injuries.[36] Our study showed a 3.5-fold increased risk of amputation in the presence of femoropopliteal combined arterial and vein injury (RR 3.5; 95% CI 1.58–7.9, $p = 0.0026$). A multivariate regression of independent factors associated with amputation after limb vascular injury during the Iraq and Afghanistan conflicts showed a 5.0-fold increased risk of amputation in the presence of bone fractures (RR 5.01; 95% CI 1.45–17.28, $p = 0.01$).[37,38] The present study showed a 3.1-fold association between bone fractures and amputation (RR 3.1; 95% CI 1.39–6.7, $p = 0.0032$). A conduct to mitigate the high amputation rate reported in our patient's cohort was the creation of the Airborne Group of Advanced Life Support in Trauma (Grupo Aerotransportable de Soporte Vital Avanzado en Trauma [GATRA]) by the Colombian Army to perform early surgical treatment at the warzone frontline.

In our vascular surgery department, venous ligation versus repair in arterial and venous combined injuries still depends on the vein injured, the magnitude of the venous injury, presence and grade of associated injuries, the patient's hemodynamic status, and the surgeon's training and experience. Arterial and venous reconstruction began with proximal and distal vascular control. Dissected intima, intramural hematomas or frayed adventitia must be removed from the injured vessel. Complex (more than 50% of the vessel circumference) or long injuries require resection and a primary anastomosis, if no significant tension, less than 2 cm or insertion of venous and arterial interposition grafts. If there are combined injuries, the vein is reconstructed first, depending on the arterial ischemia time, to relieve any outflow obstruction and allow for a better initial arterial patency rate.[39] When there are significant arterial and venous injuries combined with orthopedic injuries, a mangled extremity not mandating immediate amputation, or there has been near exsanguination from a vascular injury in an extremity, the insertion of arterial and venous shunts is appropriate with an early fracture or subluxation reduction and fixation. We used Nelaton catheters to perform the vascular shunts.[39] This process is important to mention when interpreting the results.

War injuries are considered high-energy traumas and associated with severe tissue damage, severe soft-tissue involvement, and a higher risk of developing limb compartment syndrome. A systematic review by Perkins et al.[33] showed compartment syndrome (28 vs. 6%; OR 5.11), multiple arterial injuries (18 vs. 9%; OR 4.85), and major soft-tissue injury (26 vs. 8% for no soft-tissue injury; OR 5.80) to be significant prognostic factors for amputation.[33] Our study showed a 4.2-fold increased risk of amputation in the presence of compartment syndrome (RR 4.2; 95% CI 2.1–8.6, $p = 0.007$) and a 3.3-fold increased risk when multiple arterial injuries were present (RR 3.35; 95% CI 1.5–7.6, $p = 0\ 0.0218$); however, unlike the previous study for major soft tissue injury,[38] this association was not statistically significant in the present study (RR 1.3; 95% CI 0.59–2.66, $p = 0.34$).

4.1. Study limitations

The findings of this study should be interpreted within the context of its design. It's a single center non randomized descriptive retrospective study. The results should therefore be viewed as hypothesis-generating to conduct future studies. All data were retrospectively collected from the electronic medical records and the outcomes are based on what has been registered. This study presents the risk of selection bias and the limitations secondary to the lack of individual clinical patient information, prone to recall bias or misclassification bias. Strengths of this study are the biggest cohort of vascular trauma patients during the Colombian armed conflict reported until now, the detailed short and long-term clinical outcomes of vascular injuries and the patients follow up.

5. Conclusions

Amputation rates in war vascular trauma are associated with combined arterial and vein injuries, especially those of the popliteal and distal femoral vessels, bone fractures, and limb compartment syndrome. These findings suggest that surgical repair of vein injuries of associated arterial injuries may have a role to avoid amputation, and the liberal use of fasciotomies in these cases is essential to decrease the risk of amputation.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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