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USE OF TOURNIQUETS FOR HAEMORRHAGE CONTROL IN CIVILIAN AND MILITARY PREHOSPITAL SETTINGS: METABOLIC, HAEMODYNAMIC, AND ANATOMICAL COMPLICATIONS DERIVED FROM EXPOSURE TIME

Jose Luis Pineros Alvarez, Dayana Villate-Lamos, Angie Nathalia Munoz-Trejos

Faculty of Medicine, Universidad del Valle, GINAPH Research Group, Cali, Colombia

ABSTRACT

INTRODUCTION: Haemorrhage control is an essential component in the management of traumatized patients, given its significant global contribution of approximately 1.5 million annual deaths. Extremities, prone to bleeding, offer opportunities for early haemostatic intervention, recognizing tourniquets as critical lifesaving tools in severe limb injuries. Despite global acceptance in medical guidelines, concerns persist regarding ischaemic complications and limb loss associated with tourniquet application, especially in civilian settings. This scoping review aims to examine current literature on the use of tourniquets for haemorrhage control in both civilian and military settings. It seeks to assess metabolic, haemodynamic, and anatomical complications derived from tourniquet exposure duration.

MATERIAL AND METHODS: A search strategy was conducted following JBI and PRISMA-ScR protocols in PubMed databases. Study characteristics, setting, tourniquet time, environment, and reported complications were extracted from eligible studies.

RESULTS: The literature review identified 2,094 studies, of which 9 met the inclusion criteria. These studies mainly originated from North America and Europe, with 8 being retrospective analyses. Characteristics of 2,136 participants who received tourniquet applications were evaluated, with 84.8% male representation. Complications were detailed in relation to exposure times, ranging from 22 to 268 minutes, revealing diverse outcomes, including temporary paraesthesia, acute kidney injury, nerve compression injuries, rhabdomyolysis, ischaemia/reperfusion injuries, and compartment syndrome.

CONCLUSIONS: This scoping review highlights the scarcity of local data and the need for a comprehensive assessment of tourniquet use in different traumatic scenarios. Understanding the specific impact of prolonged tourniquet application on clinical outcomes and complication rates is crucial for formulating guidelines and effective interventions in prehospital care.

KEYWORDS: haemorrhage; prehospital care; tourniquets; trauma; complications

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CORRESPONDING AUTHOR:
Jose Luis Pineros Alvarez, Universidad del Valle, Calle 4B # 36–00, 760043 Cali, Colombia
e-mail: jose.pineros@correounivalle.edu.co
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INTRODUCTION

Haemorrhage control is a crucial pillar in trauma patient care. Haemorrhage is estimated to account for a significant number of global deaths, around 1.5 million deaths each year [1], making it one of the leading causes of preventable death in young individuals [2]. In Colombia, there has been a reported trend in mortality due to trauma injuries between 2007 and 2017, attributing a total of 214,258 deaths to trauma; the leading cause of death in the male population is attributed to firearm injuries, while in the female population, it is traffic accidents [3].

The loss of blood components can progress to a state of shock with catastrophic outcomes if bleeding is not controlled early, indicating a need for prompt management to prevent dysregulated pathophysiological responses. Among the anatomical sites where bleeding frequently occurs are the extremities, which are amenable to early haemostatic management.

Tourniquets are a critical lifesaving tool in the treatment of severe limb injuries [4]. Despite their widespread adoption in medical guidelines globally, concerns persist regarding potential ischaemic complications and limb loss associated with their application [5]. The inclusion of tourniquets in prehospital emergency care has been based on modern data from military contexts, where complications are not as common, especially when used for short durations [6]. However, the situation differs for patients suffering traumatic injuries in rural and remote areas, where transport times to definitive medical care can be significantly longer [7]. In this context, there is still uncertainty regarding the actual risks and benefits of using tourniquets during prolonged application periods. Furthermore, most guidelines have not adequately compared outcomes and complication rates concerning extended tourniquet use.

Therefore, understanding ischaemic complications and complication rates in the context of prolonged tourniquet application is crucial for informing clinical practices and improving prehospital haemorrhage management protocols. However, there is a lack of sufficient local information that could shed light on how these specific conditions impact clinical outcomes and complication rates in the study setting. Local guidelines are mainly based on data from military experience and a few civilian data, where significant differences in injury patterns and healthcare systems can be observed.

Complications associated with prolonged tourniquet use have been thoroughly investigated in medical disciplines such as orthopaedics (controlled settings) [8], but assessing them in the prehospital environment has proven challenging, perhaps due to differences in the personnel applying them, uncontrolled environments, and limited supervision. These complications have been linked to limb amputation, accumulation of toxic metabolites, and even mortality [5]. Given the considerable magnitude of risks associated with tourniquet use in acute trauma situations, a comprehensive review of this topic is justified.

This research addressed an analysis of the current literature available on the use of tourniquets for haemorrhage control in civilian and military settings, as well as the presence of metabolic, haemodynamic, and anatomical complications derived from tourniquet exposure time.

MATERIAL AND METHODS

This scoping review was conducted following the methodology of a scoping review following the JBI protocol [9] and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist [10].

Research question

What are the time-dependent effects of tourniquet exposure for haemorrhage control in military and civilian prehospital environments on secondary metabolic complications?

Eligibility criteria

Studies that met all the following criteria were included:

— participants of any age who had a tourniquet applied after acute trauma to a limb where the mechanism of injury was described;
— both improvised or commercial tourniquets applied for any duration of time or distance were considered. This included tourniquet application by anyone, such as bystanders, first responders, physicians, or self-applied, in the prehospital setting;
— studies conducted in both civilian and military settings;
— full-text articles published in indexed journals;
— original research, including randomized controlled trials, non-randomized controlled trials, cohort studies;

— articles published within the past 5 years (2019––2023).

Exclusion criteria

— Tourniquets first applied in hospital settings, such as emergency rooms or operating rooms;
— Abstracts or full-text articles published as brief communications, editorials, guidelines, websites;
— Case-control studies;
— Studies conducted on animals;
— Studies conducted on cadavers or mannequins;
— Studies on surgical tourniquets.

Search strategy

Relevant studies were identified through an electronic search in the PubMed, LILACS, and ScienceDirect databases. The keywords "tourniquet", "trauma", and "injury" were used for the search. Articles published within the previous 5 years were classified; the search was not limited to reports published in English.

Equations

— Pubmed: ("Wounds and Injuries" [Mesh] OR trauma[tiab]) AND ("tourniquets" [MeSH Terms] OR "tourniquet*"[tiab]);
— Lilacs: (Tourniquets) AND (Wounds and Injuries);
— ScienceDirect: Tourniquets AND trauma OR injuries OR wounds.

Data extraction (selection and coding)

Data extraction from the included articles was performed by two researchers who collected the data, with a third researcher verifying whether the data met all the criteria. The searches were merged in the RAYYAN® web application [11], where duplicates were removed, and studies were selected for evaluation by title and abstract. An analysis of the selected articles was then conducted to determine if they met the inclusion or exclusion criteria in an Excel matrix, with a critical focus by the researcher. This stage aimed to identify studies that met the inclusion and exclusion criteria, and duplicate records were removed considering the variables to be analysed in the study.

Risk of bias assessment (quality)

After data extraction, agreement and disagreement regarding the content of the selected articles among the researchers were addressed. Discussion and the involvement of a third evaluator were established in cases of disagreement between the authors. This also helped avoid the risk of selection bias in the included articles/studies.

RESULTS

The literature review enabled the registration of 2,094 studies from the three mentioned databases. 171 records were eliminated during the duplicate removal phase using the RAYYAN® web automation tool, limiting the search to the period 2019–2023 and scientific articles only. A total of 1,923 records were evaluated based on title and abstract, with 328 excluded by the automation tool and investigator selection (1,570), leaving 25 studies for full-text reading, of which 16 studies were excluded for not meeting inclusion criteria or presenting any exclusion criteria. Thus, a total of 9 articles were included for comprehensive analysis (Fig.1).

Bibliography characteristics

Among the 9 included studies, 55% (n = 5) were found in the PubMed database, followed by 45% (n = 4) in Lilacs. Among them, 8 were retrospective analyses, and one was a prospective multicentre study. 67% (n = 6) of the articles were from North America, followed by 22% (n = 2) from Europe and 1% (n = 1) from Oceania. All 9 articles were in English.

Participant characteristics

Participant characteristics are summarised in Table 1. A total of 2,136 participants received at least one tourniquet placement. Gender was specified in 4 articles, totalling 1,017 participants, of whom 84.8% were male. Tourniquet exposure time was reported in all articles, however, for 3 of the selected articles, the exposure time was unknown for all their participants. The calculated mean exposure time was 83.8 minutes. However, there are statistical limitations because, in civilian scenarios (8/9), tourniquet exposure times were shorter, and within the same articles, there were significant variations in times depending on coverage area. In the single military scenario article, the tourniquet time was 268 minutes, consistent with literature reporting that longer exposure times increase complication probabilities.

Complication evaluation

Complications were evaluated for each reported tourniquet exposure time in each article. Three

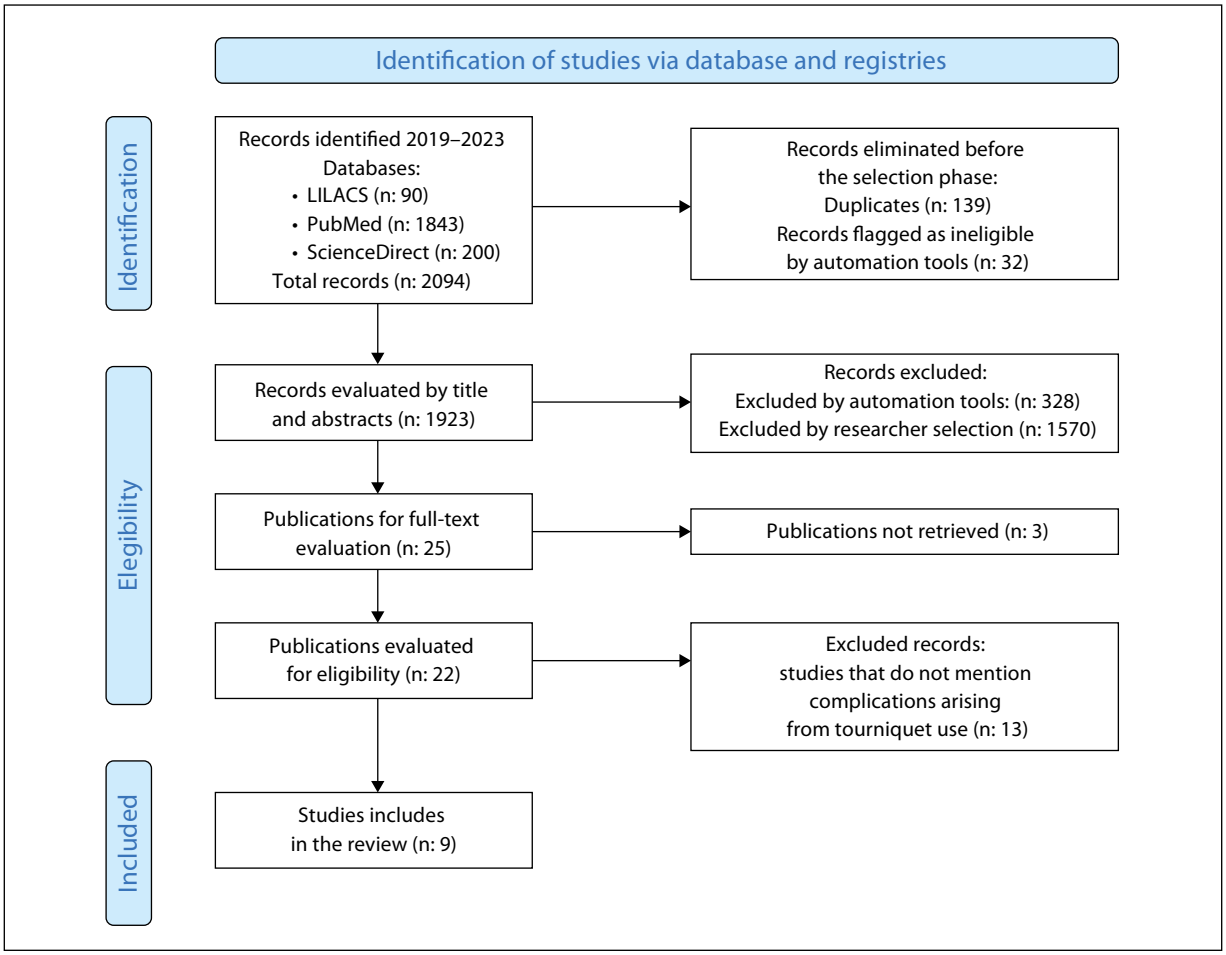

FIGURE 1. PRISMA flowchart

articles reported times less than 55 minutes: 22, 40, 48, and 52 minutes, respectively [12–15]. These articles did not report significant complications. However, it is interesting to clarify that the research conducted by Schroll et al. [15], is the first and largest prospective investigation into the use of prehospital tourniquets for civilian extremity trauma, with a total of 1,130 tourniquets applied, including 962 prehospital tourniquets. Their reports indicate that commercial-type tourniquets were predominantly used; 63.1% belonged to the combat application tourniquet (CAT) type, 0.2% to The Rapid Application Tourniquet System (RATS) and 0.1% to the Special Operation Forces Tactical Tourniquet (SOFT-T). There was a significant portion where the type of tourniquet was unknown, 35.9%. Exposure times varied between 4 to 506 minutes, with a mean of 40 minutes. Data were compared with a control group, showing an incidence of limb complications that was not statistically significant compared to the control group ($p > 0.05$).

Three articles reported times of 56, 60, and 78 minutes; McCarthy et al. [16], covers a population of 182 patients; however, data on tourniquet duration are available for only 52, with a median of 56 minutes. Complications included: temporary paraesthesia in 5 cases, bruising in 1 case, fasciotomy in 2 cases, and nerve compression injury in 2 cases. Severe complications occurred in 7.7% of the evaluated population. In the study by Wellme et al [17], with a population of $n = 56$, tourniquet exposure times were only known for more than 50% of the total evaluated, $n = 21$. Reporting exposure times ranged between 15 and 100 minutes, with a median of 60 minutes. The authors report the use of a tourniquet with the blood pressure cuff and nine improvised tourniquets; 4 of the improvised tourniquets were converted to commercial ones upon arrival of prehospital personnel. Complications were found including 2 amputations, 4 fasciotomies, 1 compartment syndrome, 3 acute kidney injuries, and 13 nerve injuries. However, they do not attribute the amputations to the tourniquets.

Table 1. Bibliography features

Authors	Title	Objective	Methods	n	Application time and (n) with reported application time	Complications	Setting
Smith et al. [12]	Prehospital tourniquet use in penetrating extremity trauma: decreased blood transfusions and limb complications	To determine whether the prehospital use of tourniquets in patients with significant penetrating trauma is associated with differences in outcomes compared to an equivalent control group	Retrospective analysis of 8 years of adult patients with major penetrating limb trauma amenable to tourniquet use at a level I trauma centre. Patients with prehospital tourniquet placement were identified and compared with an equivalent group of patients without tourniquets. Univariate analysis was used to compare outcomes between the groups	204	22.5 min (n: 204)	Tourniquets were not associated with nerve paralysis (p = 0.330) or secondary infection (p = 0.43)	Civil
Bedri et al. [13]	Tourniquet application for bleeding control in a rural trauma system: outcomes and implications for prehospital providers	Examine the safety of applying tourniquets for haemorrhage control in patients presenting to a trauma centre. Compare the outcomes with those from an urban tourniquet dataset	Retrospective review of medical records of adult patients admitted to a level I trauma centre between July 2015 and December 2018. Demographic data (age, gender), injury (injury severity score, Glasgow Coma Scale, mechanism of injury), tourniquet (type, location of tourniquet application, duration of tourniquet, application and removal site, indication), and outcome data (complications such as amputation, acute kidney injury, rhabdomyolysis, or nerve paralysis, and mortality)	92	Urban 48 min Rural 123 min (n: 92)	Urban nerve injury: 2/92 (2.2) Rural nerve injury: 12/197 (5.8)	Civil
Wellme et al. [17]	Evaluating tourniquet use in Swedish prehospital care for civilian extremity trauma	Evaluate the prehospital use of tourniquets for haemorrhage control in limb traumas and analyse potential complications associated with their use	Descriptive and retrospective cohort study of limb haemorrhage in all patients (n = 56) with documented prehospital tourniquet use admitted to the trauma centre at Karolinska University Hospital from August 1, 2015, to December 31, 2017. Data were analysed including indication, duration, blood loss volume, complications, and ultimate injury	56	60 min (n: 21)	Compartment syndrome: 1 Acute kidney injury: n = 3 Nerve damage: n = 13 Loss of motor function: n = 10 Loss of sensory function: n = 11	Civil

Table 1 (cont.). Bibliography features

Authors	Title	Objective	Methods	n	Application time and (n) with reported application time	Complications	Setting
Read et al. [19]	Prehospital tourniquet use in civilian extremity trauma: an Australian observational study	Describe the initial experience with prehospital tourniquets from the perspectives of safety and efficacy	Retrospective review of all patients who utilized tourniquets for haemorrhage from August 1, 2016, to December 31, 2019. Data were compared from the RMH Trauma Registry and Ambulance Victoria Registry. Clinical presentation, including prehospital observations, exposure times, limb outcomes, and complications, are described	31	124 min (n: 26)	Complications attributable to the tourniquet: 4/30 (13.3%) Ischaemia and/or reperfusion injury of the limb: 6.7% Temporary sensory deficit: 3.3% Motor and sensory deficit: 3.3%	Civil
McNickle et al. [18]	Effect of prehospital tourniquets on resuscitation in extremity arterial trauma	Describe a cohort of patients with arterial injuries of the extremities who received prehospital tourniquet placement and compare them to a matched cohort with similar injuries but without tourniquet placement	Retrospective evaluation from 2013 to 2017. Described in terms of usage, duration, and frequency of tourniquet application over time. The primary outcome was transfusion within the first 24 hours, with secondary outcomes of morbidity (rhabdomyolysis, renal failure, compartment syndrome), amputation (early versus late), and length of stay	69	78 min (n: 69)	Rhabdomyolysis: n = 15 (22%) Compartment syndrome: n = 1 (1%) Acute kidney injury: n = 4 (6%)	Civil
McCarthy [16]	Tourniquet use in the prehospital setting	Describe the prehospital use of tourniquets in a regional EMS system served by a single trauma centre	Description of documented cases of prehospital tourniquet use between 2015 and 2020. Primary outcomes included tourniquet application duration, success of haemorrhage control, and complications. Secondary outcomes encompassed time of day (based on EMS arrival time), transport interval, affected limb, tourniquet application or removal personnel, and mechanism of injury	182	56 min (n: 52)	Temporary paraesthesia n = 5 Ecchymosis n = 1 Fasciotomies n = 2 Nerve compression n = 2 injuries Serious complications rate: 7.7% (4/52)	Civil
Schroll et al. [15]	AAST multicenter prospective analysis of prehospital tourniquet use for extremity trauma	Assess the outcomes in patients with prehospital tourniquet use. The hypothesis is that prehospital tourniquet use reduces the incidence of patients arriving at the trauma centre in a state of shock	Prospective data collection for adult patients with tourniquet use in 26 trauma centres between 2015 and 2020. Limbs with tourniquets applied in the prehospital setting were included in the tourniquet group, while limbs without prehospital tourniquets were enrolled in the control group	962	40 min (n: 962)	The incidence of complications in the limbs was not significantly higher in the tourniquet group ($p > 0.05$)	Civil

Table 1 (cont.). Bibliography features

Authors	Title	Objective	Methods	n	Application time and (n) with reported application time	Complications	Setting
Legare et al. [14]	Prehospital tourniquets placed on limbs without major vascular injuries, has the pendulum swung too far?	Examine the potentially harmful outcomes of prehospital tourniquet placement in patients without definitive vascular injury. The hypothesis was that prehospital tourniquets were being applied without appropriate indications	Retrospective review of a prospectively collected database maintained by the American Association for the Surgery of Trauma (AAST), comprising 29 level I and level II trauma centres with major extremity trauma (MET) for a subset of all patients without vascular injury	585	52 min (n: 585)	No differences were found in nerve paralysis, compartment syndrome, and mortality between the two groups. No cases of compartment syndrome were identified in either group. There were no secondary infections in the intervention group, while there was one in the control group (2.7%, n = 1/37, p = 0.06)	Civil
Sabate-Ferris et al. [20]	Prolonged tactical tourniquet application for extremity combat injuries during the war against terrorism in the Sahelian strip	Report on complications following prolonged tourniquet application in combat-related limb injuries treated by the French Military Health Service in the Sahel region	A retrospective review was conducted at a French advanced medical treatment centre deployed in Gao, Mali, between 2015 and 2020. All patients treated for a limb injury with the application of at least one tourniquet for a minimum of 3 hours were included. Prehospital data included injury pattern, associated shock, tourniquet location, and duration. Subsequent complications and surgical procedures performed were analysed	11	268 min (n: 11)	Rhabdomyolysis: 100% Compartment syndrome: n = 10 Deaths due to injuries: 2 severely wounded	Military

The group of McNickle et al. [18], evaluates a cohort of 69 patients who required tourniquet application for bleeding control, treated at an urban trauma centre. They report tourniquet exposure times ranging from 15 to 260 minutes (mean 78 minutes), indicating the extensive coverage area served by this trauma centre. They reported complications such as rhabdomyolysis in 15 cases (22%), compartment syndrome in 1 case (1%), and acute kidney injury in 4 cases (6%). For the manuscript with a 124-minute exposure time [19], they evaluated a population of 31 patients, having only exposure time data for 26 of them. Tourniquet-attributable complications were observed in 4 out of 30 cases (13.3%), with ischaemia/ /reperfusion injuries (6.7%) and sensory (3.3%) and motor deficits (3.3%) as the reported complications. It is worth noting that one patient with compartment syndrome due to prolonged exposure was included, who previously had limb entrapment with a requirement for prolonged extraction of 2 hours, making it not easily attributable to the tourniquet. Finally, one article with the longest exposure time (268 minutes) [20] found rhabdomyolysis in all cases, with 10/11 injuries complicated by compartment syndrome requiring urgent fasciotomy. Two severely injured patients died from their wounds, but the others had a favourable outcome.

DISCUSSION

It is important to note that this review does not seek to diminish the importance of prompt action for haemorrhage control using tourniquets when necessary. Scientific evidence strongly supports their use in prehospital settings to save lives [21]. However, it is crucial to recognize and understand the potential complications that may arise from their prolonged use. Complications range from temporary paraesthesia to severe injuries such as rhabdomyolysis and compartment syndrome [5]. By delving into these complications, we can work to reduce their risk and improve the safety of their application in pre-hospital care. With this approach, we can ensure more effective and safer care for patients requiring acute haemorrhage treatment in critical situations.

Ischaemic complications resulting from prolonged tourniquet application represent a significant concern in the prehospital management of haemorrhages [5]. Prolonged ischaemia can lead to irreversible tissue damage, necrosis, and loss of function in the affected limb [5]. Additionally, the accumulation of toxic metabolites in compromised tissue can trigger systemic inflammatory responses and metabolic complications, increasing the risk of shock and multiorgan failure [22].

In this regard, the results of this review show that the occurrence of complications is scarce when times do not exceed 55 minutes of ischaemia, *i.e.*, complication rates associated with prolonged tourniquet application can vary based on exposure duration, applied pressure, and individual patient characteristics [22]. Previous studies have shown that prolonged tourniquet application is associated with an increased risk of limb amputation and severe systemic complications [22].

Another important element to assess complications resulting from tourniquet exposure is the scenario in which it is used, the transfer times, definitive medical care, or even the type of personnel applying the tourniquet. Data suggest that tourniquet duration varies significantly between civilian and military settings, with longer exposures in military environments. This finding underscores the importance of considering the operational context when evaluating methodologies or protocols to enhance tourniquet use safety.

It's important to report the limitations that may arise when evaluating complications resulting from exposure time in this scoping review because, for each patient who required tourniquet application, there were individual factors such as age variability, sex, clinical history, or haemodynamic instability that by themselves represent physiological changes affecting renal, tissue, and nervous function, masking the evaluated results.

One possible explanation for the above paragraph is that for a population of patients where complications were reported, these were also related to additional interventions such as fracture stabilization, blood transfusion, revascularization, or limb amputation. Data could also help explain the increase in complications.

For example, in the prospective research presented by Schroll et al. [15], the group of patients who required prehospital tourniquets exhibited a higher average score on the Limb Abbreviated Injury Scale (AIS) and Mangled Extremity Severity Score (MESS), despite having similar demographic characteristics, Injury Severity Score (ISS), and prehospital vital signs. Additionally, they state that patients with prehospital tourniquets showed no differences in terms of the need for blood products, overall or 24-hour

mortality, amputation rates, or limb complications ($p > 0.05$).

CONCLUSIONS

In conclusion, the results of this review highlight the importance of considering tourniquet exposure time, differences between civilian and military settings, and population heterogeneity when evaluating the efficacy and safety of these devices. Furthermore, they underscore the need for broader and more diverse research addressing identified gaps and providing precise, evidence-based clinical guidance.

Article information and declarations

Author contributions

Jose Luis Piñeros, Dayana Villate, and Angie Muñoz contributed to the study design. Jose Piñeros drafted the manuscript. Jose Luis Piñeros, Dayana Villate, and Angie Muñoz developed the search strategy. Dayana Villate and Angie Muñoz screened the resulting bibliographic references and extracted the required data. Jose Luis Piñeros and Dayana Villate conducted the analyses and interpretation. All authors reviewed and critically revised the manuscript.

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Conflict of interest

The authors declare no conflict of interest.

Supplementary material

None.

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