TITLE

Tourniquets as a haemorrhage-control measure in military and civilian care settings: an integrative review

ABSTRACT

Aims and objectives: The aim of review was to describe and synthesise the evidence on the use of tourniquets to control haemorrhages, summarising both civilian and military use.

Background: Trauma-related haemorrhage constitute one of the most preventable deaths among injured patients, particularly in multi-casualty incidents and disasters. In this context, safe instruments such as tourniquets are essential to help healthcare professionals to minimise loss of life and maximise patient recovery.

Design and Methods: An integrative review was conducted in Medline, Nursing & Allied Health Premium, and Health & Medical Collection, using published data until March 2021 and following the PRISMA guidelines.

Results: A total of 25 articles were included. Evidence has been synthesised to understand the use of different types of tourniquets, environment of application, indication for their placement and potential complications associated with tourniquet placement.

Conclusions: Commercial tourniquets such as Combat Application Tourniquet or Emergency Tourniquet models are a valuable and safe instrument for haemorrhage control in both military and civilian out-of-hospital care settings. Nurses, as part of emergency teams, and other professionals should be aware that there is a possibility of adverse complications, but they are directly proportional to the time of tourniquet placement and generally temporary. In addition, national and international guidelines ensure the need for all civilian emergency services to be equipped with these devices, as well as for the training of healthcare professionals and first responders in their use.

Relevance to clinical practice: Despite the lack of complications in the use of tourniquets in these cases, their use has been a matter of debate for decades. In this sense, this review

yields up-to-date guidelines in the use of tourniquets, their recommendations and their significance among professionals to manage complicated situations.

KEYWORDS

Extremity trauma; First aid; Hemorrhage control; Injuries; Review Literature as Topic; Tourniquets

IMPACT STATEMENT

What does this paper contribute to the wider global clinical community?

- The findings of this integrative review shed some light on the controversial use of tourniquets in both civilian and military settings. Lack of training in these instruments appears as one of the major concerns among civilian professionals particularly in prehospital settings and following mass-casualty incidents or disasters.
- Commercial tourniquets constitute a safe and valuable instrument for healthcare professionals and first responders, including nurses, in prehospital, out-of-hospital and hospital care. However, further research is needed to understand the specific needs and difficulties of these professionals in this matter.

Introduction

Trauma-related injuries are one of the leading causes of mortality and disability, accounting for 29.6% of deaths worldwide as per the latest data from the World Health Organization (WHO, 2018). Although many of these injuries are unintentional, violent trauma contributes significantly to the mortality of mass-casualty incidents (MCIs) or disasters, which have become more frequent in recent decades (Ahmad, 2018; Haider et al., 2014). As a result of these injuries, post-traumatic bleeding represents the major cause of potentially preventable death among injured patients, but which may quickly lead to hypovolemic shock and be fatal if not rapidly controlled (Day, 2016; Rossaint et al., 2016).

Haemorrhage is a medical emergency and is defined as an acute blood loss of intravascular volume that could lead to hemodynamic instability (Tintinalli et al., 2020). Notwithstanding several compensatory mechanisms are activated at the onset of trauma-related haemorrhage, this sympathetic response may fail if the circulatory volume becomes too low. If so, shock follows as a result of an accumulation of oxygen debt, as well as progressive cellular and organ dysfunction (Convertino et al., 2016; Schiller et al., 2017). In this scenario, estimating blood loss can be complicated by a number of factors, including oedemas or urinary loses, although the estimated adult blood volume is 7% of body weight and 8-9% for children. Likewise, there is a classification of four classes of haemorrhage in order to help guide volume replacement. This classification system is broken down from Class I, where there is a non-shock state as a donation of one blood unit, to Class IV, which is considered a preterminal event and aggressive measures are required. Blood loss in Class I is up to 750 ml with normal blood pressure and normal or increased pulse pressure, whereas the blood loss in Class IV is greater than 2000 ml with decreased blood pressure and pulse pressure (Caldwell et al., 2020; Cannon, 2018; Tintinalli et al., 2020).

In this manner, early recognition and prompt action to stop bleeding are lifesaving, especially in prehospital and out-of-hospital care. Haemorrhage management strategies include handling visible haemorrhage, ensuring adequate intravenous access and evaluating tissue perfusion (Klein et al., 2020; Peng, 2020; Tran et al., 2019). External wound bleeding can usually be controlled by direct pressure, although a tourniquet might be required for massive blood loss. Tourniquets have been used for decades as a quick and effective aid to control major bleeding, and include some widely-used commercial types such as Combat Application Tourniquet (CAT), Emergency Tourniquet (EMT), SOF-Tactical Tourniquet-Wide (SOFTT-W) or Stretch-Wrap-And-Tuck Tourniquet (SWATT) (Drew et al., 2014; Ross et al., 2018). Tourniquet use and haemorrhage-control training have shown a reduction in mortality from approximately 10 to 16% in the battlefield, which can be mirrored in injured victims in civilian contexts, where the literature is more limited (Goolsby et al., 2019; Kotwal et al., 2011). Whereas it is true that adequate knowledge and training of nurses and medical staff has shown to be effective for safe use of tourniquet (Jensen et al., 2019), further understanding of their use in other scenarios, such as MCIs or disasters where emergency teams need to take quick and efficient decisions, is still needed (Moore, 2017; Pepper et al., 2019).

Having said that, there is still a controversy over the use of tourniquets due to their potential risks caused by inappropriate usage, lack of training or prolonged use (Jensen et al., 2019; McCarty et al., 2019). These may lead to some of adverse effects, which entail permanent nerve and muscle injury, ischemia, vascular injury or skin necrosis (Ahn et al., 2019; Spruce, 2017). For these reasons, some studies have discouraged their use particularly in non-military prehospital care settings, highlighting the need for better training, more consistent protocols and adequate number of healthcare first responders to safely treat patients (Duignan et al., 2018; Lee et al., 2007; Wall et al., 2014), although recent literature shows their efficacy and safety in both civilian prehospital care (Cunningham et al., 2018; A. A. Smith et al., 2019; Teixeira et al., 2018) and hospital care (Masri et al., 2020; Præstegaard et al., 2019). However, little has been written about the grade of evidence of their use, agglutinating both civilian and military use of tourniquets when used in out-of-hospital or prehospital care. In view of the incidence of trauma-related injuries and the importance of controlling their bleeding, organizations and professionals must therefore ensure that up-to-date evidence-based practices are used in order to minimise any potential risks, particularly in the event of MCIs or disasters (Sanak et al., 2018; Wall et al., 2014).

Aims

Thus, the aim of review was to describe and synthesise the grade of evidence on the use of tourniquets to control haemorrhages, summarising both civilian and military use. Based on limited evidence of the use of tourniquets in civilian contexts, which sometimes mirrored those seen in the military context, both settings were chosen to provide broader evidence of tourniquet management.

Methods

Design

An integrative review design was used to conceptualise and provide new understanding about the topic, following the Preferred Reporting Items for Systematic Reviews and

Meta-Analyses (PRISMA) guidelines (Supplementary File 1). The process included a definition of the search strategy, assessment of methodological quality in selected articles, analysis and interpretation of the data, and synthesis of the findings (Whittemore & Knafl, 2005). In this manner, the following research question based on PIO (Patient-Intervention-Outcome) framework (Stone, 2002) was raised to this purpose: "Is the tourniquet (I) recommended (O) for bleeding control in out-of-hospital or prehospital care (P)?".

Search strategy

Three electronic databases, Medline, Nursing & Allied Health Premium, and Health & Medical Collection, were consulted via ProQuest until March 2021, using natural and structured language based in the following search strategy, validated by a librarian: ((((Tourniquet [Title/Abstract]) OR Tourniquets [MeSH Terms])) AND (((Bleeding [Title/Abstract]) OR Hemorrhage [Title/Abstract]) AND Hemorrhage [Mesh Terms])) (Supplementary File 2). Snowball strategy and grey literature were not included in this integrative review.

Inclusion and exclusion criteria

The inclusion criteria were as follows: (i) articles published in English or Spanish, (ii) and papers focused on the use of tourniquets to control haemorrhages, (iii) premised on MCIs or disasters. Similarly, (i) papers based on paediatric population, (ii) those investigating the use of tourniquets in surgeries for bleeding control, and (iii) preclinical studies.

Data screening

Initially, two authors (AR, PR) independently performed a first screening of titles and abstracts and a full-text reading. In case of discrepancy, a third author (MR) was consulted to reach a consensus based on the aim of the study and research question.

Quality appraisal

Appropriate criteria were used for each study, depending on the research design used in each one of them, according to Critical Appraisal Skills Programme tools (CASP, 2019). The Grading of Recommendations Assessment, Development and Evaluation (GRADE) ranking system was used to evaluate the quality of evidence for study outcomes, rated from A (high) to D (very low). The GRADE approach evaluates five domains: risk of bias, inconsistency/indirectness, inadequate precision, and publication bias, classifies the bodies of randomized controlled trials as initially starting with high certainty and the bodies of observational studies as initially starting with low certainty (Schünemann et al., 2013).

Data abstraction and synthesis

Consecutively, the data from the included studies was extracted by two authors independently (AR, PR) and, if necessary, a third author (MR) was consulted to reach a consensus based on the aim and research question. Data were tabulated in an Excel sheet according to (i) author(s), (ii) methods, (iii) type of tourniquet, (iii) anatomic location, (iv) environment of use (military or civilian), (v) participants numbers and (vi) main findings (Table 1). Finally, descriptive and narrative analyses were used to synthesise the extracted data, according to the research questions and collaboratively analysed by all authors.

Results

Characteristics of selected papers

In a first stage, 877 articles were retrieved from Medline (n=461), Nursing & Allied Health Database (n=172), and Health & Medical Collection databases (n=244). After title, abstract and full-text screening, a total of 568 articles were excluded on the basis of the selection criteria. Ultimately, 25 studies were included in this review (Figure 1).

[*INSERT FIGURE 1 ABOUT HERE*]

All included articles are displayed in Table 1. Ten (40%) of these articles were primary research studies, among which 3 were randomized controlled trials, 2 used a cohort design, 1 with a quasi-experimental design, 3 were case reports, and 1 was a clinical study. Based on these primary studies, the sample size in each study ranged from 1 to 562 participants. Fifteen (60%) of the remaining articles were literature reviews. Overall, 3 (12%) papers aimed their studies at both civilian and military settings to use tourniquets, while 15 (60%) were focused only at civilian contexts and 7 (28%) at military scenarios.

[*INSERT TABLE 1 ABOUT HERE*]

The data synthesis revealed four categories related to the current evidence on the use of tourniquets to control haemorrhages. In this manner, this evidence would be associated with the use of different types of tourniquets, environment of application, indication for their placement and potential complications associated with tourniquet placement. These categories are described below.

Using different types of tourniquets

The improvised tourniquet is a type of tourniquet used by the military and medical services, particularly in event of disasters or MCIs (D. R. King et al., 2015). In order to be effective, these tourniquets must meet the following criteria: (i) be wide enough so that they do not produce necrosis in the applied area, and (ii) have enough pressure to occlude arteries for which an element acting as a windlass is required. In this sense, the findings show the effectiveness of commercial tourniquets as opposed to improvised ones. Commercial tourniquets usually have a wide band with differences between models and different devices to achieve adequate pressure, such a windlass or a pinwheel, among others (Chaudhary et al., 2019; R. B. King et al., 2006; Kue et al., 2015).

Amongst the wide range of commercial tourniquets available, most of the selected articles dealt with CAT or EMT systems (Callaway et al., 2015; R. B. King et al., 2006; Kue et al., 2015; Scerbo et al., 2017; Scott et al., 2020). The CAT model appears to be the tourniquet of choice in the army due to its ease of transport, its high durability over time and its ability to self-apply, which enables soldiers to apply the tourniquet with minimal and necessary training (Beaven et al., 2017).

According to Beaven and collaborators (2017) as well as Ellis and collaborators (2020), the CAT model is ineffective in the control of bleeding in mid-thigh injuries, one of the most common anatomical bleeding locations, and therefore the use of EMT model is recommended due to its efficacy in this situation. Notwithstanding the potential of the EMT system to stop the haemorrhage more quickly and less painfully as it distributes pressures more evenly (Kragh et al., 2012), its greatest limitation is the greater amount of exposed tissue and the effort needed to achieve the necessary tension (Lewis, 2014). Likewise, the CAT model is associated with a higher rate of pain among all types of tourniquets available. This is due to the width of its cuff being 30mm, far smaller than that of the EMT model (being 110mm), which would pinch the skin and cause more pain by distributing the pressure less evenly (Drew, Bird, et al., 2015; Lewis, 2014; Mullins & Harrahill, 2009). The recommendation for emergency and military services is therefore to have and use both types of EMT and CAT systems on the basis of these reasons (Beaven et al., 2017; Goodwin et al., 2019).

Environment of application

In some cases, the results can be extrapolated despite the variability of the tourniquet application scenarios (Callaway et al., 2015; Drew, Bennett, et al., 2015; D. R. King et al., 2015; Kragh et al., 2012; Lewis, 2014; Scerbo et al., 2017). However, in scenarios other than MCIs or disasters, the mechanisms of injury in both military and civilian scenarios are rather different. Bullet and blast injuries are more unusual in civilian out-of-hospital contexts, where unintended injuries are mainly related to road accidents, falls, machine crushing, or other trauma-related injuries. Moreover, differences between populations should be also taken into account, since soldiers are usually young without pathologies, whereas civilians include all age ranges and may or may not have associated pathologies (Beekley et al., 2008; Goodwin et al., 2019).

Nevertheless, the results in both areas coincide with the safety and suitability of the use of tourniquets in prehospital, out-of-hospital and hospital care, as well as the need to prepare nurses and other emergency professionals (military and civilian) for use in emergency situations as they play a key role identifying the risk factors for complications and planning their use (Brodie et al., 2007; Kauvar et al., 2018; D. R. King et al., 2015; Scerbo et al., 2016).

Indication for tourniquet placement

One of the main controversies about using the tourniquet is about when a tourniquet should be placed. In this regard, some authors identified a number of indications for the use of tourniquets, including: not controlling bleeding with direct pressure or direct pressure bandages, amputation, haemorrhaging in multiple locations, protrusion of a foreign body, the need to control airways, situations such as fires or total darkness, and events involving multiple victims (Beekley et al., 2008; R. B. King et al., 2006; Schauer et al., 2017).

Conversely, Beekley and collaborators (2008) suggested the use of tourniquet as a first-line treatment when exsanguinating haemorrhage occurs, as it achieves almost total haemorrhage control in a short time compared to other traditional methods, increasing survival with few associated complications. In this sense, Drew, Bennett and collaborators (2015) compared the results between traditional methods, including direct pressure, pressure points, elevations of limbs, compression bandage and improvised tourniquets as a last resort, and current methods of haemorrhage control. As suggested by these authors, limb elevation and pressure points show efficacy only initially, as coagulation is resumed within 60 seconds in the upper limb and 30 seconds in the lower limb. Therefore, these two measures may be useful for a short period of time while placing a commercial tourniquet, compressive bandage or haemostatic agent, which are currently considered to be recommended haemorrhage control measures (Eilertsen et al., 2021; R. B. King et al., 2006; Schauer et al., 2017; E. R. Smith et al., 2016).

At the same level of results, the most common mistakes made by participants without prior training when placing the tourniquets were excessive belt slack and few turns of the windlass. In order to avoid them, the literature suggests that it is necessary to tighten the belt strongly before starting to turn the windlass and to make as many turns of the windlass as necessary to stop the bleeding or to achieve the absence of a pulse (Beaven et al., 2017; Cornelissen et al., 2020; Kragh et al., 2012). In particular, a pressure of 200 mmHg or more is necessary in order to achieve total bleeding control, for which between 630-1170 degrees of windlass rotation must be carried out, coinciding between 2 and 4 turns, or more when applied at the mid-thigh level (D. R. King et al., 2015; R. B. King et al., 2006; Lewis, 2014).

Potential complications associated with tourniquet placement

Most studies concur on the scarcity of complications associated with the use of tourniquet, which are mainly related to time of placement (Beaven et al., 2017; Beekley et al., 2008; Callaway et al., 2015; Scerbo et al., 2016). Compressive neuropraxia and compartment syndrome are the most common local complications, but systemic complications are of greater concern (Drew, Bennett, et al., 2015). Some toxic metabolites are released when a tourniquet is removed and perfusion returns to the ischemic limb and may contribute to myonephrotic syndrome, which is characterized by metabolic acidosis, hyperkalaemia, myoglobinemia and myoglobinuria (Drew, Bird, et al., 2015; Lewis, 2014). This myoglobinuria is the result of muscle damage due to ischemia caused by rhabdomyolysis, which can lead to acute renal failure. And besides, ischemic cells may release potassium causing hyperkalaemia and heart arrhythmias (Lewis, 2014). On the other hand, another major systemic complication is a long-term syndrome called post-tourniquet syndrome, usually resolved within 3 weeks, which is relatively common and manifests as weakness, paraesthesia, pallor, and stiffness of the affected limb (Lewis, 2014; Scerbo et al., 2016). Similarly, Beekley and collaborators (2008) emphasized the role and frequency of the appearance of neurological complications, indicating that there were no complications in participants in whom the tourniquet lasted less than 70 minutes, starting to be observed when the time was extended between 109-180 minutes.

These complications appear to be related to the injury suffered rather than to the application of the tourniquet. However, the risk of amputation associated with the use of tourniquet was the complication of greatest concern, although no study has shown that the use of tourniquet is associated with amputations rather than with the severity of the injury (Callaway et al., 2015; Drew, Bird, et al., 2015; Kauvar et al., 2018; Scerbo et al., 2016).

Discussion

This study was aimed to describe and synthesise the grade of evidence on the use of tourniquets to control haemorrhages, summarising their civilian and military use in out-of-hospital care settings. In this respect, this integrative review of 25 studies found that tourniquet-related complications have a very low incidence and their combination with training and policy has been proven to be lifesaving; as well as the existing guidelines for their use in different settings, taking into account the types of tourniquet, indications of tourniquet placement and possible complications.

The use of tourniquet has been controversial for many years, believing that it caused more harm than benefit, and hence discouraged to be used in civilian settings (Klenerman, 2005; Kragh et al., 2012). However, most international agreements such as Hartford Consensus (Moore, 2017) or Victoria Consensus (Martín-Ibáñez et al., 2019), among others, recommend tourniquets in intentional MCIs or disasters by being safe and effective in these scenarios. After analysing the results, as in other studies (Duignan et al., 2018; Knickerbocker et al., 2019), it was found that nurses, medical staff, emergency services and first responders had to use improvised tourniquets. Some of them were effective, but the vast majority of them produced a paradoxical increase in bleeding as a result of misuse of the tourniquet. Direct pressure is considered to be inefficient for extended periods such as direct threat situations or the transportation of the injured individual (Day, 2016; Wall et al., 2014). Therefore, healthcare professionals in emergency services and other first responders should be trained in the use of commercial tourniquets such as CAT or EMT as they have been shown to be safe, improving long-term outcomes and increasing survival in trauma-related injuries (Beaucreux et al., 2018; D. R. King et al., 2015; A. A. Smith et al., 2019).

These findings support the idea of controlling haemorrhages depending on the situation at the time, in both military and civilian settings. First, direct compression is recommended by applying a pressure of 5-7 cm above the injury when the situation is safe (Kragh et al., 2012; Scerbo et al., 2017). These findings differs from some published studies (Drew, Bennett, et al., 2015; Kue et al., 2015), which stated that it should be placed 2-3 cm above the injury, regardless of the type of tourniquet used. On the other hand, the first measure of choice in unsafe situations such as disasters or MCIs will be the tourniquet, leaving elevation of limbs, direct pressure or compressive bandages for later (Caspers et al., 2018; Caubère et al., 2019; Klenerman, 2005). Thus, in the event of uncertainty as to the ideal placement of the tourniquet or because the origin of the injury cannot be traced due to an excessive amount of blood, it is recommended that it be placed in the most proximal part as possible (Kauvar et al., 2018; Scott et al., 2020).

Once a tourniquet is in place, two phenomena may occur: ischaemia-related metabolic effects as well as muscle and nerve damage due to compression (Drew, Bennett, et al., 2015). In order to reduce nerve damage, it is recommended that the width of the tourniquet cuff be increased, although the appropriate width of the tourniquet has not yet been firmly established (Beaven et al., 2017; Lewis, 2014). In addition, particular consideration must be held on the pressure exerted, as most complications are associated with this factor; insufficient pressure may lead to a paradoxical increase in bleeding (venous tourniquet) and excessive pressure may lead to nerve damage (Kragh et al., 2011, 2012).

As mentioned by Drew, Bird and collaborators (2015) and Malo and collaborators (2015), tourniquet conversion is just as important as training in their use. In this sense, it is recommended that it be re-evaluated every 30 minutes to ensure that bleeding or possible complications have been properly controlled to optimise tourniquet use (Malo et al., 2015). There is a 2-hour safe time window for the release of the tourniquet, although there are documented cases that kept the tourniquet in place for up to 6 hours (Callaway et al., 2015; Drew, Bird, et al., 2015; Ellis et al., 2020; R. B. King et al., 2006; Scerbo et al., 2016). Lewis (2014) stated that a tourniquet should only be released for two reasons: (i) to check whether bleeding continues or (ii) whether definitive treatment is available. In order to remove the tourniquet, according to Drew, Bennett and collaborators (2015) and Drew, Bird and collaborators (2015), it is necessary to place another tourniquet on top of the main one for two reasons: firstly, given the possible rupture of the first one and, secondly, due to the patient's own process as it may cause bleeding to be restored. Only the cuff is tightened in this new tourniquet and the main one is progressively loosened. Sometimes it may be necessary to put a compressive bandage or to use some haemostatic agent once the tourniquet has been removed (Caldwell et al., 2020; Klein et al., 2020; Peng, 2020).

Historically, fear of possible complications caused by tourniquets might have led to the use of direct pressure or compressive bandages as main methods for haemorrhage control, particularly in civilian settings (Goodwin et al., 2019; Kragh et al., 2012; Lewis, 2014). Sometimes this fear of possible complications associated with the tourniquet causes a delay in the choice of use, leading to a higher risk for patients, as delay is associated with increased mortality due to haemorrhagic shock (Scerbo et al., 2017). Therefore, it should be implanted as soon as possible once the decision to use a tourniquet has been taken, preferably before the onset of haemorrhagic shock, as it is directly related to increased survival and reduced need for blood transfusions (Callaway et al., 2015; Scerbo et al., 2017). Lack of training among the military, nurses, medical staff and first responders also aggravated these complications and hence further training was reported as necessary to avoid risks in the use of tourniquets (Chaudhary et al., 2019; Scerbo et al., 2016; Scott et al., 2020; E. R. Smith et al., 2016).

Limitations

The main limitation in this integrative review concerned the heterogeneity of the methods used in the selected studies, which made it difficult to discuss our findings and generalise the results. Although most studies aimed at studying tourniquet placement in military settings or using retrospective designs in MCIs, which may have overlooked other outcomes of civilian health professionals and settings, this review provides an approach based on lessons learned from military and civilian out-of-hospital care settings that could be applied to events such as MCIs or disasters.

Relevance to the clinical practice

Haemorrhage control in MCIs or disasters constitute one of the most preventable deaths among injured patients. Despite the lack of complications, safe use and efficacy in the use of tourniquets in these cases, their use has been a matter of debate for decades. In this sense, this review yields up-to-date guidelines in the use of tourniquets, their recommendations and their significance among nurses, medical staff and other emergency responders to manage these situations as their combination with training a policy has been proven to be safe, effective and lifesaving. Similarly, training for civilians, nurses, medical staff and first responders is critical to improving the speed and quality of tourniquet use by moving these trainees into potential knowledge transmitters. Having said that, further research is needed to understand the efficacy among civilian, healthcare professionals and other overlooked needs.

Conclusions

Commercial tourniquets such as EMT or CAT models are a valuable and safe instrument for haemorrhage control in both military and civilian out-of-hospital care settings. Nurses, as part of emergency teams, medical staff, and other professionals should be aware that there is a possibility of adverse complications to consider during using tourniquets such as effect on skin, risk of local complication or risk of vascular compromise, but they are directly proportional to the time of tourniquet placement and generally temporary. Particularly in intentional MCIs or disasters, the use of commercial tourniquets is safe and recommended over other traditional methods such as direct pressure, elevations of limbs or improvised tourniquets. These recommendations state that the maximum time of tourniquet placement should be 2 hours with re-assessments every 30 minutes. In addition, national and international guidelines ensure the need for all civilian emergency services to be equipped with these devices, as well as for nurses, medical staff and first responders to be trained in their use in order to provide timely and safe care in these scenarios.

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