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Tourniquets, types and techniques in emergency prehospital care: A narrative review

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ABSTRACT

Massive uncontrolled hemorrhage is an important cause of preventable death in trauma. Therefore, applying an arterial tourniquet (TQ) is recommended as a pre-hospital measure to control bleeding after severe traumatic bleeding. Limb TQ applies circumferential compression proximally to the injury site to compress the arteries, resulting in blood flow and consequently hemorrhage interruption. The use of commercial tourniquets (C-TQ), which are designed, tested, and registered to control hemorrhages in pre-hospital care, is a consensus. However, they are still uncommon in many prehospital emergency services and the overall level of evidence in most studies is low. This narrative review aimed to characterize the importance of tourniquets use in prehospital emergency care and its application techniques. Furthermore, it proposes to stimulate the development of new devices, more accessible and easier to use, to suggest new directions of studies and medical education demands, with manikin and simulation development.

1. Introduction

Hemorrhages represent a vital topic in emergency pre-hospital care [1] due to the possibility of killing trauma casualties within minutes [2] and the uncontrolled bleeding is an important cause of preventable death in trauma [3], in both civilian [2], and tactical (military/police) scenarios [4,5], among other conditions and concerns [6].

Massive blood loss demands immediate control [1,3], and it has become the recommendation of initial procedure in all the main guidelines in Prehospital Care (PHC) civilian (C-PHC) and tactical (T-PHC) [7–10].

Severe bleeding can be controlled mainly with the use of tourniquets (TQ) [1,3–5], whose fundamental scientific concept is circumferential compression, which results in a complete interruption of blood flow [11]. The timely application of TQ, which can be compromised by improvisation and lack of device, can stop severe bleeding, also currently called "massive" or "exsanguinating," and reduce the need for volume and blood replacements [12]. Its application may be associated with a reduction in mortality and should be recommended from the beginning for applications in PHC. [7–10,13]. Thus, the use of Commercial TQ (C-TQ), approved and certified devices, in PHC, is a consensus [7–10].

There are several types of C-TQ, but there is no consensus about the best model or design (type) for application in the civilian scenario [14]. The C-TQ models differ in their design and operating mechanisms. Several factors can be associated with better TQ application results, such as the capacity for arterial occlusion, the prevention of tissue and nerve damage, the proper circumferential pressure, the distribution of mechanical stress across the width of the device, the induced discomfort, the materials, the speed of application and the intuitive use [11,13–21], and possibly more.

In addition, the costs are a variable that significantly impacts the implantation capacity of those devices [24], especially in the civilian scenario of PHC and the development of new viable models is necessary.

This analysis of medical literature focuses on the history, physiology, types and mechanisms of tourniquets and their current use and application techniques for bleeding control. Additionally, it presents the importance of that device in prehospital care and the demand to develop

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new models, to reduce deaths in acute trauma with massive bleeding.

2. Scientific referential

2.1. Brief history

There are traces that the Hindus from the 6th century BC are responsible for introducing the technique to the Greeks, who did not associate blood loss with death, due to the knowledge limitations about human physiology, at the time [23].

In the 16th century AD, TQ was explored in surgical applications for limb amputation, and in 1593, *Wilhelm Fabry de Hilcer* described the use of a stick to twist a circumferentially compression dressing [23], a technique that became known as "Spanish windlass tourniquet", currently known as "improvised tourniquet" [24].

In 1674, *Étienne J. Morel*, a surgeon in the French army, described the "block tourniquet" [25]. His-work is credited for providing the first record of using standardized TQ on the battlefield [23]. That device provided the basis for improvements during the following century. It was in 1718 that *Jean-Louis Petit*, then Paris's chief surgeon, created a screw device giving rise to the well-known "Petit's Screw Tourniquet" [26].

The first operational guidelines for the use of twist-rod TQ, emerged during the US Civil War (1861 – 1865) and World War I (1914 – 1918) [27]. However, several concerns have arisen about its consequences of use, mainly related to the effects of its prolonged use [28].

Most concerns regarding the use of TQs are related to inadequate training, delays in transport to medical services, and lack of technique. In association with the absence of antibiotics, injury severity and contamination, these factors resulted in the frequent need for limb amputation [29].

In World War II (1939 – 1945), there was progress in the field of combat trauma care. With case studies, the need for early use of these devices became clear. But with essential differences between the scenarios, military (the main origin of TQs) and civilian (still looking for a definitive insertion), myths and concerns were created about the effectiveness and consequences of TQ applications [30].

Studies from the 1940s already demonstrated the effectiveness of the early application of TQ for hemorrhage control [30], and many preliminary conclusions occurred, relating amputations to the TQ application [28]. Through many case reviews, it was observed there was no relationship or significant clinical evidence of limb loss as a direct consequence of TQ use [2,16,30]. Generally, the amputation is related to the injury severity [30]. However, even in current times there are myths of contraindication among general public and health professionals [24,12].

The Operation Iraqi Freedom (OIF), in Iraq (2003 – 2011) and the Operation Enduring Freedom (OEF), in Afghanistan (2001 – 2014), by US military forces, made it possible to develop and advance knowledge, techniques, and devices in combat casualty care [31,32]. Exsanguinating hemorrhage was then prioritized as the initial treatment of combat casualties [31,32].

Although there have been TQ records since ancient times, their recommendation has changed significantly [33,34]. With the recognition of traumatic hemorrhage as the primary cause of death [31,34] and the consensus on the early control of massive bleeding, the cost-benefit rule was applied, and the indication for the use of TQ became clearer [35,36]

2.2. Most important interest guidelines applied in civilian and military PHC

Important guidelines applicable in prehospital emergency care agree, as a consensus, indicating the use of certified TQs.

The Hartford Consensus and the American College of Surgeons [4] advocate the use of certified TQs and the standardization of training [37–40], through the "Stop the Bleed" initiative [4,22,38,37]. It is one of the most important and evident international strategies to bring this reality to the civilian PHC scenario, including the lay public.

The Tactical Combat Casualty Care (TCCC or TC3) [8] – guideline for emergency care of wounded in military operations – and the Tactical Emergency Casualty Care (TECC) [9] – guideline for casualties from terrorist actions and multiple-victim incidents in the civilian environment – aim the hemorrhage as the main cause of death, and TQ as the first-choice technique to control massive bleeding and to increase survival rates [41].

The Prehospital Trauma Life Support (PHTLS), currently in its ninth edition [7] – a guideline for pre-hospital emergency care for trauma victims – changed, in 2018, its mnemonic protocol of "ABCDE" to "XABCDE", suggesting, as a first concern (where "X" is "exsanguinating"), the control of massive bleeding [1,3,42].

Recently, the American Heart Association (AHA) published, in 2020, its Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care, along with the International Consensus on First Aid. As in other editions, first aid procedures were reviewed with the American Red Cross, where, this time, commercial, tested, and certified TQ were cited, as well as improvised TQ for the control massive bleeding [43].

Although there is consensus regarding the use of prehospital TQ, the data regarding mortality and its effects are uncertain or unclear, given the high risk of bias, the heterogeneity of the studies and the absence of high quality RCTs in contrast to the high number of observational studies [44].

2.3. Recommended devices by the committee on tactical combat casualty care (CoTCCC)

The TCCC guidelines were developed by the Joint Trauma System (JTS), Committee on Tactical Combat Casualty Care (CoTCCC) [45,46]. This committee recommends, through the "CoTCCC Recommended Devices & Adjuncts", some commercial models of devices for emergency management of combat casualties [47,48].

The committee recommends not only TQ, but also other applicable devices in tactical medicine, including bleeding control, airway access, and maintenance, among others. This recommendation is conducted through analysis of the devices available on the market, followed by voting and publication. However, there is no predominance of unbiased clinical data and substantial scientific evidence index [49].

Currently, the list of devices, guidelines, and materials, are published on the Deployed Medicine platform [50]. The evaluation of C-TQ involves arterial occlusion, application time, occlusion time, and ease of application (usability) [52,53]. In addition, functional details are verified regarding pressure (involving mechanical stress to reach the initial occlusion and damage point), design specifications (involving width, length, locking mechanism, place for recording the application time and weight), complications, security (involving failures and reported problems), combat usage reports, civilian usage reports, and logistics (involving US inventory and cost per unit) [51,52].

The reality of the recommendation or registration of devices is relevant information. Many operators believe that a device can only be used in tactical medicine if recommended by the CoTCCC, which is not valid. In each country, regulatory standards must be considered.

2.4. Types of TQ

The TQs are differentiate in the literature in a few ways, so it becomes necessary to standardize terminology to understand better the topics that relate to those devices.

First, considering the mechanism, such as: (A) pneumatic tourniquets (pn-TQ), which works by inflating a cuff; and (B) non-pneumatic tourniquets (np-TQ), which generate pressure by another way, mainly through a rod, to twist the strap [55] or by elastic composition. The pn-TQ is very common in intrahospital [54] and surgical scenarios

[57–59].

Second, based on the intended application site, prehospital TQ are currently available for application: (A) to limbs (much more common); and (B) in junctional areas (regions that connect the trunk to the extremities, in which case, usually applied groin, but can also be applied to the armpit) [60–62].

More commonly and importantly, TQs are presented and discussed in the literature as: (A) Commercial Tourniquets (C-TQ), those designed, produced, tested, and certified for commercialization, accompanied by a registered trademark; (B) Improvised Tourniquets (I-TQ), those produced with materials available at the scene of the incident [14,16,63] and very controversial, given their variability and impossibility of scientific consensus on a specific model.

About the main guidelines cited, only the AHA consensus presents recommendations for the use of I-TQ, based on the risk/benefit ratio for the control of massive hemorrhages in the pre-hospital environment [10].

In addition, C-TQ often ends up suffering from imitations and counterfeits. There are devices often found that can be called "counterfeit tourniquets" or even "fake tourniquets" (F-TQ), usually with low strength of materials, sold irregularly for the general public, who are unaware of the risks of its applications [59].

The C-TQ usually present themselves mainly as: (A) TQ with twisting rod (in the literature called "windlass tourniquets," classically called "stick and strap tourniquets") are the most common type in both tactical and civilian scenarios and exert pressure through the torque generated by the rotation of the rod; (B) Elastic TQ, which are less common and consist of elastic bands applied with compressive bandaging techniques, proximal to the bleeding site [11]; (C) Pneumatic TQ, more common in intra-hospital and surgical environments, although there are versions for use in tactical and civilian PHC [64]. There are other less common types of design, present in a few models, such as a ratchet system, for example.

The colors of C-TQs for prehospital applications are also a factor of interest when talking about those devices. The employment of orange, black/gray and blue colors is already an international standard that has been formed and has become very widespread, used by several C-TQ models, which facilitates the visual identification of function.

The C-TQs employed in T-PHC, in military and law enforcement operations, including special operations, receive a low-visibility color pattern, usually black or gray [65]. The objective is to reduce the contrast with the environment and equipment, reducing visibility in conflagrated environments. Some manufacturers also use other colors like olive green and tan.

The C-TQs to be used in C-PHC, on the other hand, receive high-visibility colors, usually orange, to facilitate the visualization of the device by professionals in the prehospital and intrahospital systems [66]. Unlike the first case, in C-PHC the objective is precisely to highlight the TQ from the rest of the scenario, clothes and equipment, drawing attention to its existence, including the staff on admission to the definitive in-hospital care.

In parallel, blue is used for equipment intended for training [67], which are precisely the same as the others in structure, except by the color, but which will be exposed to repeated use in training activities. This separation of specific equipment for training aims to allow repeated application of mechanical stress to the device without the risk of failure in a real application. So, C-TQ intended for real use is not exposed to mechanical loads in training.

2.5. TQ application and techniques

The TQ is a device that, either by rotating a rod, by elastic composition or by other mechanisms, causes a circumferential compression on the limb, proximal (anatomical term for closest to the origin of the limb - groin or armpit - in relation to the injury) to the bleeding site, with a pressure higher than the blood pressure, interrupting the blood flow distally from the application site [2].

The tension exerted by a TQ is a variable of interest in the study of TQ effectiveness [68]. In the case of windlass tourniquets, the main strap is passed and locked circumferentially to the limb, and the rod is attached to this strap (or to another one, internally) [49,69,70]. By exerting force on the ends of the rod, twisting the strap, it results in the reduction of the effective length (the length of material that travels through the limb area). This action produces tensile stress on the strap so that the twisting of the TQ's internal braces around their central axis (perpendicular to their application) results in a decrease in the cross-section (which is the area proportional to the diameter of the member) and the material creates circumferential compression against the limb.

In windlass tourniquets the strap traction tension and the compression against the limb increase directly proportional to the number of turns in the rod due to the torque generated by applying forces in opposite directions at each end of the rod [71].

The increase in compression by the TQ aims to exceed the blood pressure values, interrupting the arterial flow from the point of application [2,72]. That is why TQ is applied proximally to the injury and bleeding point [5,7,46]. Thus, the device secondarily stops severe bleeding due to the cessation of blood flow promoted by compression [73,74].

The TQ application is performed at a location proximally to the injury, ceasing blood flow from that point, as illustrated in **Fig. 1**.

The greater the tension and compression produced by the TQ, the higher the tension gradients and the increase of device-related injuries risk [75]. For lower risks of injury, the TQ must present arterial occlusion capacity with lower tension values [11]. The ability to achieve optimal arterial occlusion pressures is a necessity for such a device. Producing partial occlusions may not control bleeding [17,98] and lead to complications as compartment syndrome [92].

Classical studies have allowed C-TQ to evolve to safer standards as arterial occlusion with lower pressures may be related to a lower probability of nerve damage. However, an adequate swathe width must be employed to effectively distribute pressure across the TQ range [76]. The C-TQ varies in bandwidth according to the type of device. Although virtually all promote arterial occlusion [70], there is a lack of studies with data on pressure distribution and its effects on the body.

The evaluation of the compression generated by C-TQ is controversial. For example, tensions in manikins and simulators depend on how the response compares to the reaction in human limbs.

There is a lack of scientific data on the application of TQ compression and the use of manikins and humans [16], as well as appropriate measurement methods and techniques [11,93,97,73]. Some authors use Doppler and pulse oximetry to assess vascular occlusion [18,77,111,] and adaptations of sphygmomanometer cuffs to indirectly assess compression [11,18,73]. There is a need to develop more realistic manikins and simulations [78].

Furthermore, the evaluation of the mechanical stress distribution by the contact area of the C-TQ application, which makes it possible to understand better the mechanism of injuries secondary to the application [17], is also represented in a few studies, principally comparing models.

2.5.1. Initial and final tightening

In this work, the term "initial tightening" is used to represent the tightening promoted by the first part of the application, in which the device is positioned in the place of interest and its fixation is promoted. In some models, this is done by the traction of the strap, velcro, friction, specific locking systems, or by the association of more than one.

The term "final tightening" was chosen to refer to the tightening that occurs in the TQ with the objective of overcoming blood pressure and promoting total vascular occlusion, ceasing blood flow distally to the device application site. The mechanical advantage of a TQ (like the twist rod) relates to the final tightening of the device.

There are data to suggest that a TQ should produce, from initial tightening, a compression of at least 150 mmHg and with visible

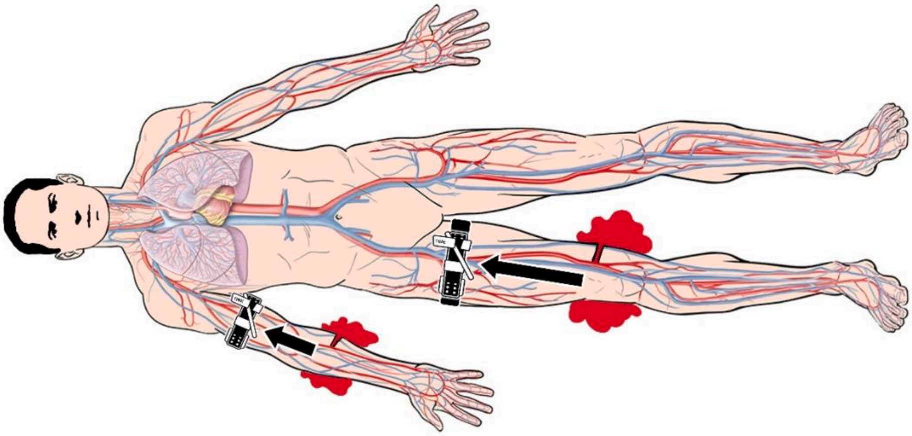

Fig. 1. TQs applied proximally to injuries with massive hemorrhages. The black arrows emphasize that the devices are positioned closer to the origin of the limbs in relation to the injury.

deformation of the skin [19] followed by the final tightening. For example, in the C-A-T (Combat Application Tourniquet) model, a 180° rotation of the rod may be sufficient to achieve arterial occlusion, generating pressures between 250 and 428 mmHg in normotensive adults' thighs [16].

2.5.2. *TQ application techniques*

About the application of C-TQ, there are two main distinct forms: one involves the use of only one hand when self-application is performed on the upper limb, for example; and the other involves the use of both hands, as when self-application is applied to the lower limb or applied to another person [7,9,23,37,44,73], as illustrated in **Fig. 2**.

The self-application of TQ in the upper limb is a technique used to control massive bleeding itself, in the upper limbs, and represents the most significant difficulty in the use of a TQ. It requires skills with one hand, contralateral to the affected limb, and familiarity with the type and model of device. This technique is widely taught in T-PHC, due to a large number of upper limb injuries in military/police officers injured in combat [90].

Each device model has its characteristics and requires specific usage techniques [32,33]. Some operators adapt established models that present difficulties, such as using the mouth and teeth, attaching some part of the device, or attaching a cord tied to the device and biting the cord. Training is what makes the big difference when using a familiar device whose skills have already been developed [21]. The efficacy of TQ application increases with training [80].

The application of TQ using two hands is a technique mostly used by professional attendants caring for other people. A TQ-type device should be evaluated for its ease of use in both one-handed and two-handed use situations.

About the place of application, there are also two techniques in the guidelines: the deliberate technique and the emergency technique. The deliberate technique, known as "deliberate TQ" consists of applying TQ approximately 2 – 3 inches proximal to the lesion and bleeding site [79]. The emergency technique, known as "emergency TQ" uses the principle of "high and tight" application, when the TQ is placed as proximal as possible on the injured limb [5,7,46].

TQ must be applied transversely to the limb and cannot be used over joints, such as elbows and knees. In tactical medicine there are pockets, velcro and patches (rubberized or embroidered images that are placed in the arms, identifying courses, specializations, etc.) that get in the way of TQ application and require additional care and training.

The deliberate application still involves application issues in segments of double bones, such as forearm and leg, which could influence the occlusion capacity. This is a current scientific question, lacking concrete and impartial data, but some studies suggest the same effectiveness [81,82].

Such a gap and lack of consensus between the guidelines offers an important demand for research on C-TQ functionality testing.

The **Fig. 3** illustrates the deliberate and the emergency TQ techniques.

The C-TQ usually has a place to demarcate the application time. It is a post-application care that aims to record interest information to the definitive care, estimating the produced time of ischemia. Currently, the guidelines refer to a safety consensus within 150 min after application [5,22].

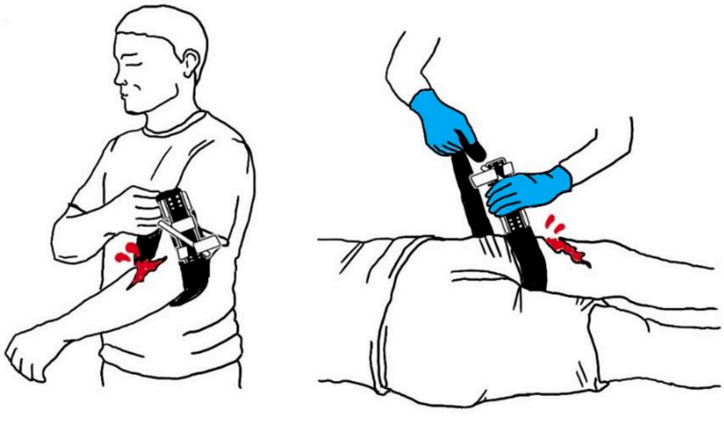

Fig. 2. One- and two-handed application techniques examples.

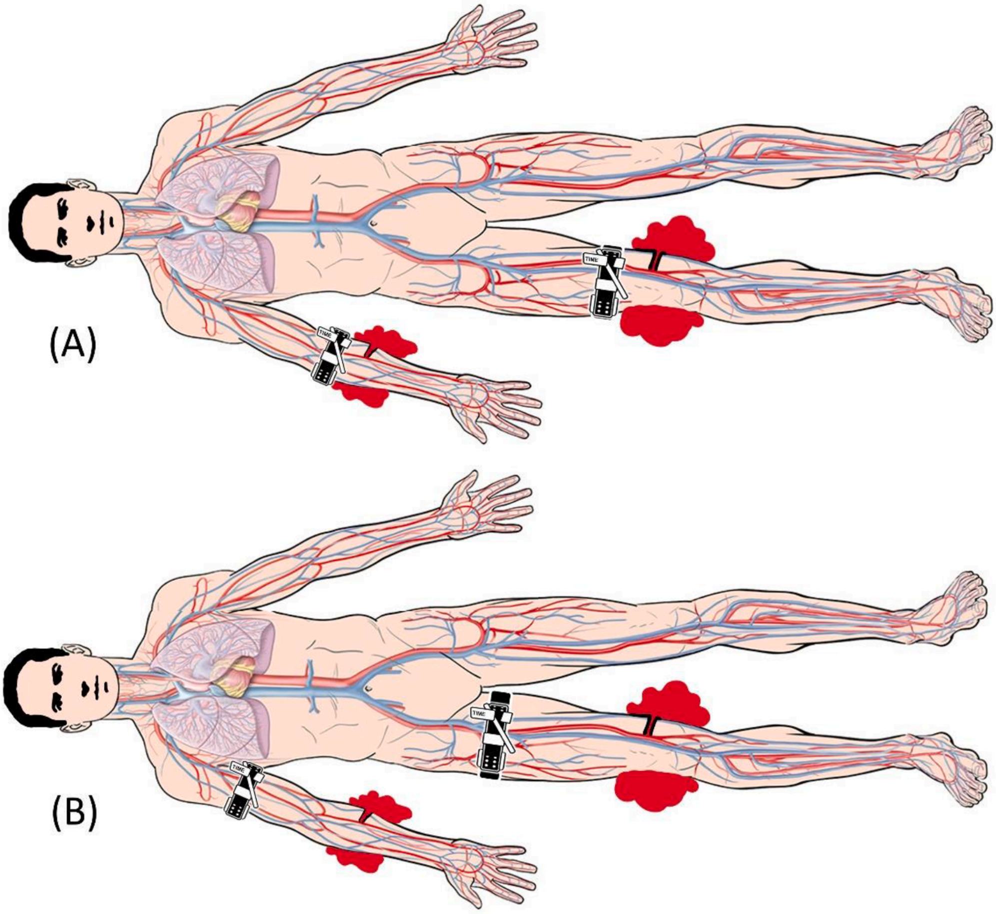

Fig. 3. . TQ application: (A) the deliberate TQ and (B) the emergency TQ.

Another issue to consider is that in the early days of consensus on the use of TQ, there was a recommendation to relieve pressure over time, which is no longer part of the standard procedures [5]. The TQ aims a compression that generates a total (arterial) occlusion of blood flow in the treated limb. When the TQ is loosened or even applied with low compression, a partial (venous) occlusion occurs, in which blood continues to enter the limb but is prevented from leaving. This can cause compartment syndrome, a cascade of events that increase interstitial pressure over capillary perfusion pressure within a closed fascial compartment, which may compromise vessels, muscles and nerve endings, causing tissue damage [75].

2.6. TQ effectiveness

The effectiveness of C-TQ in the civilian environment is demonstrated, unfortunate, with a low overall level of evidence [83], with highly heterogeneous studies [84], usually with a high risk of bias [85] and concerning only about young men [83,86]. There is no wide comparison between different commercial available models with strong scientific standards, where there is an important demand for studies.

It is still a topic for discussion, with needs for demystification, implementation, and training [38,87]. There are still some myths about the use of TQ in the pre-hospital civilian environment [1], related to possible contraindications of its use, what needs to be treated through awareness, dissemination, training and skills development [21,37].

Amputations as a result of TQ use have become one of the biggest myths. However, there is evidence of old data misinterpretation. The amputation is usually related to a primary severe injury, which not only indicates the use of the device (due to the presence of massive hemorrhage), but it is also the direct cause of traumatic or surgical amputation [5,14,27,47].

However, the decades of controversy must be considered [88], as well as the large volume of published studies that do not contain concrete and prospective clinical data [89] when analyzing the risk/effectiveness relationship of the use of TQ [90,83]. Considering that the application of TQ is related to a risk/effectiveness ratio, where the risk of death is imminent, the time of application of the TQ makes the difference [5].

2.7. Aspects that influence effectiveness

Several aspects must be considered when evaluating the effectiveness of a TQ, such as the design [1,50,51], ease of use and usability (intuitive use) [39,52], time spent on application [37,49,53], the pressure capable of promoting arterial occlusion [95,71,19] and the loss of pressure over time and due to the victim’s movement during transportation [96,18,17].

Training is a determining factor for effectiveness, especially in the lay public [110]. Failure to control severe hemorrhages may occur due to incorrect or incomplete use of the devices [97] and training requires updates and new simulations after a few months [98]. In these cases, there are frequent errors related to the positioning of the TQ, the amount of tightening and slack, the confusion regarding the locking system, and the application time [99]. All these aspects are directly related to the design of the C-TQ model, which suggests the need for simpler devices [14,29,100].

The windlass tourniquet is often more effective. Some studies suggest that TQ without a rod fails in most tests to control bleeding [101]. For this reason, there is a predominance of torsion rod C-TQ among devices for PHC, which makes it the most common design, both in the civilian and military scenarios [2,30,38,49].

But, on the other hand, torsion rod models involve production with a greater number of materials and processes [17,103], occupy a greater volume and tend to be unintuitive, and presents failures of use by people who have not been properly trained [103].

A minimalist device can even provide more conditions for use by the lay and less trained public and increase the application's success [53], allowing greater agility in approaching a hemorrhage that threatens the life of a victim [11,104,106].

2.8. Application time

The time variable can be studied regarding the device application time (from its draw to the end of tightening), as well as the occlusion time (spent in the final tightening). In the civilian environment, tourniquets are often applied outside the best window of opportunity to control exsanguinating hemorrhages. There is some evidence that even lay rescuers are capable of application of C-TQ and, with minimal training, significantly increase the success of application [53]. That is an important reason to develop more intuitive devices and simplified mechanisms.

The application time required by C-TQ models is also a critical variable, especially in the T-PHC and tactical scenarios [11,104,106]. The simpler and more intuitive C-TQ facilitate training, operation, and enable better results in application by people with less knowledge and skills, including laypersons [22,60,86].

Simulation studies and tests of TQ efficacy in military volunteers and mannequins have been performed, but there are no large comparison studies between C-TQ models or between C-TQ and I-TQ. Simulated tests suggests mean arterial occlusion time of approximately 30 s [53] and better occlusion results are quite possibly related to a more intuitive and practical design [107].

There are many commercially available TQ but no concrete evidence of simulation and comparison of application and occlusion times [56]. This is probably due to the difficulty in stating about the time of application, given the variability of scenario, equipment, type of clothing or uniform, and type of pocket, backpack or first-aid kits, which include wall-mounted ones.

2.9. Design and materials

The C-TQ emerged from military experience and its application, whether civilian or military, involves harsh environments, which can include moisture, dust, dirt, mud, rain, solar radiation, heat and cold, fresh and salt water, friction and other mechanical forces, among other factors.

The complexity of the project and the number of materials used may influence the device's behavior in terms of the application scenario [108]. For this reason, the project needs to consider design and materials that can withstand use in special operations [32,104,105].

These crucial differences in design and mechanisms [91] create space and necessity for research and improvement, both in training and in biomedical engineering, for development and performance in the use of C-TQ on bleeding control [109].

Anthropometric issues require care, regarding dimensions of the devices [73]. The strap width must be at least 20 mm, for an ideal contact area [113]. Many windlass devices have 38 mm strap width and elastic have 104 mm [71]. The width, at lower values, results in greater pressure and this can cause different responses in terms of secondary vascular-nervous injury [114]. That is a topic that requires further studies.

The strap length is also an essential anthropometric variable [115], as it can be challenging to apply in limbs with above-average diameters [102]. The C-A-T TQ is 925 mm long [94]. Smaller limb diameters are also an issue to consider, as in the case of children. There are studies with children suggesting efficiency results similar to those of adults [116]. The area right behind the TQ compression plate must be designed preventing from having a long rigid area, harming the contour of limbs with smaller diameters.

2.10. Scientific data consistency

Most of the references on TQ applications are studies with observational characteristics, with low levels of evidence [83,89]. There are practically no effectiveness rate comparisons between a significant number of C-TQ models [109] and, therefore, there is an urgent demand for research that relates and validates effects of different models.

2.11. Future directions

The use of C-TQ have been studied and they promote clinically significant pressure changes [113], being able to achieve vascular occlusion [20,94,17], as already discussed.

But in addition to the impacts of its use in terms of mortality (which was the main objective of research with TQ for many years), results should also be evaluated after the application of C-TQ [11,17,19], including other characteristics, as use in children [66,112] and in segments of double bones, such as forearms and legs [16], as well as in terms of pressure levels by time (ability to maintain the compression) [18]. These themes still have gaps in the literature and require further studies and simulations.

About new devices, a lot has been done, such as improvements in buckles and integration of torque systems [114], a pen that can serve as a resistant twist-rod for I-TQ [115], time marker embedded into the rod [116], digital cuff pressure indicator for pn-TQ [117], new models of final tightening systems, often even impairing the portability, new mechanisms of rodless traction, as well as insertion of electronic systems such as application time recording [118].

It would be useful an automated TQ, whether by a mechanical, hydraulic or pneumatic system, in terms of a circumferential tightening mechanism, simultaneously acting with a pressure sensor in order to monitor the applied mechanical stress and to guarantee the interruption of the flow and, at the same time, maintaining levels of compression that could guarantee the integrity of biological tissues.

There is no doubt that the insertion of mobile, electronic and microprocessed technology in first aid devices is part of the future, although elaboration is necessary considering the aggressive environment of special operations.

With the necessity of a TQ that works operating with only one hand, Budak et al. developed a device with a motor so when the buttons "arm" or "leg" are pressed, the system automatically starts the tourniquet process and continues until the bleeding is stopped, with feedback by sensors about blood flow and applied force. It also has Bluetooth signals transmitting the location and application time of the TQ [119].

The monitoring of vital signs, including blood pressure and applied pressure, as well as signs of communication to user or victim are also possible with on-board technologies [120]. Concerning about power loss, Dhanalakshmi et al. used wireless communicating network and solar panel to provide power backup to their automatic device [121].

3. Conclusion

Massive bleeding is an important cause of preventable death from trauma, a time-dependent emergency condition, that can be controlled by some techniques and devices, including tourniquets.

These devices, which emerged from military experiences, have already been studied for their civilian and military effectiveness, so its application is a consensus and a first-choice technique to stop exsanguination.

However, there is an important demand for unbiased studies and high quality RCTs, comparison of commercial available models, evaluation of pressure loss over time, pressure distribution by area, use in children and elderly, applications in double bone anatomical segments, and the development, in medical education, of more realistic manikins and simulations.

As regards to biomedical engineering, the development of simpler, intuitive and more efficient devices can facilitate the use by untrained people and help to reduce preventable trauma deaths by hemorrhagic shock.

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Declaration of Competing Interest

All authors must disclose any financial and personal relationships with other people or organisations that could inappropriately influence (bias) their work. Examples of potential conflicts of interest include employment, consultancies, stock ownership, honoraria, paid expert testimony, patent applications/registrations, and grants or other funding.

The authors declare that they have no conflict of interest.

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