Improvised tourniquets: Obsolete or obligatory?

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Life-threatening hemorrhage from the extremities is not confined to the military setting and is seen in civilian catastrophes such as terrorist attacks, postconflict improvised explosive device, land mine detonations, and natural disasters. In such settings, the demand for resources outstrips supply; the use of tourniquets may be necessitated despite not being readily available. Application of an improvised tourniquet in such a situation may be the only method of controlling bleeding. Despite this, evaluation of commercially available tourniquets have tended to favor analysis and debate, when their availability in such an event may be extremely limited.

Commercially available tourniquets have had extensive investigation to arrive at an opinion of what makes an ideal tourniquet.[1–4] There is currently a lack of research on the role of improvised tourniquets in situations requiring the control of catastrophic bleeding. Available literature on improvised tourniquets is often a side topic with the focus of the article being on the efficacy of commercial tourniquets. We argue that improvised tourniquets have a role in the control of hemorrhage in the prehospital environment. This is particularly in the context of civilian mass-casualty situations where commercial tourniquets may be a limited resource among caregivers.

Conflicting evidence exists regarding the role improvised tourniquets have to play in such situations, from their indication for use to whether they should be used at all.[5] This literature review sought to examine the current opinion on improvised tourniquets, albeit in its paucity, and present the arguments supporting and opposing its use in both military and civilian settings.

THE EVOLUTION OF THE TOURNIQUET

Tourniquets are among the earliest medical interventions known to man. Their history dates back at least three millennia.[3,6] Traditionally, they are associated with the battlefield, with military surgeons being largely responsible for the evolution of this device to stem catastrophic hemorrhage.[7] A strip of cloth wrapped tightly around a bleeding limb, with a stick attached to wind up and increase pressure (a technique referred to as "windlassing" or a "windlass tourniquet," Fig. 1) is postulated to have first been used in the early 17th century.[1] This particular design of the device is also referred to as a "Spanish" or "Russian" tourniquet in the literature.[1,7,8]

Over the centuries, wars were fought, and the design of the tourniquet inevitably evolved. It soon became *de riguer* to use a similar nonelasticated strap but with the assistance of a buckle to tighten the tourniquet to halt arterial bleeding. This style of tourniquet was likely the first commercially available tourniquet, with large numbers issued to troops in the American Civil War.[7] The advent of World War II saw the issue of rubberized tubing to soldiers.[1,9,10] As the 20th century progressed, the tourniquet fell in and out of favor on a recurring basis. In 1962, Klenerman[11] described how there "is no place for the tourniquet as a first aid measure." This continued to be a widely held belief for many of the succeeding decades, with numerous guidelines from national and international bodies even in the present day advocating the use of direct pressure and compression dressings as first-line measures for the control of hemorrhage over the use of tourniquets, improvised or otherwise.[12,13]

The recent campaigns in Iraq and Afghanistan have seen the injury pattern predominated by traumatic amputations secondary to improvised explosive device blasts. As such, there has been a resurgence in the research on the use of commercial tourniquets and a renewed interest in their use. Since 2006, commercially available Combat Applied Tourniquets (CAT) (Phil Durango LLC, Fig. 2) have been made a mandatory item of personal first aid kit for all US military and coalition forces, and subsequently the number of tourniquets used in the operational theater has increased severalfold.[14] As such, there is a wealth of data examining the impact on morbidity and mortality of commercial tourniquet use,[7,8,14,15] and the consensus to date is weighted toward the opinion that commercial tourniquets play a crucial role in preventing mortality from catastrophic bleeding.

PHYSIOLOGY AND INDICATIONS

Tourniquets work by inducing a systolic pressure across a limb greater than that present in the vessels running perpendicular to the tourniquet. By applying a tourniquet proximal to a site of bleeding, it serves to prevent further blood flow into the exposed limb, thereby preventing ongoing hemorrhage. Three basic physiologic principles can be considered with the use of a tourniquet on a limb, all of which are pertinent points in the context of improvised tourniquets.

First, there is a direct correlation between the limb circumference and the force applied by the tourniquet to arrest distal blood flow.[16,17] As the size of the limb increases, greater tension is required to be exerted by the tourniquet to cease blood flow. Without the mechanical augmentation that a windlass tourniquet provides or the tension that elastic material delivers, it may be impossible to occlude the distal arterial flow on a thigh as one study has shown.[18] For an individual attempting to

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Figure 1. Improvised tourniquet applied to a patient.

improvise a tourniquet out of a belt, cravat, or wire, it is likely to be a futile exercise as insufficient force can be generated.

Second, at a given occlusion pressure, a wide tourniquet provides efficacy at occluding distal pulses greater than a narrow tourniquet.[17,19] The exception to this rule is if the tension exerted from a tourniquet is great enough, then a narrow tourniquet such as rubber tubing may prove to be more effective than a wide tourniquet.[1] Finally, the small surface area over which a narrow tourniquet sits will inevitably exert a greater force on the underlying soft tissues.[20] This predisposes to crush injury of underlying muscle, vessels, and nerves and subsequently pain. This will be discussed in greater detail later.

Indications for application of a tourniquet have been summarized succinctly by Lakstein et al.[8] and widely quoted by other authors in the literature (Table 1). What is of greater consideration and gives rise to much debate is the issue of when a tourniquet should be removed. This has important implications in the context of an improvised tourniquet because experienced personnel who can advise on when a tourniquet should be removed may be absent in such a situation when an improvised tourniquet is required. In a military

Figure 2. CAT applied to a patient.

TABLE 1. Indication for Tourniquet Application

Indication
Failure to stop bleeding by direct pressure bandaging, injury does not allow direct control of bleeding with a bandage, or objective factors
Amputation
Bleeding from multiple locations
Protruding foreign body
Need for an immediate airway management or breathing control
Under fire situation
Total darkness
Mass-casualty event*

*An event in which the number of wounded or the severity of their injuries exceeds the ability of the medical personnel to render optimal medical care.
Adapted from Mabry.[7]

context, the current paradigm for tourniquet application dictates that under enemy contact ("care under fire"), a tourniquet is placed if there is any concern regarding catastrophic bleeding. This allows rapid extraction of the casualty from the danger zone, with the knowledge that any potentially life-threatening bleeding has been dealt with. The wound can then be reassessed, and if necessary, the tourniquet can be reapplied, or if bleeding is no longer catastrophic, a direct pressure dressing or hemostatic agent can be applied.[21] This scenario is clearly unlikely in a civilian environment with the majority of situations requiring application of a tourniquet being in the absence of "enemy fire." Many of the complications reported by the use of tourniquets arise as a result of prolonged duration,[22,23] and therefore, there is an emphasis in the literature at removing the tourniquet at the earliest possible opportunity. Some individuals advocate a "trial of tourniquet conversion" whereby a tourniquet is released and the alternative methods of bleeding control described earlier is used. Recommendations of when to do this include "when other life threatening injuries have been managed" and when the patient has "stable vital signs."[5] Arguably however, the layperson removing an improvised tourniquet is unlikely to be able to identify if either of these criteria has been met. Conversely, the indications for application of a tourniquet are far simpler for a bystander to understand and adhere to. This raises the question of whether application of an improvised tourniquet should have an indication to be removed, and this point will be discussed in further depth.

IMPROVISED TOURNIQUETS: THE CURRENT EVIDENCE

A retrospective analysis by Lakstein et al.[8] in 2003 examined the use of improvised tourniquets among Israeli Defense Force soldiers over a 4-year period. Ninety-one patients of a cohort of 550 had tourniquets applied. The use of three different types of tourniquet was observed in the study. First is the issued "standard" tourniquet for Israeli combatants of an elastic, silicone band. Second is the Russian windlass tourniquet (as described earlier) improvised at the scene using a nonelastic strap wrapped around the injured limb and tightened with a wooden stick. Third, the use of belts and wire

obtained at the scene was observed. For those tourniquets whose applications were considered "indicated" (Table 1), the authors found that the improvised Russian tourniquets applied to thigh wounds were successful at stemming active bleeding in 72% of cases, compared with a success rate of 66% for commercially produced silicone tourniquets at the same site. Although this difference was not statistically significant ($p = 0.06$), the raw data imply that improvised tourniquets are by no means inferior at stemming life-threatening hemorrhage in this case.

The merits of improvised tourniquet use are also substantiated in a case review, which describes the use of an improvised tourniquet in assisting the control of hemorrhage.[24] Following a gunshot wound to the forearm, application of a commercially available tourniquet consisting of a 50-mm-wide tourniquet with a spring clip was not able to stem bleeding, and a subsequent improvised tourniquet was applied consisting of two cravats, dowling, and a plastic cable tie. This simple addition was able to achieve complete hemostasis of the injured limb. Moreover, because of the operational situation the casualty found himself in, the tourniquet was in place for 16 hours. Not only was the limb injured able to be salvaged upon reaching a medical facility, but the eventual functional deficit was also minimal.

Evidence widely advocates that the optimal tourniquet time is less than 2 hours,[22,25,26] although caution must be heeded as the majority of the literature refers to pneumatic tourniquet times in the operating theater. As such, we cannot draw a conclusion as to what is an optimal maximum duration (if indeed there is one) for an improvised tourniquet on a limb as the case study earlier described demonstrates. Many authors, certified bodies, and organizations argue that improvised tourniquets should not be advocated[5,23,27] because often, the hands applying them will have limited to no understanding of the potential dangers of long-term tourniquet application. This may result in irreversible damage through local or systemic mechanisms when in fact a tourniquet was never indicated in the first instance. However, this case review serves to show that a extended duration of tourniquet application may not necessarily go hand in hand with the negative effects associated with tourniquet use and is supported by other studies that have shown that prolonged tourniquet application can occur in the absence of long-term adverse effects.[8,9] This begs the question that if there is even a slightest indication for the use of a tourniquet in a prehospital environment, surely, it warrants application of a potentially lifesaving device at the risk of losing a limb?

COMMERCIAL VERSUS IMPROVISED: HOW DO THEY COMPARE?

Although evidence suggests that improvised tourniquets may cause increased pain compared with commercially available tourniquets, evaluation of their efficacy in controlled studies has shown that they compare as well as if not better than their mass-produced counterparts at occluding arterial blood flow. King et al.[1] compared five tourniquets, two of which could be considered as improvised, namely, surgical tubing (available from any surgical center and hardware stores) and a classic windlass tourniquet using a length of triangular bandage and dowling. The remaining three were commercially produced tourniquets. The authors showed that the two improvised tourniquets ranked highest in terms of ease of learning how to use the device. This has important implications in the field of prehospital emergency care, particularly in the civilian setting. If an inexperienced layperson is able to glean from somebody else how to apply it correctly, then the tourniquet is more likely to be used successfully to stem hemorrhagic flow from a bleeding vessel than a tourniquet that is difficult to master.

One could argue that the subjects involved in this study received a briefing on how to use the tourniquets that were being trialed. In an emergency setting where improvised tourniquets are likely to be used, there will not be scope for "teaching" on how to apply a tourniquet. Nonetheless, by showing that the two most basic tourniquets were the easiest to master in terms of application provides strong evidence that their role is not obsolete and could easily be incorporated into civilian first aid education on management of life-threatening hemorrhage in prehospital settings.

Moreover, the surgical tubing tourniquet outperformed the other four tourniquets in all tests with regard to efficacy of arterial occlusion. Both manual palpation and Doppler assessment of a distal pulse were used as the two criteria to assess the success of tourniquet application. Surgical tubing was able to achieve 100% occlusion on digital palpation of the pulse, in both ideal and winter conditions (where thick clothing was on the limb tested). On Doppler pulse assessment, surgical tubing was able to achieve 90% complete arterial occlusion in both conditions. The improvised tourniquet composed of cloth and a windlass also performed well

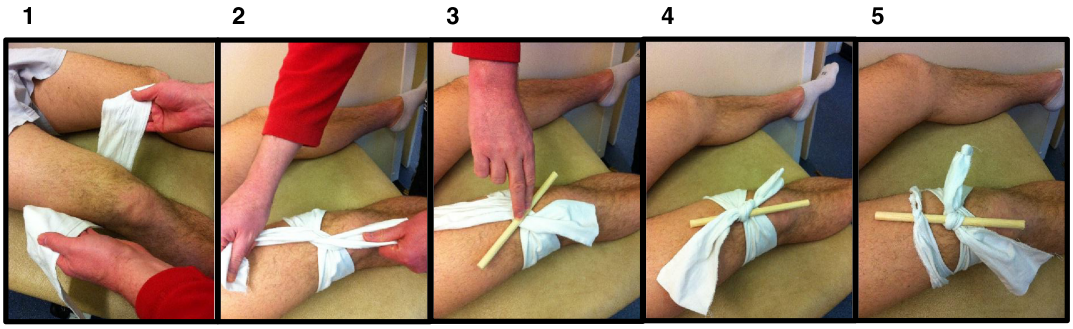

Figure 3. How to apply an improvised tourniquet.

in the study of efficacy of distal pulse occlusion. The pneumatic emergency medical tourniquet performed the most favorably out of the class of commercial tourniquets, delivering the least pain to the patient while being as effective at occluding pulses. However, these tourniquets are not recommended for field use, both in the military and in the civilian setting because of its poor durability.[3] This provides further evidence that improvised tourniquets have a role in the management of catastrophic bleeding when little else exists to control the exsanguination.

Not all authors are inclined to agree with King et al. A similar study also comparing five tourniquets, two of which could be considered as improvised, came to starkly different conclusions.[27] They found that surgical tubing and canvas strapping were both less successful than the other three commercial tourniquets being tested at occluding both upper and lower limb pulses. Moreover, they were both rated least favorably for pain scores and ease of application. Interestingly, the windlass tourniquet, which was being tested as a "commercial" tourniquet, was considered the most superior of all five devices assessed. In other studies,[1,2] the windlass tourniquet has been tested as an improvised tourniquet often because it has been tested in its most crude form of nonelastic strapping and a piece of dowling (Fig. 3). The windlass tourniquet is widely regarded as the forerunner for all tourniquets, and because of the simple design, it can be argued that there is little difference between its effect, be it in the context of a commercial or improvised tourniquet. It is therefore proposed by the authors that windlass tourniquets are considered as neither commercial nor improvised devices.

There is apprehension surrounding the use of improvised tourniquets in the prehospital emergency setting,[5] even when the evidence suggests that correctly fitted devices perform as well as, if not superiorly to, commercially available tourniquets. The complications of tourniquets, regardless of whether the device is commercially available or improvised, are widely documented[6,22,28,29] and can be considered in two categories. First, there are those complications that result from the local effect of tourniquets. Nerve damage distal to the site of the tourniquet can be attributable to two mechanisms. Direct pressure of the tight band on neural structures may lead to a neuropraxia or, worse still, a complete and long-lasting nerve palsy.[14] An alternative mechanism by which nerve palsies may occur includes being a result of neural ischemia from occluded blood supply, secondary to tourniquet placement. Other local effects include compartment syndrome, soft tissue ischemia and necrosis, as well as wound hematoma and infection.

Second, prolonged use of tourniquets can result in a systemic response. Reperfusion syndrome has been of particular interest in recent years and occurs as a result of the accumulation of lactate in the ischemic tissues distal to the site of the tourniquet. Subsequent release of the constrictive band leads to the release of these harmful substances into the central circulation, potentially causing systemic acidosis[30] and, in severe cases, a response to systemic inflammatory response syndrome.[29] Other systemic complications seen with the prolonged use of tourniquets include rhadomyolysis and fibrinolysis,[31,32] with increasing incidence correlating with tourniquet time.[33] This has implications with regard to a mass-casualty incident where the nature of the situation may result in tourniquets not being reviewed or released for several hours. However, the practice of loosening off a tourniquet in the field to assess rebleeding increases mortality,[9] contrary to recommendations by other authors.[1,25] Moreover, the emphasis in a mass-casualty situation is placed on saving lives rather than salvaging limbs. We would concur therefore with Kragh et al.,[15,24,34] who argue that the morbidity risk of such a simple device is justified in light of its major lifesaving benefits.

A QUESTION OF EQUALITY

Why the controversy surrounding improvised tourniquets if commercial tourniquets have been shown to cause a myriad of complications themselves? Lee et al.[5] advocate the use of commercial tourniquets in the prehospital setting but argue that improvised varieties should be avoided as "they may lead to an increased risk of complications." Similarly, Doyle and Taillac[6] concluded from their literature review on the prehospital use of tourniquets that improvised tourniquets are neither safe nor effective.

This widely held dogma is likely a result of the variability in size, format, and design that an improvised tourniquet may possess. The CAT, which by the very nature of it being a commercially produced item, displays uniformity and thus reliability in producing hemostasis with each episode of use. The same cannot be said for improvised tourniquets. As discussed earlier, the windlass tourniquet can provide excellent hemostasis comparable with that of commercial designs. However, in the absence of previous teaching and exposure to how to apply one, the layperson is far more likely to use items such as belts, ties, and pieces of wire. These are unlikely to produce as successful an effect as the more expertly improvised tourniquets such as the windlass and rubber tubing. Indeed, they carry the potential of causing significant harm to the patient when used.

This reinforces the importance of adequate training to both military and civilian populations on not only the importance of improvised tourniquets in mass-casualty situations but also the importance of choosing the right design. Reviewing the literature has shown that not all improvised tourniquets are created equal. However, if applied correctly (Fig. 3), they can prove to be as effective as their commercial counterparts.

Another shortfall of the improvised tourniquet is their inability to be applied single-handedly. The recommendation in 2004 by the US Army Institute of Surgical Research to issue CATs to all US military personnel[4,10] was in part due to its ability to be applied with one hand. An improvised windlass tourniquet requires the use of two hands to be applied effectively. However, the requirement for an improvised tourniquet will often occur in a mass-casualty situation, when the injured individual is likely to have a help on hand to assist with tourniquet application. Moreover, lower limbs predominate in injuries requiring the use of a tourniquet.[8,15,35,36] In these instances, one-handed application is not necessary.

THE RELEVANCE OF PAIN

The main complication that recurrently arises in the literature exclusively with regard to improvised tourniquet use is

regarding their pressure distribution. Improvised tourniquets have a propensity to have a small contact surface with the limb, leading to excessive pressure focused on a small area and subsequently causing severe pain.[1,4,20,27] This is predominantly a result of the nature of materials commonly used for improvised tourniquets, such as cloth, which has a tendency to "bunch up" and lead to a very narrow contact area with the soft tissue. This is supported by experimental studies comparing various tourniquets on human volunteers,[1,2,27] where it is a common finding that effective occlusion of distal pulses below the tourniquet comes with the cost of pain. Moreover, there is the risk that improvised tourniquets by the nature of their design may apply pressure unevenly and have sharp edges, increasing the risk of underlying tissue injury.[6]

However, Swan et al.[2] make the valid point that "pain is irrelevant" in the context of tourniquet application. To date, this study provides the most convincing evidence that certain improvised tourniquets are as effective as commercial tourniquets at occluding distal pulses. When testing three tourniquets (two of which could be considered as improvised), they found that all three devices provided sustained elimination of distal pulses (>60 seconds) on the arm, thigh, forearm, and leg. Although subjective report of pain by the human volunteers was higher when the two improvised tourniquets were applied rather than the third, commercial device (a sphygmomanometer). The authors argue two valid points regarding the insignificance of pain as a consideration when applying a tourniquet. First, a patient who is experiencing life-threatening exsanguination with concomitant hypovolemic shock is most likely going to have blunted pain perception regardless. The addition of a tight, uncomfortable makeshift tourniquet may indeed go unnoticed in such circumstances. Second and perhaps of greater magnitude is the argument that uses the age-old adage "better to lose the limb and save the life." Current military doctrine enforces the belief that satisfactory application of the tourniquet is a painful procedure. Although other articles use pain to determine the success or failure of a tourniquet, both Swan et al. and ourselves propose that pain is not given as much of a bearing on outcome when considering the efficacy of a tourniquet. Instead, efforts should be made to focus evaluation on whether a tourniquet is able to fulfill its primary purpose. That is, obliterate exsanguination and prevent mortality.

RECOMMENDATIONS

We propose that education on how to expertly construct and apply an improvised tourniquet becomes an integral part of Basic Life Support and Prehospital Emergency Care algorithms, for military and civilians alike. Specifically, we advocate the use of an improvised windlass tourniquet, such as the example shown in Figure 3. In the absence of a commercially produced tourniquet, this simple first aid measure can satisfactorily arrest life-threatening hemorrhage, while minimizing morbidity that other cruder designs may cause.

As global unrest and volatility among nations increase, never has it been more critical to equip individuals with the basic skills required to save lives. Large corporations and organizations can incorporate such teaching into mandatory first aid courses provided for their staff, with the use of visual prompts such as posters assisting in consolidating the message. Importantly however, this should coexist with careful guidelines on the indications to apply and remove the devices to minimize local and systemic complications that can arise with the use of any tourniquet.

CONCLUSION

This review of the medical literature has intended to expose the current evidence for the efficacy of improvised tourniquets and the arguments that are for and against their use. The literature presents differing opinions as to their value, and undoubtedly, a considered balance of risk and benefit exists. We conclude that improvised tourniquets, when applied correctly, do have a vital role in the control of life-threatening bleeding. Objective evidence has shown certain improvised designs, namely, the windlass type, to be as effective as, if not better than, commercially available tourniquets at controlling arterial blood flow in a limb. Moreover, the risk of complications from their use does not differ hugely from that seen in formal devices. However, it would be naive to suggest that improvised tourniquets can be regarded as equal in their efficacy to commercial tourniquets such as the CAT. By the very nature of its being, the improvised tourniquet can vary hugely in its fabrication and hence its effectiveness. Tourniquets do harm, and it is those that are applied incorrectly that cause the most harm.

It is also accepted that pain is often a more pertinent feature of improvised devices, but we argue that in the context of life-threatening exsanguination, pain is of little relevance. Similarly, the decision as to when to remove a tourniquet may be ill timed in the hands of an experienced responder. However, we advocate that a lost limb is favorable to a lost life.

DISCLOSURE

The authors declare no conflicts of interest.

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