DEVELOPMENT AND TECHNICAL EVALUATION OF MILITARY TOURNIQUETS AND EMERGENCY TOURNIQUETS FOR PRE-HOSPITAL SETTINGS

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ABSTRACT

This paper reports the development and initial technical evaluation of novel pneumatic tourniquets for pre-hospital civilian applications and for ground-based tactical military settings. In such applications and settings, tourniquets may serve as life-saving and limb-sparing devices for rapid and effective hemorrhage control.

Development to date has focused on the key requirements that such devices must be fast and simple to apply by non-medical, non-expert users with a minimum of training, and that they must be capable of completely stopping arterial blood flow at applied pressures that will minimize the probability of injuries to nerves, muscle and other soft tissues.

Aspects of the development and initial evaluation that are relevant to hospital-based tourniquet systems will be presented and discussed.

INTRODUCTION

Loss of blood is a major cause of death in military combat and emergency situations in which the injured person is alone or medical assistance is not immediately available. The use of a tourniquet to stop blood loss from an injured arm or leg is a well-known technique for preventing death in these situations. Once the primary objective of preventing death due to blood loss is achieved, it is desirable to prevent further injury to the limb due to excessive application of tourniquet pressure and time.

To minimize mechanical injury to the tissues under the tourniquet, the pressure applied by the tourniquet should be only slightly higher than that required to stop blood flow and the pressure should be applied evenly and uniformly around the limb beneath the tourniquet, without localized regions of very high or very low pressures.

To help prevent gangrene and other complications related to the lack of arterial blood flow into the portion of the limb distal to the tourniquet, it is widely accepted that the tourniquet pressure should be released for a period of 5-10 minutes and then reapplied after each two hour period of stoppage of arterial blood flow, also called arterial blood flow occlusion.

When more sophisticated care becomes available to the injured individual (such as emergency medical personnel arriving at the scene or evacuation to a field hospital), it is advantageous to have an emergency tourniquet which can be connected to more sophisticated pneumatic tourniquet systems allowing precise control of tourniquet cuff pressure and application time.

Published US Army research (Calkins) [1] defines the need for a light, compact, yet rugged tourniquet for far-forward battlefield use. The victim must be able to apply the tourniquet to his or her own arm or leg and occlude blood flow using only their non-dominant hand.

NON-PNEUMATIC TOURNIQUETS

In the past, a variety of pneumatic and non-pneumatic tourniquets were adapted as self-applicable military and emergency tourniquets. Many of these devices were tested in the Calkins study, and were found to have disadvantages or to be ineffective in occluding arterial blood flow, particularly when self-applied.

Non-pneumatic strap and ratchet type tourniquets generate inward radial compression by shortening the strap wrapped around the limb. This results in friction between the strap and the limb which increases as the tourniquet is tightened causing the underlying soft tissue to move with the strap as it is drawn tight. This friction can draw soft tissues underlying the strap into the ratchet or buckle device, pinching the soft tissue and creating a region of very high localized pressure which is hazardous to the patient.

Friction between the strap and the limb may also create regions of low pressure by preventing tension from being distributed evenly in the strap around the entire limb circumference, and as a result arterial blood may still flow through these low pressure regions although overall strap tension is very high.

McEwen and Casey [2] have shown that non-pneumatic tourniquets, when compared to pneumatic tourniquets, produce substantially higher applied pressures and higher pressure gradients. Such higher pressure levels and higher pressure gradients are associated in the clinical literature with higher probabilities of patient injuries.

In general, uneven or non-uniform application of pressure around the limb resulting from the use of non-pneumatic strap type tourniquets leads to the need for unnecessarily high overall tourniquet pressures to reliably and predictably stop arterial blood flow. These unnecessarily high pressure increases the probability of a range of unnecessary injuries to nerves, muscles and limb.

The distribution of pressure under non-pneumatic strap type tourniquets is difficult to regulate and can vary significantly both around the limb circumference and between the proximal and distal edges of the strap. In particular, pressures actually applied to the limb can be dangerously high in certain areas such as the pinched areas described above thereby increasing the risk of soft tissue and nerve damage.

OVERLAPPING PNEUMATIC TOURNIQUETS

Pneumatic tourniquet cuffs have been proven to be safe and effective devices for stopping arterial blood flow and are the standard of care in modern surgery. When a pneumatic tourniquet cuff is in use, an inflatable bladder completely encircles the limb and is inflated, causing the bladder to expand inward applying radial compression to the limb around the entire limb circumference. A pneumatic cuff was the only device tested that successfully stopped arterial blood flow in all trials in the Calkins study [1].

In contrast to the non-pneumatic devices described above, pneumatic tourniquets apply pressures to the limb that very closely relate to the inflation pressure of the bladder, and this pressure is applied evenly around the entire limb circumference minimizing areas of low pressure. Therefore, application pressures can be easily controlled by monitoring the cuff bladder pressure, and thus minimizing pinching and shearing of soft tissues.

To help maintain an even pressure around the limb and to reduce the likelihood of movement in the overlapped regions of the cuff, the overlap in surgical tourniquet cuffs is generally limited to approximately 1 to 5 inches. Therefore a selection of different cuff sizes is required to accommodate arm and leg circumferences of different individuals. In a hospital setting, surgical type tourniquets are typically selected and applied by a skilled technician. This surgical type tourniquet cuff is undesirable in a battlefield or emergency situation because; the end user may have limited tourniquet experience, a selection of different cuff sizes may not be available, surgical cuffs can not be applied quickly and are very difficult to secure on the limb using one hand, particularly on one's own limb. Surgical tourniquets also use hook and loop type fasteners which can become unreliable when wet or fouled with dirt and debris.

A further disadvantage is that surgical tourniquet cuffs require a source of pressurized gas to inflate the bladder. The weight, bulk, and power requirements of surgical tourniquet systems make them impractical for emergency self-use. A manual inflation system such as a hand pump or bulb is a practical alternative. However, the large inflated volume of a surgical tourniquet cuff is undesirable in a pre-hospital situation where the user must inflate the cuff quickly using a manual hand bulb.

DEVELOPMENT OF A NOVEL PNEUMATIC TOURNIQUET FOR PRE-HOSPITAL CIVILIAN APPLICATIONS AND FOR GROUND-BASED TACTICAL MILITARY SETTINGS

A non-overlapping pneumatic tourniquet cuff for use in pre-hospital settings was developed and evaluated to address many of the disadvantages of existing pneumatic and non-pneumatic tourniquets described above. This non-overlapping tourniquet cuff is called the Emergency and Military Tourniquet (EMT) [3].

SIZE, APPLICATION AND INFLATION CONTROL

Unlike overlapping pneumatic tourniquets, the EMT is designed as a one sizes fits all tourniquet cuff that can accommodate a wide range of both upper and lower limb sizes.

Rather than securing the cuff on the limb using traditional hook and loop materials, the EMT incorporates a sliding clamp to secure the cuff snugly around the limb. This clamp fastening system enables a non skilled user to rapidly apply the cuff to an injured limb using a single-hand application technique.

Fig. 1 Emergency and Military Tourniquet (EMT) with clamp fastening system and hand inflation bulb.

In addition to securing the cuff on the limb, the clamp fastener seals off the unused portion of the bladder such that only the portion of the bladder around the limb is inflated during use. Unlike surgical tourniquets, this allows the EMT to be rapidly inflated using only a hand bulb.

Fig. 2 Emergency and Military Tourniquet (EMT) clamp fastener.

However, even with manual inflation, elapsed inflation time and cuff pressure should be monitored and indicated to the user to minimize the potential for tourniquet injury. An optional pressure and time monitor has been developed and can be attached to the EMT for this purpose. These monitoring and indicating functions require minimal input from the user, who is likely under extreme stress while using the tourniquet.

WEIGHT AND PACKAGING

For tactical situations where a tourniquet cuff may be carried by the user or is part of a compact kit of supplies carried by a medic, it is particularly important that the packed size and overall weight be minimized. Unlike surgical tourniquets which contain an internal plastic stiffener to stabilize the inflated bladder and must be rolled for storage to prevent damage to the stiffener, the EMT tourniquet does not contain an internal stiffener and uses radio frequency welds to stabilize the bladder allowing the EMT to be folded into a small package without damage to the tourniquet cuff.

CONNECTION TO PNEUMATIC TOURNIQUET SYSTEMS

When more sophisticated care becomes available to the injured individual such as emergency medical personnel arriving at the scene or evacuation to a field hospital, it is advantageous to have an emergency tourniquet which can be connected to more sophisticated pneumatic tourniquet systems that provide precise control of tourniquet cuff pressure and application time. The EMT can be readily configured to allow connection to these hospital based tourniquet systems.

TECHNICAL EVALUATIONS AND DEPLOYMENT

The initial evaluation of the EMT design was carried out in the lab with 10 unskilled volunteers. The quality of application, application time, inflation time and the effectiveness of limb occlusion of the EMT were compared to those of an overlapping pneumatic tourniquet typically used in surgical operations.

The application time of the EMT was found to be less than 5 seconds on average for unskilled volunteers, and a good quality of application was consistently achieved. On the other hand, the minimum application time of an overlapping pneumatic tourniquet was 1 to 2 minutes, and the quality of application was observably poorer than that of the EMT.

The inflation time of the EMT using the attached hand bulb was found to be comparable to that of an overlapping pneumatic tourniquet using a pressurized source. This observation can be explained by the fact that the EMT has a considerably smaller inflatable volume and thus a hand bulb was adequate to provide a rapid inflation.

Fig. 3 Emergency and Military Tourniquet (EMT) applied to a lower limb and evaluated for use by unskilled personnel.

The effectiveness of limb occlusion of the EMT was found to be comparable to that of the overlapping pneumatic tourniquet. This effectiveness was validated by using Ultrasound Doppler technology to detect that blood-flow past the cuff had been completely stopped.

Independent studies conducted by the US Army's Institute of Surgical Research (USAISR) [4] and by John F. Kragh Jr. et al [5] have been published validating the ease of use and effectiveness of the EMT. In recent years, the EMT has helped reduce mortality and morbidity in military settings in Iraq.

SUMMARY

This paper reports the development and initial technical evaluation of novel pneumatic tourniquets for pre-hospital civilian applications and for ground-based tactical military settings. In such applications and settings, tourniquets may serve as life-saving and limb-sparing devices for rapid and effective hemorrhage control.

In addition, such devices must be fast and simple to apply by non-medical, non-expert users with a minimum of training, and they must be capable of completely stopping arterial blood flow at applied pressures that minimize the probability of injuries to nerves, muscle and other soft tissues.

Non-pneumatic tourniquets can be less effective in occluding arterial blood flow and may lead to possible skin and nerve injury; overlapping pneumatic tourniquets are unsuitable for pre-hospital settings due to the difference in sizes, the skill level required for proper application to the limb, they are difficult to apply with one hand, require a source of pressurized gas, and use hook-and-loop fastening materials which are unreliable when wet or fouled with dirt and debris.

The Emergency and Military Tourniquet (EMT) has been developed to overcome the above disadvantages and has also been evaluated to meet and exceed the above requirements. Individual studies [4, 5] have validated the ease of use and effectiveness and of the EMT.

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