Tourniquets Exposed to the Afghanistan Combat Environment Have Decreased Efficacy and Increased Breakage Compared to Unexposed Tourniquets

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ABSTRACT We hypothesize that an anecdotally observed increase in tourniquet breakage and decrease in efficacy may be secondary to environmental exposure during military deployment. This was a study comparing efficacy and breakage of 166 Afghanistan-exposed tourniquets to 166 unexposed tourniquets. Afghanistan exposure was defined as tourniquet carriage by field staff in the operational environment for approximately 6 months. In a controlled environment in the United States, a previously exposed tourniquet was tested on one thigh of each subject, while an unexposed tourniquet was tested on the opposite thigh. We recorded tourniquet efficacy (absence of distal pedal pulse for at least 30 seconds), breakage, and the number of turns required to stop the distal pedal pulse. A Wilcoxon sign-rank test was used to test differences between exposed and unexposed tourniquets. Tourniquets exposed to the environment broke more often (14/166 versus 0/166) and had decreased efficacy (63% versus 91%; $p < 0.001$). Three turns were required for most tourniquets to be efficacious. Environmental exposure of military tourniquets is associated with decreased efficacy and increased breakage. In most cases, tourniquets require three turns to stop the distal lower extremity pulse.

INTRODUCTION

The tourniquet is an essential component of combat casualty care. As a treatment for extremity hemorrhage, tourniquets are inexpensive, simple, associated with increased survival, and have a low rate of morbidity.[1,2] The U.S. military's primary tourniquet device is the Combat Application Tourniquet (CAT) (North American Rescue Products, Greer, South Carolina), which performs well in laboratory testing and in clinical use.[3,4] The CAT uses a self-adhering band that wraps around the extremity (Fig. 1); the windlass is turned to tighten an inner strap that slides within the band, thereby tightening the tourniquet.

A 14% (7/49) breakage of CATs applied by Marine Regimental Combat Team 3 during operations in Afghanistan between May and October 2009 was revealed in an informal survey done by this article's first author. All seven broken tourniquets had been used on the lower extremity; this was higher than the 8% rate measured in a laboratory report.[3] Several theories have been considered for this difference, including weakening of the tourniquet by exposure to the environment and excessive force in application.

Servicemen often wear tourniquets on the outside of their flak jackets, so they are easily accessible.[5] Although the exact extent of this practice is unknown, the authors, with a combined eight combat deployments in Iraq and Afghanistan, estimate it to be approximately half of all combat troops. Tourniquets worn on the outside of the uniform are exposed to a sometimes harsh environment and physical wear. Although we have no direct evidence for weathering that may increase the risk of tourniquet breakage in the field, such exposure can plausibly do so.

Excessive force applied to tourniquets may also cause them to break. On the battlefield, it is difficult to determine when a tourniquet is sufficiently tight because of venous oozing, medullary bone bleeding, the lack of distal pulses in traumatic amputations, and the chaotic environment that defines combat casualty care. If consistency to the number of turns of the tourniquet windlass required to stop arterial flow were known, this could help guide training.

The main goal of this study was to determine whether CATs that had been directly exposed to the Afghanistan environment had decreased efficacy or break more often compared to unexposed tourniquets. A secondary goal was to determine the average number of turns of the tourniquet windlass necessary to stop the distal pulse.

METHODS

Study Design

Our study was designed to compare Afghanistan-exposed CATs to unexposed CATs on healthy volunteers in a controlled

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FIGURE 1. Combat Application Tourniquet (generation 3). Study data were derived from generations 3 to 6.

environment. The first author collected exposed CATs from U.S. Marine Corps infantry while deployed to Afghanistan from May to November 2009. All CATs had been worn on the outside of a uniform (on helmet or body-armor) and were directly exposed to the environment for 5 to 6 months—the usual deployment length for Marines. No study CAT had been used previously in clinical care. The unexposed CATs were obtained from 1st Medical Battalion in early 2010. The date of manufacture (stamped with white ink) was recorded, when available. Age was calculated for each CAT using number of months from the month manufactured until the month tested. An exposed CAT was tested on one thigh in each subject, while the unexposed CAT was tested on the contralateral thigh. Subjects were randomized to one of four groups to determine which thigh the unexposed CAT would be tested on and which thigh would be first.

Setting

The study was performed at Marine Corp Base Camp Pendleton. The protocol was granted approval by the Naval Medical Center San Diego Institutional Review Board and was conducted in compliance with all applicable federal regulations governing the protection of human subjects in research (Protocol NHCP.2010.0014). Physicians supervised data collection in June 2010.

Selection of Participants

Civilian investigators recruited active duty male military members over the age of 18 years. Volunteer subjects gave informed consent in writing. Subjects were excluded if they had a history of a blood clotting disorder, deep vein thrombosis, or other vascular disorder. Of the 168 military active duty personnel who consented and participated in the study, two individuals were excluded from analysis because of missing data. This left us with a study group of 166 human subjects and 332 tourniquets.

Methods and Measurement

Breakage was defined as any component of the tourniquet (i.e., windlass, self-adhering band, clip, etc.) that broke during application of the CAT over the Battle Dress Uniform. If a CAT broke, we recorded the specific area of breakage, along with the number of turns required before breakage. A CAT was efficacious if it terminated the distal pulse (dorsalis pedis artery) for at least 30 seconds without causing intolerable pain—regardless of tourniquet breakage. The distal pulse was measured using a Doppler stethoscope (Huntleigh Healthcare, Eatontown, New Jersey). The number of turns required to stop the distal pulse was reported, up to a maximum of three turns. One turn was defined as a 180-degree arc (the displacement of full supination or pronation of the wrist without regripping), plus an additional 90 degrees to fasten the windlass into the clip.

Data Collection and Processing

Before the CAT was applied, the subject's age, height, weight, heart rate, blood pressure, and thigh circumference were obtained. Doppler signal of the distal pulse was detected and marked on the skin. An investigator applied the CAT over the Battle Dress Uniform, parallel to and approximately 2 cm inferior to the inguinal ligament. After ensuring the tightest possible fit by confirming that no more than three fingers could fit under the tourniquet, the windlass was turned by the subject until: (1) the CAT successfully eliminated the pedal pulse for at least 30 seconds; (2) the CAT broke in a way that prevented further turns; (3) pain from the CAT became intolerable; or (4) three turns had been completed without eliminating the distal pulse.

Outcome Measures

Our outcome measures were efficacy, breakage, and the number of turns required to successfully stop the distal pulse for exposed and unexposed tourniquets.

Data Analysis

Statistical analysis was performed using STATA Data Analysis and Statistical Software (StataCorp LP, College Station, Texas). Wilcoxon sign-rank test was carried out for comparison between exposed and unexposed tourniquets for tourniquet breakage and efficacy. A two-tailed *t*-test was carried out to test for differences in tourniquet age between exposed and unexposed tourniquets. A p-value ≤ 0.05 was the critical value for determining significance for all tests.

RESULTS

Study Subject Traits

A description of the study group consisting of 166 active duty males is shown in Table I. The range of the thigh circumferences was 45 to 77 cm, corresponding to the 0.17th and 99.9th percentiles of U.S. male soldiers, respectively.[6]

Tourniquet Characteristics

Of the exposed tourniquets, only 30% clearly displayed a visible month and year of manufacture. Ten percent had no visible month but did display the year; 60% had neither a visible month nor the year. All unexposed tourniquets had a visible month and year of manufacture. Among tourniquets

TABLE I. Study Group Traits.

	Mean ± SD
Age (year)	21 ± 3.1
Body Mass Index	26 ± 4.2
Height (cm)	176 ± 9.0
Weight (kg)	79 ± 9.8
Thigh Circumference (cm)	61 ± 5.3
Resting Heart Rate (bpm)	69 ± 12.7
Blood Pressure (mmHg)	
Systolic	124 ± 13.6
Diastolic	68 ± 10.0

with an established age, the mean age of exposed tourniquets (mean = 25.7, SD = 7.4) was statistically different from unexposed tourniquets (mean = 9.8, SD = 4.9) ($p < 0.001$).

Tourniquet Exposure

The efficacy of exposed tourniquets was lower (63%) compared to unexposed tourniquets (91%) ($z = 3.74$, $p < 0.001$). None of the unexposed tourniquets broke, and 14 (8%) of the exposed tourniquets did break ($z = -6.07$, $p < 0.001$). Of the 14 tourniquets that broke, five still stopped the distal pulse. Among the 14 tourniquets that broke, 12 broke at the stabilization plate slot (Fig. 2), one at the self-adhering band, and one at the friction adaptor. The predominance of failure at the stabilization plate slots is consistent with the thin nature of the plastic at that point.

Number of Turns

Overall, 59% of CATs required three turns to be efficacious. No statistically significant difference was found between exposed and unexposed tourniquets with regard to the median number of turns required to stop the distal pulse. The median for exposed tourniquets was 2.0 (mean SD = 1.3), and the median for unexposed tourniquets was 2.0 (mean SD = 0.889).

DISCUSSION

This study was designed to evaluate the effectiveness and break rate of tourniquets exposed to the combat environment. The results indicate that CATs exposed to the environment broke more often and were less efficacious at stopping the distal pulse than unexposed CATs when tested in a controlled environment. The study also showed that most CAT applications needed three turns to be efficacious. Although previous tourniquet studies have focused on the efficacy of different brands of tourniquets or associations with mortality, we are not aware of previous research assessing the effect of environmental exposure on performance or assessing how many turns it takes of the CAT windlass to stop the distal pulse.

Doppler auscultation was used to determine the presence or absence of the pulse, which was our measurement for efficacy. Although occlusion plethysmography has been reported to be more accurate than Doppler at detecting arterial flow, we chose to use Doppler because it is the most accepted method.[3,4]

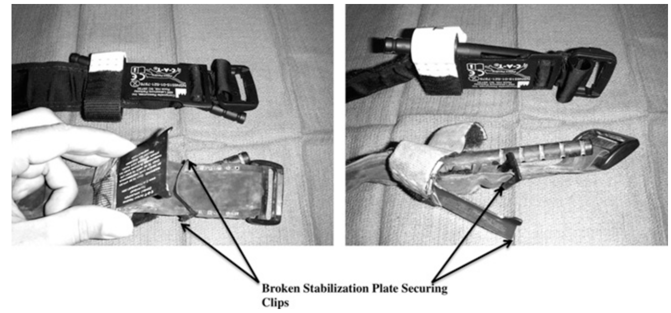

FIGURE 2. Images of Afghanistan-exposed CATs that broke at the stabilization plate.

A review of the current tourniquet literature revealed Doppler as the primary method of testing for efficacy,[3,7–12] and the 2010 Tourniquet Summit at Quantico, Virginia, reached consensus that testing should be performed by Doppler foremost.[13]

Although results suggest that environmental exposure may cause tourniquets to be more prone to breakage and less efficacious, it did not reveal which variable, or combination of variables, led to worse performance. Heat, wear and tear, humidity, and sunlight are all factors that could have led to worse performance. A laboratory study might have controlled for the different variables. We chose our methods because tourniquets that have actually been worn in a combat arena have been exposed to all variables, both seen and unseen. The design of the study was to test whether a difference existed among the variables; establishing the exact cause of any differences was beyond the scope of the study.

Although it is outside the scope of the study to address manufacturing practices, the manufacturer of the tourniquets has been made aware of our findings. Several studies have been published by the military on how tourniquets are tested and recommended for use.[3,10] The CAT was among five tourniquets that was evaluated for use in the U.S. Military in 2005 by a Navy Experimental Diving Unit. To simulate combat conditions, the tourniquets were soaked in a blood analog solution, rolled in sand, and applied while subjects were blindfolded (to simulate night conditions). However, our study suggests that it may be necessary to include additional elements, such as heat, sun exposure, and wind, when testing tourniquets for military use.

CATs are designed to be stored until ready to be used in the protective plastic wrapper in which they are issued to protect the device from the elements. Servicemen may prefer to not have a critical item wrapped in this way as it could delay application when trying to open the package in a field environment; many are currently taught to remove the CAT from its wrapper and keep it in their Individual First Aid Kit (IFAK). Although when carried inside the IFAK, the CAT may also weather; the weathering is likely less extreme compared to when the device is worn on the uniform without IFAK protection.

Tourniquet age is an important quality assurance marker, yet only 30% of the exposed CATs in our study had a visible date; accordingly, it would be advantageous to troops engaged in combat casualty care if tourniquet manufacturers ensured a more permanent indicator of age on these products. Our study cannot conclude whether age of the tourniquet was associated with failure because many of the dates stamped on the exposed tourniquets had worn off. When age could be established, the exposed tourniquets were noted to be older than the unexposed tourniquets; thus, it is possible that the exposed tourniquets broke because they were older, not because they were exposed to the environment. However, CATs do not have specific expiration dates; the manufacturer's only recommendation is that they should be replaced after use.

Three turns had been chosen as the upper limit before the study began. Unpublished data obtained during the study of military casualties by one of the study authors initially indicated that more than three turns increased the risk for deformation and breakage. Newer data indicate more turns incrementally increase risk of breakage, but the limit may be closer to six turns before breakage is common.

In the field, it is important to maintain a low threshold for applying a second tourniquet side-by-side to the first tourniquet, effectively creating a wide tourniquet. Previous studies have shown that wider tourniquets require less pressure to eliminate blood flow.[11,12,14]

Limitations

The study had several methodological limitations. The investigators and subjects were not blinded to the type of tourniquet (exposed or unexposed) that was used on each leg. Weathering was visibly obvious because of the layers of dust coating the exposed tourniquets; however, this was unlikely to affect our objective endpoints of efficacy and breakage. Additionally, the tourniquets were worn by one military unit during the summer of 2009 in Afghanistan and may limit the generalizability of our results. Not all deployments last 5 to 6 months, not all units carry their tourniquets on the outside of their uniforms, some deployments occur in different environments than Afghanistan, and physical wear may vary among units. Our results show that efficacy was lower for exposed tourniquets; however, if additional turns were allowed (as might be applied in field settings), the number of effective tourniquets may be more.

CONCLUSIONS

The results of our study suggest that some modest changes in military policy seem prudent. We recommend that field commanders consider storing their CATs in the IFAK and not exposed to the environment by being worn on the uniform unwrapped. Service members should be taught that CATs may routinely require three turns to be effective. Continued careful analysis of CATs and other medical equipment is critical to quality control of life-saving medical procedures in the challenging operational environment. Further investigation is necessary to improve the design of tourniquets and to determine how often to reissue new tourniquets to deployed combatants to help mitigate tourniquet breakage. Furthermore, it is important to determine which variables (i.e., sunlight, heat, age, or physical wear) increase the risk for tourniquet failure.

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