

Efficacy of Tourniquets Exposed to the Afghanistan Combat Environment Stored in Individual First Aid Kits Versus on the Exterior of Plate Carriers

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ABSTRACT Between February and May 2010, 1st Battalion, 6th Marines reported a 10% (10/92) breakage rate for tourniquets. One theory suggested was that tourniquets were weakened by exposure to the Afghan environment. Our study was designed to compare three groups of Afghanistan-exposed tourniquets to unexposed tourniquets. The three experimental arms were: (1) Afghan-exposed tourniquets worn on the plate carrier, (2) Afghan-exposed tourniquets carried in the Individual First Aid Kit (IFAK) and wrapped in manufacturer plastic wrapping, and (3) Afghan-exposed tourniquets carried in the IFAK with the manufacturer plastic wrapping removed. The outcome measures of this study were efficacy, breakage, and number of turns required to successfully stop the distal pulse. Tourniquets worn on the plate carrier had an efficacy of 57%, which was significantly lower than the control efficacy rate of 95.2%. When compared to the control arm, there were no significant differences in efficacy between the tourniquets stored in the IFAK with or without manufacturing packaging. No control tourniquets or tourniquets stored in IFAKs broke; however, 46 (12%) of the plate carrier-exposed tourniquets did break. No statistically significant differences were found between the four groups with regard to the median number of turns required to stop the distal pulse.

BACKGROUND

It is estimated that 7 in 100 combat deaths could be prevented by correctly applied tourniquets.^{1,2} Data from recent conflicts involving U.S. military personnel confirm the continued importance of hemorrhage control.¹⁻³ Hemorrhage from injured limbs is a leading cause of battlefield death, and emergency tourniquet use during the current war has improved survival rates for patients enduring major limb trauma.^{2,4,5} All military personnel in theater carry tourniquets, and tourniquets are commonplace on the battlefield in Afghanistan with medical and nonmedical personnel. The U.S. military's primary tourniquet is the Combat Application Tourniquet (CAT). Each Marine and Corpsman is issued two CATs in their Individual First Aid Kit (IFAK) before deployment in support of Operation Enduring Freedom. The CAT is a self-adhering band that wraps around the extremity; a windlass is turned to constrict an inner strap, which slides within the band to tighten the tourniquet (Fig. 1).

A 14% (7/49) CAT breakage rate was reported by Marine Combat Team 3 in support of Operation Enduring Freedom

between May and October 2009.⁶ During an internal review conducted between February and May 2010, 1st Battalion, 6th Marines reported a 10% (10/92) breakage rate for CATs during application. The review noted that 9 out of 10 breakages occurred in a single company whose protocol was to wear tourniquets on the outside of their plate carriers. Lower extremity efficacy rates for CATs directly exposed to the Afghanistan environment have been reported as low as 59%, compared with a 91% efficacy rate for unexposed CATs.⁶ Several theories have been considered to determine why the breakages occurred, including the possibility that tourniquets are weakened by exposure to hostile environments or excessive force during application. Although published results suggest that direct environmental exposure may increase susceptibility of tourniquets to breakage, further investigation is warranted to determine whether storing tourniquets in IFAKs preserves their efficacy.

The primary objective of this study was to compare the effectiveness of three groups of CATs exposed to the Afghanistan environment: (1) those worn on plate carriers, (2) those stored in IFAKs without manufacturer packaging, and (3) those stored in IFAKs with manufacturer packaging. A secondary end point was to determine the average number of turns, up to 4, of the tourniquet windlass needed to stop the distal pulse.

METHODS

The protocol for this study was approved by our institutional review board and was conducted in compliance with all federal regulations governing the protection of human subjects in research.

Our study was designed to compare three groups of Afghanistan-exposed CATs to unexposed CATs on healthy

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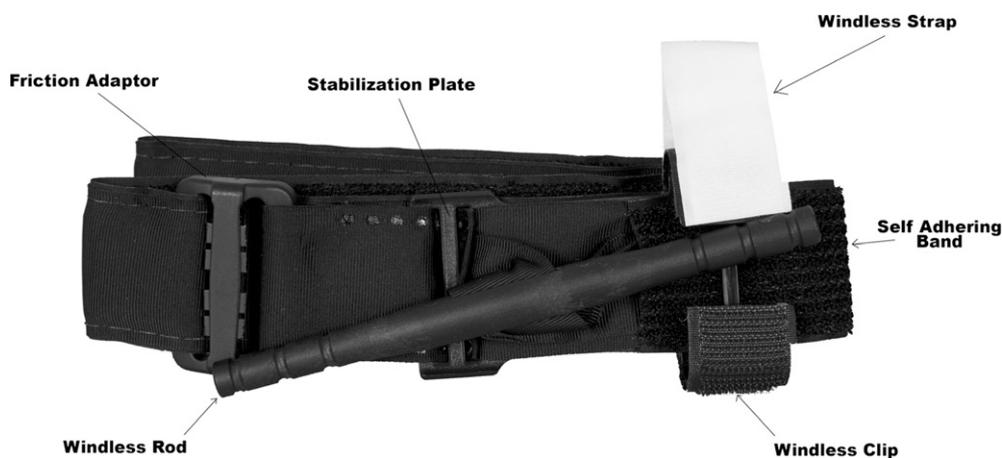


FIGURE 1. Combat Application Tourniquet (CAT) (Generation 6).

volunteers in a controlled environment. The three experimental arms were: (1) Afghan-exposed CATs worn on the plate carrier vest, (2) Afghan-exposed CATs carried in the IFAK and wrapped in manufacturer plastic wrapping, and (3) Afghan-exposed CATs carried in the IFAK with the manufacturer plastic wrapping removed. The outcome measures of this study were efficacy, breakage, and number of turns required to successfully stop the distal pulse for these three experimental groups and a control group.

We numbered 1,600 generation-6 CATs, manufactured between 90 and 120 days before deployment, and randomized the CATs to four study arms, each of which received 400 tourniquets. Eight hundred healthy volunteers from the same Marine Infantry Battalion were enrolled and assigned to one of the four study arms. Volunteer subjects provided informed written consent. In the three experimental groups, each volunteer was randomly issued two CATs. Per protocol, the experimental tourniquets were not to be used for treating combat injuries or for training purposes. Three arm-specific instructional periods were given on proper carrying of the tourniquets in Afghanistan. The date of landing in Afghanistan on deployment and departing Afghanistan on redeployment were recorded for each participant. Each month, an associate investigator inspected each volunteer's tourniquets for location and compliance with the study protocol. The 400 control tourniquets were stored in the manufacturer plastic wrapping in the locked, climate-controlled, Battalion Headquarters at Camp Lejeune, North Carolina.

Subjects were excluded if they had a history of clotting disorder, absence of a dorsalis pedis pulse, deep vein thrombosis, diabetes mellitus, hypertension requiring treatment, or other vascular disorder. Of 800 original participants, 23 participants and their tourniquets were lost to combat injury or death, 3 were excluded after they used their tourniquets to treat wounded coalition forces, and 1 was excluded when a participant lost his tourniquets on patrol. The final study group consisted of 773 male active duty Marines and 1,546 tourniquets.

Following the 7-month deployment, each volunteer's two CATs were randomly assigned to one of the participant's thighs. Before CAT application, the subject's age, height, weight, heart rate, blood pressure, and thigh circumference were noted. Doppler signal of the distal dorsalis pedis pulse was detected, and the location was marked on the skin. An investigator applied the CAT over the Desert Marine Corps Camouflage Utility Uniform, parallel to and approximately 2 cm inferior to the inguinal ligament. After ensuring a tight fit of the tourniquet, the windlass was turned by the participant until either: the CAT successfully eliminated the dorsalis pedis pulse for 30 seconds, the CAT broke in a way that prevented further turns, pain from the CAT became unbearable, or four turns had been completed without eliminating the distal pulse. Once the first CAT was tested, the procedure was completed on the opposite leg with the second CAT. To ensure consistency, the same evaluator conducted all CAT testing.

Breakage was defined as any part of the tourniquet breaking during application of the CAT over the Desert Marine Corps Camouflage Utility Uniform. If a CAT broke, we recorded the specific area of breakage and the number of turns completed before breakage. Efficacy was defined as successful elimination of the dorsalis pedis pulse for at least 30 seconds without causing unbearable pain, regardless of tourniquet breakage. The distal pulse was measured using a Doppler stethoscope (Huntleigh Healthcare, Eatontown, New Jersey). One turn was defined as a 180° arc, as described by the displacement of full supination or pronation of the wrist without regripping, plus an additional 90° to fasten the windlass into the clip. We recorded the number of turns, up to a maximum of four, required to stop the distal pulse for 30 seconds.

RESULTS

Study group characteristics are shown in Table I. Thigh circumferences ranged from 49 to 77 cm (1–99.9 percentile of U.S. soldiers).⁷ An independent sample *t*-test, using a 99.9% confidence level, was used to compare each study characteristic across the four groups. There were no statistically

TABLE I. Study Group Characteristics, Reported as Means \pm SDs

Study Group Trait	Control	Plate Carrier	IFAK (With Manufacturer Packaging)	IFAK (Without Manufacturer Packaging)
Age (Years)	21.7 \pm 3.0	21.6 \pm 3.0	21.7 \pm 2.9	21.7 \pm 3.0
Body Mass Index (kg/m ²)	25.2 \pm 3.0	24.9 \pm 3.0	24.8 \pm 3.1	25.3 \pm 3.2
Height (cm)	176.7 \pm 6.1	177.7 \pm 6.3	177.6 \pm 6.4	178.6 \pm 6.4
Weight (kg)	88.4 \pm 10.7	88.5 \pm 11.2	88.6 \pm 10.3	88.2 \pm 11.5
Thigh Circumference (cm)	60.9 \pm 5.0	60.1 \pm 4.9	61.8 \pm 5.0	60.1 \pm 4.9
Resting Heart Rate (bpm)	67.9 \pm 10.1	67.8 \pm 11.7	68.0 \pm 12.2	67.4 \pm 11.1
Systolic Blood Pressure (mm Hg)	118 \pm 15.2	120 \pm 14.1	119 \pm 14.0	122 \pm 14.9
Diastolic Blood Pressure (mm Hg)	76.9 \pm 8.6	77.8 \pm 9.0	77.9 \pm 8.1	76.6 \pm 8.6

significant differences in physical characteristics between the four groups.

The tourniquet mean age at the time of testing was 11.3 \pm 0.46 months. The mean time that each tourniquet was exposed to the Afghan environment was 212 \pm 12 days for plate carrier, 211 \pm 11 days for IFAK with manufacturer packaging, and 212 days \pm 12 for IFAK without manufacturer packaging. Tourniquets worn on the plate carrier had an efficacy of 57%, which was significantly lower than the control efficacy rate of 95.2% ($Z = 3.3$; $p < 0.0005$). When compared to the control arm, there were no significant differences in efficacy between the tourniquets stored in the IFAK with manufacturing packaging and those stored in the IFAK without manufacturer packaging ($Z = 3.3$; $p < 0.0005$). No control tourniquets or tourniquets stored in IFAKs broke; however, 46 (12%) of the plate carrier-exposed tourniquets did break ($Z = 3.3$, $p < 0.0005$). Of the 46 tourniquets that broke, 40 broke at the stabilization plate slot and 6 broke at the friction adaptor. None of the 46 tourniquets that broke were able to stop the distal pulse.

Of the 1,320 CATs that were efficacious, 9% required one turn, 26% required two turns, 60% required three turns, and 5% required four turns to successfully eliminate the pedal pulse (Table II). No statistically significant differences were found between the four groups with regard to the median number of turns required to stop the distal pulse. The group medians were as follows: control median 3.0 (mean 2.6 \pm 0.747), plate carrier median 3.0 (mean 2.7 \pm 0.635), IFAK with manufacturer packaging median 3.0 (mean 2.6 \pm 0.729), and IFAK without manufacturer packaging median 3.0 (mean 2.6 \pm 0.741).

DISCUSSION

Currently, the CAT manufacturer recommends keeping the tourniquet in the plastic packaging until needed to protect the

tourniquet from the elements. However, to prevent critical delays in tourniquet application, many units prefer to remove the manufacturer packaging before storage on the plate carrier or in the IFAK. This study was primarily designed to evaluate the effectiveness and breakage rates of tourniquets directly exposed to the combat environment and those stored in IFAKs with and without manufacturer packaging. The results indicate that, in the controlled testing environment, CATs directly exposed to the Afghan environment broke more often and were less efficacious at stopping the distal pulse than unexposed CATs. We found no reduction in the efficacy of CATs exposed to the Afghan environment and stored in IFAKs, with and without manufacturer packaging. Moreover, our results support previous reports that most CATs require 3 turns to be efficacious.⁶

Although occlusive plethysmography has been reported to be more accurate than Doppler auscultation to detect distal blood flow, we used Doppler auscultation because it is the most accepted method to determine the presence or absence of the distal pulse.^{5,8} The 2010 Tourniquet Summit at Quantico, Virginia, reached consensus that testing should be performed by Doppler auscultation, and a review of the current tourniquet literature reveals Doppler as the primary method for testing efficacy.⁹

Four windlass turns was chosen as the upper limit before study implementation because the first author's unpublished data indicated that more than four turns increases the risk of tourniquet breakage. Newer data indicate that the turn limit may be closer to six before breakage is common.⁶

The study had several procedural limitations. Tourniquets were only applied to the lower limb. As limb circumference increases, the percentage of tourniquet pressure reflected in the underlying soft tissues varies inversely.¹⁰ Hence, cessation of arterial flow in the upper limb is easier to achieve and

TABLE II. Number of Turns Required to Eliminate the Pedal Pulse for 30 Seconds

Number of Turns	Control, <i>n</i> (%)	Plate Carrier, <i>n</i> (%)	IFAK (With Manufacturer Packaging), <i>n</i> (%)	IFAK (Without Manufacturer Packaging), <i>n</i> (%)
1	39 (10.1)	9 (2.3)	37 (9.6)	39 (10.1)
2	91 (23.4)	72 (18.7)	93 (24.2)	89 (22.9)
3	221 (57.0)	128 (33.3)	219 (56.7)	223 (57.4)
4	18 (4.6)	10 (2.7)	16 (4.1)	17 (4.4)
Not Efficacious	19 (4.9)	165 (43.0)	21 (5.4)	20 (5.2)

would have a higher efficacy rate than the lower extremity.¹¹ However, 68% of injuries requiring a tourniquet occur in the lower limbs.¹¹ The study was also limited by investigators and participants not being blinded to the type of tourniquet (plate carrier, IFAK with or without manufacturer packaging, control) that was used on each leg. However, the lack of blinding is unlikely to affect our objective end points of efficacy and breakage. The results of our study can be generalized to a 7-month deployment to Afghanistan and may not extrapolate to longer deployments or different theaters of operation.

CONCLUSIONS

The results of our study indicate that exposing tourniquets directly to the Afghan environment decreases tourniquet efficacy and increases breakage rates. We recommend that commanding officers ensure that tourniquets are not worn externally on plate carriers or on other gear which would decrease their efficacy. There was no decreased efficacy of the CATs exposed to the Afghan environment stored in IFAKs with or without manufacturer packaging. We recommend that the Commanding Officer ensure the storage of CATs in IFAKs. Although no differences were observed between tourniquets stored in IFAKs with and IFAKs without manufacturer packaging, the Commanding Officer should carefully weigh the advantage of quickly applying the unwrapped tourniquet versus not following the manufacturer recommendation of keeping the tourniquet sealed until use. Service members should be trained that most CATs may routinely require three turns to be effective. Further investigation is warranted to evaluate the maximum number of turns that can be applied to CATs without increasing breakage rates and the exact variables that increase the risk for failure.

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