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Effects of Training and Simulated Combat Stress on Leg Tourniquet Application Accuracy, Time, and Effectiveness

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ABSTRACT The lower extremity tourniquet failure rate remains significantly higher in combat than in preclinical testing, so we hypothesized that tourniquet placement accuracy, speed, and effectiveness would improve during training and decline during simulated combat. Navy Hospital Corpsman ($N = 89$), enrolled in a Tactical Combat Casualty Care training course in preparation for deployment, applied Combat Application Tourniquet (CAT) and the Special Operations Forces Tactical Tourniquet (SOFT-T) on day 1 and day 4 of classroom training, then under simulated combat, wherein participants ran an obstacle course to apply a tourniquet while wearing full body armor and avoiding simulated small arms fire (paint balls). Application time and pulse elimination effectiveness improved day 1 to day 4 ($p < 0.005$). Under simulated combat, application time slowed significantly ($p < 0.001$), whereas accuracy and effectiveness declined slightly. Pulse elimination was poor for CAT (25% failure) and SOFT-T (60% failure) even in classroom conditions following training. CAT was more quickly applied ($p < 0.005$) and more effective ($p < 0.002$) than SOFT-T. Training fostered fast and effective application of leg tourniquets while performance declined under simulated combat. The inherent efficacy of tourniquet products contributes to high failure rates under combat conditions, pointing to the need for superior tourniquets and for rigorous deployment preparation training in simulated combat scenarios.

INTRODUCTION

The lower extremity tourniquet failure rate remains significantly higher in combat than in preclinical testing, but the effect of training and simulated combat stress on tourniquet failure rate was unclear. No improvement in the prehospital care of combat casualties over recent years has saved more lives than the rapid application of a tourniquet to major extremity trauma.[1] As improvised explosive devices have become more powerful and more common, the combat casualty care community is increasingly challenged to provide an effective prehospital treatment for traumatic leg injuries.[1–4] Proper early tourniquet application, before the onset of shock, can increase survival nearly tenfold compared to delayed application.[3]

However, despite the conceptual simplicity of a tourniquet, the failure rate in battle remains surprisingly high. A recent analysis of combat casualties indicated a 21% failure rate for the Combat Application Tourniquet (CAT), the most commonly used prehospital tourniquet, and a 34% failure rate for the Special Operation Forces Tactical Tourniquet (SOFT-T), which advertises, "Proven to be 100% effective during USAISR testing."[2] This is unacceptable, particularly given that 91% of potentially survivable battlefield deaths from 2001 to 2011 were due to hemorrhage.[5]

Although it is possible that these devices are deficient for the target task, the reported success rate of tourniquets in civilian prehospital and classroom training settings is high.[4] This suggests that the stressful nature of the combat environment may contribute to tourniquets being improperly placed or secured, thereby decreasing effectiveness. However, no published reports have explored leg tourniquet placement under simulated combat scenarios.

Therefore, the purpose of this study was to contrast two tourniquets (CAT and SOFT-T) across training and simulated combat scenarios during a predeployment Tactical Combat Casualty Care (TCCC) training course. It was hypothesized that training would improve performance in tourniquet application time, accuracy, and effective cessation of blood flow, and that performance would decline during the simulated combat scenario for both CAT and SOFT-T tourniquets.

METHODS

Population and Setting

Participants were 89 U.S. Navy Hospital Corpsman (HM), scheduled to be deployed within 180 days, enrolled in a 5-day TCCC training course from July 2011 to February 2012 (4 separate monthly classes totaling 89 subjects). Data were collected at Naval Medical Center Portsmouth (NMCP), Portsmouth, Virginia, where facilities include settings for training medical personnel for battlefield scenarios.

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The initial results of this study were presented at the April 2012 GSACEP (Government Services Chapter American College of Emergency Physicians) conference in Squaw Valley, California, as a 15-minute Powerpoint presentation entitled: "The Effectiveness of Navy Hospital Corpsman in Applying TCCC Recommended Prehospital Tourniquets Under Simulated Combat Stress."

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Participant data were excluded if incomplete. Of 98 possible participants, 9 did not provide complete data, resulting in $N = 89$ for statistical analysis.

Human Subject Committee Review

This study was approved by the Institutional Review Board of Naval Medical Center Portsmouth. Each participant provided informed consent in writing on the first day of the course.

Materials

The CAT is a small, lightweight one-handed tourniquet used to stop the arterial blood flow of an extremity. The CAT uses a Velcro strap and buckle (plastic) to fit a wide range of extremity sizes, combined with a one-handed windlass (Old Norse vindass: vinda "to wind" + ass "pole") system. The windlass (durable plastic) uses a free-moving internal band to provide circumferential pressure to the extremity. The windlass is then locked in place with a clip and strap for further securing of the windlass once tightened. The CAT has a 3.8 cm width that is consistent throughout the entire length. (Note that a newer version is available. SOFTT-W is 5.1 cm for the chassis and 3.8 cm for the adjustable webbing.)

The SOFT-T is a small, one-handed tourniquet that is generally similar to the CAT in windlass design, but SOFT-T is narrower and incorporates a metal buckle and clamp secured with a set screw. An internal band is attached to the windlass to provide pressure to the extremity. Either of the two tri-rings can be used to secure the windlass. The windlass is made of aircraft aluminum and the tri-rings that are used for locking the windlass in place are molded acetyl, a high-impact plastic. The SOFT-T is 5 cm at its widest (on the chassis), and 2.7 cm wide for the adjustable webbing.[6]

Two Ultrasonic Doppler Flow Detector Model 811-B with 9.2 MHz 3/4 in. probes were used to identify the dorsalis pedis pulse site for marking and for verifying the elimination of blood flow after tourniquet placement.

Measurement of Key Outcomes

Time to Placement

Time to placement was assessed as the time elapsed from the provider's first touch of the tourniquet to when the provider verbally declared the placement to be completed. Time to placement was measured by stopwatch and recorded to the tenth of a second.

Placement Accuracy

Correct placement was defined as (1) the distal edge of the tourniquet a minimum of 4 inches (instructed to be more than one hand's width) above the proximal edge of the patella, and (2) secured properly per device training instructions (through both loops on the CAT; with windlass fastened on the SOFT-T). Placement accuracy was recorded as either correct (coded as 1) or incorrect (coded as 0) and operationally defined as percent correct placement per group.

Cessation of Blood Flow Pulse

The presence or absence of pulsatile blood flow distal to the tourniquet was assessed using laser Doppler flowmetry (Ultrasonic Doppler Flow Detector Model 811-B with 9.2 MHz 3/4 in. probe) at the dorsalis pedis. Elimination of pulse was recorded as pass (coded as 1) or failure (coded as 0) and operationally defined as percent passing pulse per group. To foster reliability and validity, dorsalis pedis was located and marked (x) with a permanent marker each day, before data collection.

Study Design

This study incorporated a mixed design, with CAT and SOFT-T tourniquet products contrasted within-subjects across three time points: after initial training (day 1), on day 4 of training (day 4), and in field test under simulated combat scenario (field test) (Fig. 1).

Each participant was tested using both CAT and SOFT-T at each time point, with the order of product and leg of application (left or right) randomized using the random number generator in Microsoft Excel software.

Experimental Protocol

Training

TCCC is a 5-day course taught monthly at Naval Medical Center Portsmouth. The first 4 days are primarily classroom and simulation lab training on the indications for and the application of tourniquets, nonsurgical airways (nasopharyngeal), surgical airways (cricothyroidotomy), needle thoracostomies, permissive hypotension with Hextend, and interosseous access.

On day 1 of the course, after a pretest to evaluate their basic knowledge and an introductory brief about TCCC, the students were given an initial familiarization brief on the 2 recommended tourniquets, CAT and SOFT-T.

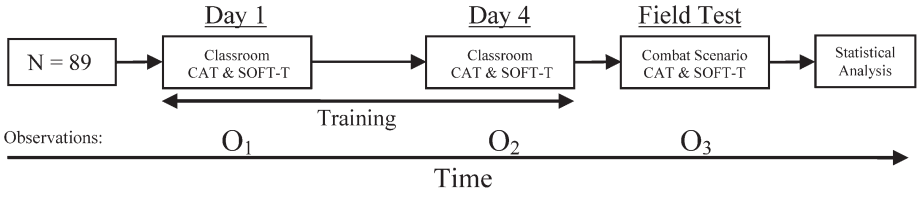

FIGURE 1. Design timeline.

During days 2 and 3, the basics of tactics were covered, including taking appropriate cover, priority of returning suppressive fire, and effective means of getting casualties off of the battlefield (drags and carries). Day 4 included testing in a classroom setting in preparation for the combat scenario field test on the fifth day.

Data Collection

Data were collected in classroom and in field settings (Fig. 1). Measures were assessed identically in both settings.

Classroom setting (Day 1, Day 4). Informed consent was acquired after the primary investigator explained the study and provided students the opportunity to ask questions. It was stressed that opting out would not affect their TCCC course evaluation. Following written acquisition of informed consent, students removed their boots and socks so the dorsalis pedis pulse could be located via Doppler and marked with permanent marker in preparation for testing. Participants worked in pairs in the classroom setting, taking turns acting as the wounded and as the corpsman/medic. Although one participant lay supine on the floor with one boot and sock removed, the partner applied the tourniquet laying prone (tactical position). Prone position was appropriate to simulate the Care Under Fire portion of TCCC, but in a low-stress environment. Students were instructed to tighten the tourniquet until they thought it was sufficient to stop the pulse and to be indifferent to the possible discomfort of their simulated patient.

Measurement of time started when the student first touched the tourniquet, located on the simulated patient's chest. Measurement of time ended when a pulse check was requested. Time to placement was recorded. Placement accuracy was then assessed and recorded. Finally, dorsalis pedis pulse was assessed and recorded. Participants then switched roles and repeated these steps until both CAT and SOFT-T were applied by both paired partners. Partner pairing and the order of pairs in playing roles were accomplished by self-selection, whereas the choice of leg used (left or right) and the order of product (CAT of SOFT-T) usage was randomized. Setting and measurements were identical for day 1 and for day 4. The same partner pairs were maintained through the entire course.

Simulated Combat Scenario Field Test. On the last day of the course, students were transported to a wooded training area for a simulated combat test-out, where the skills trained in TCCC were evaluated with each student (paired with a partner) dressed out in Kevlar vest, helmet, facemask and eye protection (personal protective equipment), and dummy weapons.

Students ran (literally) through a 250-yard preset obstacle course with their partner from the week to complete five preset stations corresponding to TCCC training : (1) tourniquet, (2) cricothyroidotomy (simulated mannequin), (3) interosseous access (simulated mannequin), (4) needle thoracostomy (simulated mannequin), and (5) tourniquet. To get to the first tourniquet station, students ran 100 yards through heavy plant (sometimes mud/water depending on rain) up to an embankment, where they came under (simulated) fire. A 160 lb mannequin lay in an open area. Students had to stay low and "provide suppressive fire," then when told it was clear, they dragged the mannequin behind the small barricade next to a real person, who had 1 foot exposed and marked. While one student provided suppressing fire, the other student applied the tourniquet that was prepositioned on the chest of the prone person. "Patients" were encouraged to loudly express discomfort to add to distraction and stress. Paint balls were fired continuously, such that if students exposed themselves, they risked getting shot (head, arms, legs, etc.). Measures of time, placement, and pulse were assessed identically to the classroom setting.

Student then ran 50 yards through the woods to complete a cricothyroidotomy station and another 50 yards to a station to complete needle thoracostomies and interosseous access (these data are not included in the present study). Students then ran 50 yards to the last station, the second tourniquet station, where the students "leap frogged" from a cover wooded area to two separate covered areas while under fire. From the last covered area they could see their wounded "patient" behind a covered area in the supine position and would make the short sprint while the partner provided suppressive fire. The "patient" setup was similar to the first station, but with a different tourniquet product. Measures of time, placement, and pulse were acquired as one student applied the tourniquet and the other student provided suppressing fire.

Students were unaware of which tourniquet product would be used at each station before arrival at the station. Students applied tourniquets—odd numbered groups used a CAT at station 1 and a SOFT-T at station 5, where even numbered groups used a SOFT-T at station 1 and a CAT at station 5. Note that while side was randomized, the left and right leg data were essentially identical, so side was not included in the analysis. Students worked in pairs for two rounds at each station, such that one student played the role of the medic on one round and provided suppressing fire on the other round.

Analytical Methods

Sample size determinations

Sample size was based on tests of power and availability of participants. To assess the important contrasts of this study, tests of power revealed that, assuming a 95% confidence interval (CI) and a medium-sized effect, significant differences would be conferred 80% of the time (power = 0.80) with as few as 64 participants. Therefore, the present sample size of 89 participants, each providing paired data (from the CAT condition and from the SOFT-T condition), was considered to be adequate for testing the hypotheses of this study.

Statistical analysis. Data were analyzed using mixed ANOVA, with post hoc pairwise comparisons to localize significant differences between tourniquet products (CAT vs. SOFT-T) and across time to assess the effect of training (day 1 to day 4) and the possible drop-off in performance associated with the simulated combat scenario (day 4 to field). Data from differences may appear slightly off because of rounding.

RESULTS

Placement Accuracy

Correct placement was evident in 87% of participants on day 1 for each product. On day 4, CAT accuracy rose to 94% ($p = 0.07$), whereas SOFT-T remained at 87%. In field testing, SOFT-T dropped from 87% to 83%, whereas CAT dropped from 94% to 91%. None of these trends were statistically significant ($p > 0.05$) (Table I; Fig. 2).

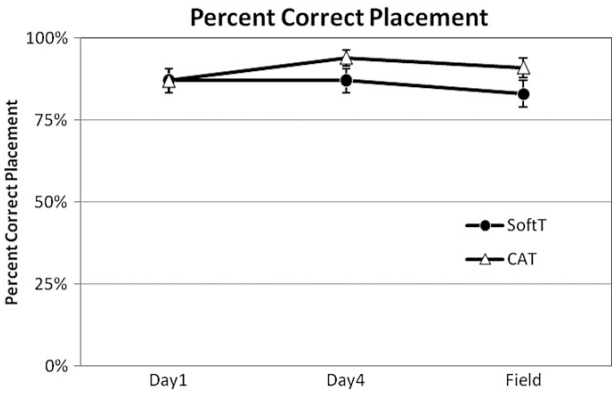

FIGURE 2. Placement accuracy for CAT and SOFT-T. Error bars indicate standard error of the mean (SEM).

Time to Application

Time to application from day 1 to day 4 declined for both SOFT-T (55 to 50 seconds) and for CAT (43 to 38 seconds), reflecting a 5-second effect of training ($p < 0.001$). Time to application in field testing increased in both SOFT-T (to 64; +14) and CAT (to 57; +18), showing the effect of the simulated combat scenario in significantly slowing time to application ($p < 0.001$). The significant quadratic effect over three measurement periods ($p < 0.0001$) further supported improvement from training and the decline under simulated combat stress across products. CAT was ~10 seconds faster than SOFT-T across day 1, day 4, and simulated combat field testing ($p < 0.001$) (Table II; Fig. 3).

Elimination of Pulse

The percentage of pulse elimination improved from day 1 to day 4 for both SOFT-T (30%to 43%) and for CAT (57% to 73%). This difference reflected an average 15% raw difference effect of training for across products (44% to 58%) and a 33% improvement over day 1 (15%/44% = 33%) ($p < 0.02$).

The percentage of pulse elimination declined somewhat for both SOFT-T (43% to 39%) and for CAT (73% to 67%) from day 4 to field test, but these differences were not statistically significant ($p > 0.05$). The significant quadratic effect over three measurement periods ($p < 0.03$) reflected that the significant effect of training was followed by a nonsignificant 5% raw effect of simulated combat scenario in reducing percent passing pulse across products (58% to 53%) and an 8% decline over day 4 (4%/58% = 8%) ($p > 0.05$). CAT was more effective than SOFT-T on day 1 (57% and 30%, respectively), day 4 (73% and 43%, respectively), and in field testing (67% and 39%, respectively) (each $p < 0.0001$), indicating an average ~28% advantage for CAT in raw scores (67% – 39% = 28%) and a 76% advantage over SOFT-T across time points (28%/39% = 76%) ($p < 0.001$) (Table III; Fig. 4).

DISCUSSION

This study contributes to the literature by translating efficacy from the lab to the field, a gap that has not been adequately addressed in hemorrhage control.[6] Training improved tourniquet placement time and improved pulse cessation. Placement accuracy data showed no clear pattern, but overall findings support the efficacy of training on tourniquet application time and elimination of pulse. Simulated combat scenario scores showed a significantly longer time to application, along with smaller reductions in performance for placement accuracy and effectively eliminating pulse. These findings show a

TABLE I. Placement Accuracy Descriptives for CAT and SOFT-T

	Day 1	95% CI		Day 4	95% CI		Field	95% CI	
Source	Mean	Low	High	Mean	Low	High	Mean	Low	High
SOFT-T	87	94	80	87	94	80	83	91	75
CAT	87	94	80	94	99	89	91	97	85
Difference	0	9	–9	8	16	–1	8	18	–2

	Day 1 to Day 4			Day 4 to Field		
Change Over Time	Mean (%)	Low (%)	High (%)	Mean (%)	Low (%)	High (%)
SOFT-T	0	–11	11	–3	–14	7
CAT	8	–1	16	–3	–11	5
Difference	–8	–21	6	0	–13	13

TABLE II. Time to Placement Descriptives for CAT and SOFT-T

	Day 1	95% CI		Day 4	95% CI		Field	95% CI	
Source	Mean	Low	High	Mean	Low	High	Mean	Low	High
SOFT-T	54.8	60.1	49.4	49.7	52.8	46.6	63.5	69.1	57.9
CAT	43.1	46.5	39.7	38.5	40.3	36.7	56.8	62.1	51.5
Difference	11.6[a]	6.7	16.5	11.2[b]	8.1	14.3	6.7	–0.4	13.8

	Day 1 to Day 4			Day 4 to Field		
Change Over Time	Mean (%)	Low (%)	High (%)	Mean (%)	Low (%)	High (%)
SOFT-T	–5.1	–10.6	0.5	8.8[a]	1.7	15.8
CAT	–4.6[b]	–8.2	–1.1	13.7[a]	8.2	19.2
Difference	0.4	–6.1	6.9	4.5	–3.4	12.5

[a] $p < 0.0001$, [b] $p < 0.01$.

performance decline when applying a tourniquet under simulated combat conditions.

Placement accuracy was improper in 1 of 11 under classroom conditions following training and in 1 of 8 under simulated combat. However, improper placement cannot account for the ~50% rate of failure in eliminating dorsalis pedis pulse across this study. This unacceptable rate of failure in eliminating pulse suggests close inspection of the tourniquet products.

Differences Between Tourniquet Products

CAT was superior to SOFT-T in time to application and in elimination of pulse, with a smaller nonsignificant advantage in placement accuracy. However, even after 4 days of training, one-in-four participants failed in pulse elimination using the CAT and more than half failed using the SOFT-T. These results were consistent with those of Hill et al,[7] who found 74% no flow for CAT and 48% for SOFT-T when applied by trained medical personnel.[7] In actual casualties received at a Combat Support Hospital, Kragh et al[2] found 79% effectiveness of CAT and 41% effectiveness of SOFT-T. King et al[8] studied the use of tourniquets at a forward surgical team in Afghanistan in 2011 and found that, of 79 tourniquets (90% of these were CAT) presenting for care, 83% still had palpable pulses present. Although these former reports provide convergent validity to the present findings of an advantage of CAT over SOFT-T, they also highlight a surprising ineffectiveness of tourniquet products across classroom and battlefield scenarios.

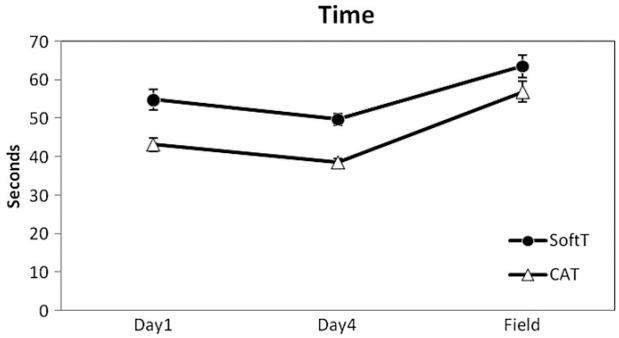

FIGURE 3. Time to tourniquet placement for CAT and SOFT-T. Error bars indicate standard error of the mean (SEM).

CAT and SOFT-T tourniquets are similar windlass designs, with differences in strap width and mechanism. SOFT-T has a locking screw, which adds an additional step and can therefore increase the application time. Although Hill found similar application time for CAT and SOFT-T, present results indicated a 10 second longer application time for SOFT-T than CAT.[4] Participants complained that the apparatus was clumsy and that windlass locks could get caught on the locking screw of the SOFT-T, which added more time to the application, precluded proper alignment of the chassis (webbing strap) on the limb, and resulted in poor application of pressure and a failure of the tourniquet to eliminate distal pulse.

Further, the windlass design is limited by the somewhat arbitrary choice of the number of turns to apply and that the windlass can only be secured along one 180° axis, so the error is ±90° degrees in choosing when to secure the windlass. When tourniquets were further tightened under the supervision of the attending surgeon, medics were generally surprised at how tight the tourniquet must be to eliminate the distal pulse.[9] Two prior studies found that the CAT was effective after 3 turns (59% to 60% of the time) and that turns in excess of 4 to 6 may increase the risk of breakage.[9,10]

In contrast to the present results, one study found that the CAT and SOFT-T each eliminated popliteal pulse 100% of the time when applied to the proximal thigh.[4] However, unlike the present study and the methods of others, Doppler flowmetry was continually checked until the pulse was eliminated, reflecting a precision of feedback that is rarely present with actual casualties.

Clinical Ramifications

Wider is better. The CAT (3.8 cm, 1.57 in.) is wider than SOFT-T (2.7 cm, 1.1 in.). Because pressure is the ratio of force to the area over which that force is distributed, the wider form has mechanical advantage, which may in part explain why the CAT outperformed the SOFT-T. The newer SOFTT-W, which has a wider adjustable webbing (3.8 cm, same as CAT), was not included in this study, but may provide greater efficacy that the standard SOFT-T. The 75th Ranger Regiment

TABLE III. Elimination of Pulse Descriptives for CAT and SOFT-T

	Day 1	95% CI		Day 4	95% CI		Field	95% CI	
Source	Mean	Low	High	Mean	Low	High	Mean	Low	High
SOFT-T	30	40	20	43	53	33	39	49	29
CAT	57	67	47	73	82	64	67	77	57
Difference	27[a]	40	14	30[a]	43	18	28[a]	42	14

	Day 1 to Day 4			Day 4 to Field		
Change Over Time	Mean (%)	Low (%)	High (%)	Mean (%)	Low (%)	High (%)
SOFT-T	12	–1	26	–3	–18	11
CAT	16[b]	2	29	–6	–19	8
Difference	3	–15	22	–2	–22	17

[a] $p < 0.0001$, [b] $p < 0.05$.

yielded a prehospital preventable combat death rate of zero over an 8.5 year period[11] using CAT and SOFT-T tourniquets. Although their focus on continued and realistic medical training is part of this success, another important factor is the application of a second tourniquet when bleeding is still evident. In combat settings, a second tourniquet is often used by the Ranger Regiment for severe leg wounds, particularly when the leg has large girth. The application of a second CAT can improve the rate of eliminating pulse from 75% to 92%, largely because the second tourniquet effectively makes the restriction area wider.[2]

Limitations

Study "patients" were young, healthy, uninjured sailors who had presumed normal blood pressure and normal heart rate, not hypotensive with tachycardia as seen in combat casualties with traumatic amputations. The study sample included only basic HMs, not more experienced medical providers, such as Special Operations Medics, who have a reported 3% preventable death incidence rate compared to 24% for U.S. military overall.[10] In addition, this study did not include the average Sailor, Marine, or Soldier—those who are most likely to find themselves applying a tourniquet in self-aid or in buddy-aid, an important area for future research. Only the lower extremity was assessed. Because of greater girth, the failure rate of tourniquets on the lower extremity is high when compared to the upper extremity.[12,13]

Doppler assessment of pulse cessation on a healthy limb is not identical to effectively stopping bleeding on a combat-damaged limb. The Doppler assessment for presence or absence of a pulse is a binary measurement recommended by the 2010 Tourniquet Summit in Quantico, VA.[14] Doppler may be considered the gold standard for in vivo studies of tourniquet effectiveness, but in the absence of Doppler signal, 20% of baseline blood flow can still be present.[15] Therefore, Doppler flowmetry of dorsalis pedis pulse may have overestimated the effectiveness of the tourniquets tested compared to occlusion plethysmography. It is also possible that popliteal pulse may prove more sensitive than dorsalis pedis pulse. No allocation was made for applying a second tourniquet, or for checking the immediate effectiveness of the tourniquet by palpating the dorsalis pedis pulse or assessing bleeding, as may occur in combat.

The instruction to position the tourniquet 4 inches above the patella was aimed at applying the tourniquet superior to Hunter's canal. Because Hunter's canal is near the medial condyle of the femur, which protects the superficial femoral artery from compression, tourniquets placed here were found to be effective only 67% of the time.[2] It is possible that 4 inches above the patella may be too close to this anatomic location, which may have affected present findings.

The personal protective equipment and Kevlar vests worn by the subjects in this study are lighter and less cumbersome than the body armor and helmets worn in combat theaters. This limitation suggests that the data provided here may overestimate performance compared to actual combat environments. Finally, this study did not account for the effect of prior training in combat scenarios.

Areas of Future Research

Rigorous training in realistic and varied simulated combat scenarios will be necessary to fully characterize the effects of pseudo-combat training on performance before deployment into combat zones and subsequent performance in combat situations. Although running across irregular terrain and applying a tourniquet while ducking simulated fire was a solid first step in simulating realism, delivering medical care in combat can require the proper execution of skills in hostile environments that may also include noise, darkness, snow, rain, temperature extremes, sandy wind, and fatigue. It is important to follow trainees long-term to determine the efficacy of simulated combat scenario training on tourniquet application performance in actual combat.

It is important to contrast the effects of self-aid versus buddy-aid in tourniquet application training. The present study was buddy-aid, with a second individual applying the tourniquet. However, in combat, each soldier carries a tourniquet, such as the CAT or SOFT-T, and has been trained to self-apply the device if the situation warrants. Tourniquet application can be quite painful, which may limit the efficacy of windlass style tourniquets in self-aid, an open empirical question for future research. Our understanding of tourniquet

efficacy would be greatly enhanced if trauma registries captured whether tourniquets were applied by self-aid, by buddy-aid, by HM/Medic, or by nonmedical personnel.

We need to continually improve our combat tourniquets. Although current tourniquet products have had an enormous impact on mortality, there still remain preventable deaths from extremity hemorrhage.[5] Present results overall parallel other studies findings of an unacceptably high rate of tourniquet failure. An ideal battlefield tourniquet would be small, light, easy to use, easy to self-use, highly reliable, highly effective, and regardless of the compact configuration for storage, an effective tourniquet must be wide. Pneumatic tourniquets may have important practical advantages if the limitations of pneumatic designs can be effectively and cost-effectively overcome. Regulating pressure effectively may be easier with a valved cuff than with a stick that can only be secured in a limited range along a single axis. Further, hospitals routinely use pneumatic tourniquets, similar to blood pressure cuffs, to create bloodless fields for surgeries, even though windlass technology is available. A useful design for combat application must balance the tradeoff of the advantage of increasing width with the disadvantage of increasing bulk and weight. Just as the windlass designs are subject to decay in combat environments,[12,13] pneumatic designs may be challenged by exposure to dirt, heat, cold, or puncture, and significant altitude changes, which can expand the air in the cuff, increasing pressure and possibly damaging tissue. A preclinical study comparing the Emergency and Military Tourniquet (EMT), a pneumatic tourniquet, to the CAT found that the CAT occluded popliteal artery flow in only 12.5% of subjects while the EMT was 100% successful.[2] The EMT has been shown to be 92% effective in actual combat,[3] showing the potential of pneumatic designs towards 100% preservation of salvageable life on the battlefield. However, it is important to note that the application of two CAT tourniquets effectively doubles the width of the CAT to match the EMT width and also shows 92% effectiveness[2,3] suggesting that it may be width, not the choice of pneumatic or windlass mechanism, that largely determines tourniquet efficacy.

CONCLUSION

Findings highlight the important role of training in fast, accurate, and effective application of prehospital tourniquet above the knee, and validate performance declines evident under simulated combat. Results supported the hypothesized effects of training and simulated combat. The wider CAT was more quickly and effectively applied than SOFT-T, but overall findings suggest that the inherent efficacy of tourniquet products contributes to high tourniquet failure rates under actual combat conditions, pointing to the need for superior tourniquets for combat use and to the need for rigorous deployment preparation training in simulated combat scenarios.

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