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Comparison of Two Tourniquets on a Mid-Thigh Model: The Israeli Silicone Stretch and Wrap Tourniquet vs. The Combat Application Tourniquet

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ABSTRACT Introduction: Experience from recent conflicts underlines the dramatic impact of effective tourniquet use on combat casualty mortality. Although the Combat Application Tourniquet (CAT) is replacing the silicone band tourniquets (IST; "Israeli Silicone Tourniquet") in the Israeli Defense Forces, no direct comparison was made between them. The purpose of this study is to compare the performance of the two tourniquets on a mid-thigh model. Methods: Participants were Israeli military recruits who previously had the military first aid course. Each participant applied both the CAT and the IST. Applications were assessed by the HapMed Leg Tourniquet Trainer, which measured the applied pressure and the time required to reach it. Results: IST application resulted in higher rates of effective occlusion pressure compared with the CAT (91% vs. 73.1%, $p < 0.01$), and a higher mean occlusion pressure (41 mmHg, $p < 0.01$) was recorded using the IST. Among effective attempts, application time did not differ significantly between the tourniquets. Conclusion: The IST was superior to the CAT in producing effective occlusion pressure while not prolonging application time. These results may indicate that the IST remains a valid option for controlling mid-thigh bleeding.

INTRODUCTION

Hemorrhage is a major preventable cause of mortality on the battlefield, responsible for over 90% of deaths.[1–4] Analyses of injury type and severity in recent conflicts revealed an increased occurrence of severe limb injuries resulting in hemorrhage-related death.[5,6] Moreover, proximal limb injuries and amputations represent an increasing proportion of the surgical workload of adjacent military hospitals.[7] Tourniquets have evolved over the years from improvised instruments such as slings or belts into commercially designed devices.[8] Such tourniquets are designed to control hemorrhage, thereby reducing morbidity and fatality rates if applied early and properly in the pre-hospital setting.[9,10] Consequently, correct use of advanced tourniquets has become a fundamental skill taught in both civilian and military emergency care courses worldwide.[11]

The Israel Defense Forces (IDF) has incorporated two types of tourniquets. The "Israeli Silicone Tourniquet" (IST) was introduced in the 1980s and works according to the "stretch and wrap" principle. Following its successful use by physicians and combat medics, it was later issued to every combat soldier. The Combat Application Tourniquet[12] (CAT; Composite Resources, Rock Hill, SC, USA), recommended for use by the United States Armed Forces according to the Committee of Tactical Combat Casualty Care,[8,12,13] was adopted by the IDF in 2012 and was chosen as the preferred tourniquet. Recently, concerns have been raised regarding the ability of narrow windlass tourniquets (such as the CAT) to control hemorrhage when applied at the mid-thigh level.[14,15] We therefore sought to compare the efficacy of the CAT tourniquet in producing occlusive pressures with that of the IST, using a simulated mid-thigh application.

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METHODS

Tourniquet

Two types of tourniquets were compared, the CAT and the IST. The CAT is 38-mm wide and uses a Velcro strap and a plastic buckle combined with a windlass system (Fig. 1). The windlass system tightens an internal band to provide circumferential pressure to the limb. The IST is composed of a 200-cm-long and 65-mm-wide elastic silicone band. This tourniquet is wrapped and stretched circumferentially around a limb in order to produce supra-arterial pressure (Fig. 2).

Simulation Model

The HapMed Leg Tourniquet Trainer (CHI Systems, Fort Washington, PA) is a mannequin simulating an amputation injury proximal to the knee (Fig. 3). This mannequin is an accepted model for tourniquets studies and inspections.[16,17] The medial hip-pelvic area of the leg trainer has an embedded computer with a touch screen and is operated by input entered to the mannequin's software (version 1.12). The HapMed Leg

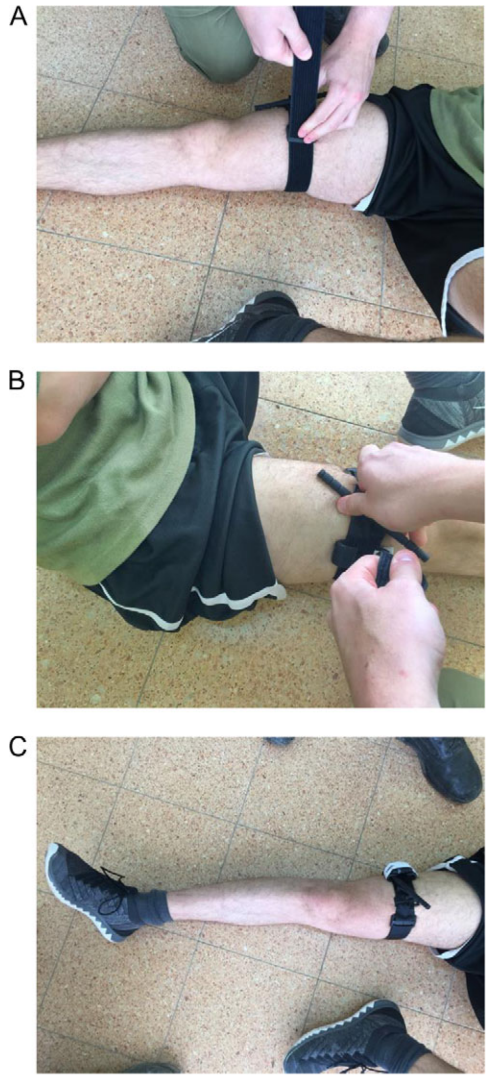

FIGURE 1. CAT application. (A) The tip of the strap is passed into the slit of the buckle and the tourniquet is pulled tightly. (B) The rod is twisted to create a higher pressure around the limb, (C) The rod is placed inside the clip of the tourniquet to secure it.

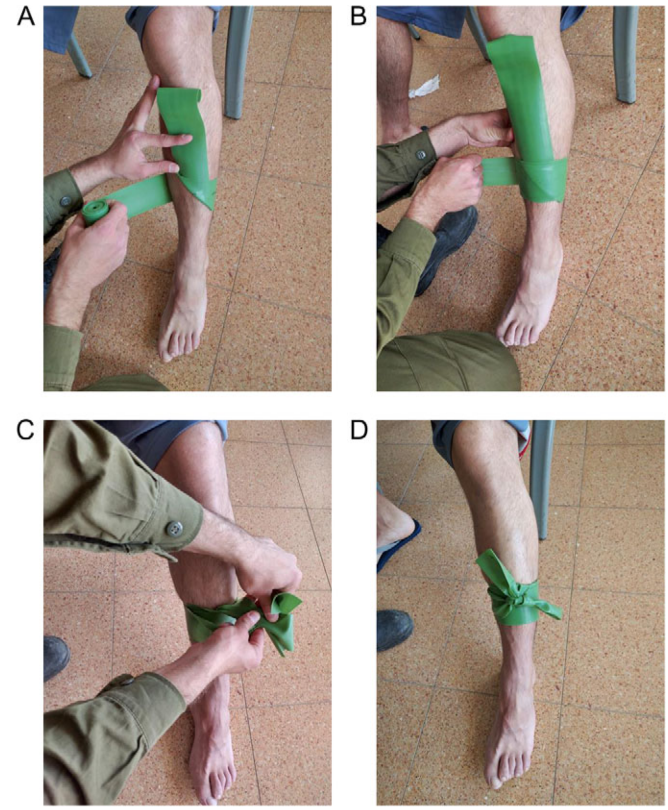

FIGURE 2. IST application. (A) A tail of approximately 30 cm should remain outside the first lap. This lap should be made loosely around the limb to avoid skin damage. (B) The following wraps are performed following the "stretch and wrap" principle, so after each round, the silicone is pulled and tightened. (C and D) The distal end of the strap is tied to the 30-cm tail, which was left outside the wrapping at the beginning.

FIGURE 3. The HapMed Leg Tourniquet Trainer (CHI Systems, Fort Washington, PA) simulates an amputation injury proximal to the knee. The trainer contains a computer with touch screen and is operated according to input entered by the operator. The trainer senses pressure applied by a tourniquet and can provide feedback accordingly.

Trainer senses pressure applied by a tourniquet and can provide trainees feedback on whether the tourniquet was successfully applied to control active bleeding. The mannequin was placed on the ground with blood-like fluid to simulate active bleeding.

Study Design and Population

This study was an observational study conducted without intervention. Given that the study was voluntary and mannequin-based, the IDF-MC Institutional Review Board granted this study as exempt from review. Investigators were physicians from the IDF-MC and highly competent in application of CAT and IST tourniquets. The study was conducted in accordance with good clinical practice principles.

Male soldiers who were recruited to active service in August 2014 from two randomly selected platoons were studied. All had graduated the IDF-MC's first aid course 1–3 mo before the study. This course is part of the standard combat basic training and includes, *inter alia*, 3.5 hours of hemorrhage control classes. Tourniquet application is one of the basic certifications required for the graduation of combat training in the IDF. During the course of training, each soldier has to train at least 12 times with CAT application and five times with the IST application. Training for both is performed on a fellow soldier's limb. One important point that is emphasized to soldiers who participated in the training is the importance of tightening the tourniquet as much as possible, as battlefield conditions might not allow for bleeding cessation confirmation. The application's effectiveness was determined by the absence of a distal pulse, assessed by an instructor. Instructors in the first aid course are medics who graduated a 4-week instructors' course in the School of Military Medicine, IDF-MC.[18] None of the participants had prior experience with the HapMed Leg Tourniquet Trainer.

Before initiation of the study, each participant was briefed by one of the investigators. Instructions included how to hold the tourniquet (CAT or IST) and how to apply it on an amputated casualty (simulated by the HapMed). Verbal consent was obtained from all participants. Each participant was led to the trial zone in order to avoid cross-learning between participants. There was no simulated tactical threat, and the participants, while equipped with weaponry and protective gear, did not perform any rigorous physical activity before the assessment.

Each participant applied both types of tourniquets, the first being the CAT, followed by the IST. Participants were not allowed to consult the investigator during application and were given only one attempt at applying the tourniquet. The investigator confirmed the tourniquet's integrity and functionality after each and every use. Each CAT device was only used twice then replaced with another. After the trial, participants were asked to fill an anonymous short three-question survey that assessed their experience (Appendix 1). Two questions were based on ease of application of the tourniquet on a 10-point Likert scale, 1 being easiest and 10 most difficult. The third question addressed the participant's tourniquet preferences. Survey sheets were collected immediately upon their completion.

Data Collection and Analysis

Parameters evaluated included application time, the time interval from the moment the investigator directed the participant to start until the latter declared he was done, applied pressure, the pressure sensed by the mannequin right after the investigator pressed the touch pad to end the trial, and effective occlusion, considered as an attempt in which the applied pressure reached at least 200 mmHg.

Data were analyzed using SPSS V23 software (IBM Inc.). Variables were tested for normality using the Shapiro–Wilk test. Comparison of continuous variables was performed using the Wilcoxon test. Comparisons of categorical variables were performed using McNemar's test. All variables were found to significantly deviate from normal distribution, except from the time of effective stoppage of the bleeding with the IST. Therefore, non-parametric tests were used.

RESULTS

A total of 78 participants applied both tourniquets. Table I summarizes their performance. The IST was significantly more effective than the CAT in producing effective occlusion pressure (91% vs. 73%, respectively, $p = 0.007$) and also provided a median occlusive pressure, which was 44 mmHg higher ($p < 0.001$). The median occlusive pressure only among the attempts in which effective occlusion pressure was reached remained significantly higher with the IST. Although the CAT device was found to be less effective in terms of occlusion, 69.2% of participants preferred the CAT over the IST, and found it easier to use ($p = 0.006$).

Table 2 demonstrates the effect of the elapsed time since the first aid course on the tourniquets' application success rate. Participants who underwent the first aid course within 1 mo of the study had significantly higher success rate in applying the CAT than their counterparts with longer intervals since course participation (50/63 [79.4%] vs. 7/15 [46.7%], $p = 0.01$). Conversely, the time elapsed from the course did not influence the IST application success rate.

DISCUSSION

This study demonstrates that the IST was superior to the CAT in producing effective occlusion pressure on a modeled thigh

TABLE I. Performance and Difficulty Assessment

	CAT	IST	*p*-Value
Maximal pressure, median (range), mmHg	217 (0–385)	261 (153–505)	**<0.001**
Effective occlusion, *n* (%)	57 (73.1)	71 (91.0)	**0.007**
Maximal pressure among effective attempts, median (range), mmHg	228 (201–385)	271 (201–505)	**<0.001**
Time to effective occlusion (among effective attempts), seconds (range)	27 (11–90)	33 (5–74)	0.58
Difficulty 1–10 scale, median (range)	2 (1–8), mean 2.3	2 (1–9), mean 2.8	**0.006**

Note: The Number under the p-value column provides the significance. The bold values are the statistically significant.

TABLE II. Effect of Elapsed Time Since First Aid Course on Success Rate

	Experience More Than 1 mo (*n* = 15)	Experience Equal to or Less Than 1 mo (*n* = 63)	*p*-Value
Succeeded with CAT, *n* (%)	7 (46.7)	50 (79.4)	**0.01**
Succeeded with IST, *n* (%)	14 (93.3)	57 (90.5)	0.59

Note: The Number under the p-value column provides the significance. The bold values are the statistically significant.

without significantly increasing the time of application. Ninety one percent of participants achieved effective occlusion pressure with the IST compared with 73.1% with the CAT. Our findings negate the common belief that windlass tourniquets, such as the CAT, are superior for controlling bleeding in thigh injuries.[19] Recently, reports studying the ability of CAT to control bleeding in proximal mid-thigh applications have suggested that the CAT was relatively ineffective in controlling arterial blood flow.[20] Furthermore, when the CAT efficacy was evaluated experimentally in a human model by Doppler ultrasound measuring the distal arterial flow, the success rate in controlling thigh bleeding was 78%,[21] similar to the rates in the current study. Observational analysis of battlefield injuries showed an overall similar success rate when applied in different anatomic regions, but with lower rates seen when examining mid-thigh region applications alone.[14] Vice versa, a retrospective observational study by Lakstein et al compared the Improvised Russian Tourniquet (an improvised tourniquet based on a windlass system) with the IST and found the first to be more effective in controlling thigh bleeding.[19] However, it is difficult to directly compare between these results with those reported in the current report, as Lakstein's study documented tourniquet applications in live wounded patients, whereas ours was conducted in a "sterile" environment with a mannequin. Moreover, the Improvised Russian Tourniquet and other improvised tourniquets are difficult to compare with the CAT, as there is a wide variance in their fabrication and application.

The pressure required to occlude a bleeding vessel by a tourniquet increases with limb circumference.[22,23] As the mid-thigh region is rather wide, sufficient pressure is needed in order to control bleeding. The higher occlusion pressures reached with IST may be critical in this regard. Additionally, tourniquet width is also an important factor, with a wider tourniquet being able to provide higher efficacy in occluding distal pulses at a given occlusion pressure.[22,24] As the IST is 27 mm wider than the CAT, this feature may be a relative advantage, especially in the challenging region of the mid-thigh.

CAT's effectiveness is proved to be influenced by the time passed since the last training with the tourniquet.[11,18] This is demonstrated in the study with a clear skill decay with CAT usage. The same was not apparent with the IST. A study examining the reasons for CAT application failure 7–14 d following the training found that forgetting how to use the CAT was among the leading causes of failure.[17] The rapid decline in the ability to use the CAT is alarming and may warrant more frequent training.

This study has several limitations. First, the study was performed using a mannequin model in a "sterile" environment with the CAT applied first and then the IST. The model is composed of a single limb without an attached body and therefore does not fully simulate applying a tourniquet to a human in battlefield conditions. However, the mannequin model does allow accurate measurements and comparison of occlusion pressures.[18] As the study focus was to compare occlusion pressures while excluding potentially confounding components that affect tourniquet efficacy that may exist on battlefield, this model was ideal. Regarding the order of applications, as all participants applicated the two tourniquets dozens of times before during their recent first aid training and were thoroughly instructed on using the HapMed before the study, we assume that the success of a single additional application was not influenced by participants' learning curve. Second, in order to define an effective application, we used the threshold criteria of 200 mmHg. Clearly, there is no standard tourniquet application pressure to control bleeding. However, this threshold has been used previously and considered reliable for estimating tourniquets' application performance. Third, the mannequin model does not asses tissue damage, which might be a consequence of tourniquet application. This concern might be especially relevant when considering the high pressures that can be reached with the IST (up to 505 mmHg). However, neurological complications were found to be a rare side effect after tourniquet application and should not prevent tourniquet use when indicated.[14,19] Lastly, the participants in this study were all from the same infantry base and were trained together in the same setting and by the same instructors. Nevertheless, the same tourniquet training is given uniformly to every combat soldier as part of the basic training. Additionally, the soldiers' population was heterogonous in terms of socioeconomic background and intelligence level and therefore allows our findings to be generalized to a wider population.

CONCLUSION

This study demonstrated that the IST was superior to the CAT in producing effective occlusion pressure when applied at the mid-thigh region on a mannequin model while not impacting application time. Given these findings, it might be reasonable to reconsider the role of the IST, especially when used by soldiers who lack sufficient training. Further studies comparing tourniquets efficacy in larger populations are warranted in order to provide a definite answer regarding the best tourniquet application strategy.

PRESENTATIONS

Accepted for the Young Investigator (YI) plenary presentation of the 2016 Military Health System Research Symposium (abstract number: MHSRS-16–1123).

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