

# Slack Reducing Band Improves Combat Application Tourniquet Pressure Profile and Hemorrhage Control Rate

CAPT Dean Nachman, MC IDF<sup>1</sup>; MAJ Avi Benov, MC IDF<sup>1</sup>; MAJ Amiram Shovali, MC IDF;  
MAJ Yavnai Nirit, MC IDF; CAPT Roy Nadler, MC IDF; LT Yitzhak Avraham, MC IDF;  
COL Elon Glassberg, MC IDF

**ABSTRACT** Background: The Combat Application Tourniquet (CAT) is the tourniquet of choice in the Israeli defense forces. Applying the device loosely before windlass twisting is a main pitfall in CAT application. This study objective is to assess the effectiveness of a novel design modification of the CAT, aiming to prevent loose applications, by minimizing the slack. Methods: Using the HapMed leg tourniquet trainer, an above the knee traumatic amputation was simulated. Active duty combatants and Special Forces basic medics were randomly assigned to apply the modified ( $n = 67$ ) or conventional CAT ( $n = 65$ ) once. Applied pressure, hemorrhage control status, time to stop the bleeding, and estimated blood volume loss were measured. Results: Using the modified CAT, the mean ( $\pm$ SD) pressure applied was significantly higher compared to the conventional one ( $231.49 \pm 37.84$  mm Hg vs.  $213.31 \pm 45.51$  mm Hg,  $p < 0.05$ ). Hemorrhage control rate was 86.6% in the modified CAT group versus 67.7% in the conventional CAT group ( $p < 0.05$ ). Analyzing only the applications that succeeded in hemorrhage control, blood loss ( $171.12 \pm 72.43$  mL vs.  $187.75 \pm 91.72$  mL,  $p > 0.05$ ) and time to stop bleeding ( $27.27 \pm 13.15$  seconds vs.  $27.5 \pm 11.25$  seconds,  $p > 0.05$ ) were similar. Conclusions: The modified CAT demonstrated an upgraded pressure profile and hemorrhage control rate, potentially indicating its improved efficacy.

## INTRODUCTION

Deaths resulting by injuries that are potentially survivable in the battlefield are mainly the result of hemorrhage, with trauma to the extremities being a major cause.<sup>1</sup> Tourniquets have been used since the days of ancient Greeks, some two millennia ago,<sup>2</sup> but their usage has been subjected to various controversies concerning their safety and effectiveness ever since.<sup>3</sup> In recent years vast research led to profound improvements in tourniquet design and application methods, leading to the introduction of modern tourniquets to the battlefield.<sup>4</sup> Substantial experience with tourniquet application have been gained by military personnel in recent military conflicts, demonstrating improvement in mortality rates of soldiers suffering major limb injury, with relatively minimal morbidity.<sup>3,5-8</sup> It has been estimated that tourniquets saved the lives of 1,000 to 2,000 U.S. military personnel during “Operation Enduring Freedom” and “Operation Iraqi Freedom.”<sup>9</sup>

Recent increase of violence acts in a civilian setting, such as firearms shooting and explosions, highlights the need for implementing insights from treating mass trauma casualties in the battlefield to the civilian sector.<sup>10</sup> The Hartford consensus recommendations, issued after several active shooting events, stress the importance of early hemorrhage control in mass casualty events, even by unexperienced laypersons.<sup>11</sup>

Thus, in addition to the obvious need in battlefield trauma care, it is essential to provide laypersons and novice first responders an effective and intuitive means for hemorrhage control.

One of the most commonly used tourniquets is the 38-mm-wide, windlass and band designed Combat Application Tourniquet (CAT; Composite Resources, Rock Hill, SC). The CAT is the only advanced tourniquet used by the Israel Defense Forces (IDF),<sup>12</sup> and is widely issued to deployed U.S. soldiers.<sup>13</sup> Despite the importance of hemorrhage control, there is a lack of actual data on tourniquet effectiveness arising from the battlefield. A prospective survey of casualties from the Iraqi campaign demonstrated a success rate of 79% to the CAT, which achieved the highest rate among all prehospital tourniquets,<sup>5</sup> whereas a more recent study from the campaign in Afghanistan found that in 83% of the CAT applications distal pulses were present, indicating ineffectiveness.<sup>14</sup> As a result of several after-action reports of failed CAT applications in the IDF, we conducted a study (data not published) aiming to identify the specific flawed phase in CAT application, leading to device ineffectiveness. It was found that the leading cause to failure was applying the device loosely, i.e., not pulling the band tight enough before windlass twisting. This finding matches reports by others, who have also demonstrated the importance of slack reduction for an effective application.<sup>15,16</sup> Insufficient slack reduction leads to an ineffective windlass twist, not compressing the limb despite further twisting. Furthermore, excess windlass twists might cause the CAT to roll and even brake.<sup>4,13</sup>

The purpose of the present study was to assess the effectiveness of a novel modification in the design of the CAT, aiming to minimize slack and improve applied pressure.

Israel Defense Forces Medical Corps, Surgeon General's Headquarters, Military POB 02149 Tel Hashomer, Ramat Gan, Israel, Military Postal Code 01215.

<sup>1</sup>These authors contributed equally to the manuscript and are co-first authors.

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## METHODS

### Study Design

This cross-sectional randomized study was granted a waiver by the Institutional Review Board of the IDF Medical Corps and was conducted in accordance with the guidelines of good clinical practice.

### Modified CAT

To address the tightening phase insufficiency, we have developed a novel modification of the CAT, by adding a band designed to reduce the slack (Figs. 1A and 1B). The ad on band is attached to the buckle of the CAT, allowing slack to be minimized, by pulling it to the counter direction of the original band after the last pass through the buckle. The rest of the application of the modified CAT was identi-

cal to the application of the conventional one. It is of importance to highlight that the modified CAT is an investigational modification, and that it has not been reviewed by any regulatory administration.

### HapMed Manikin

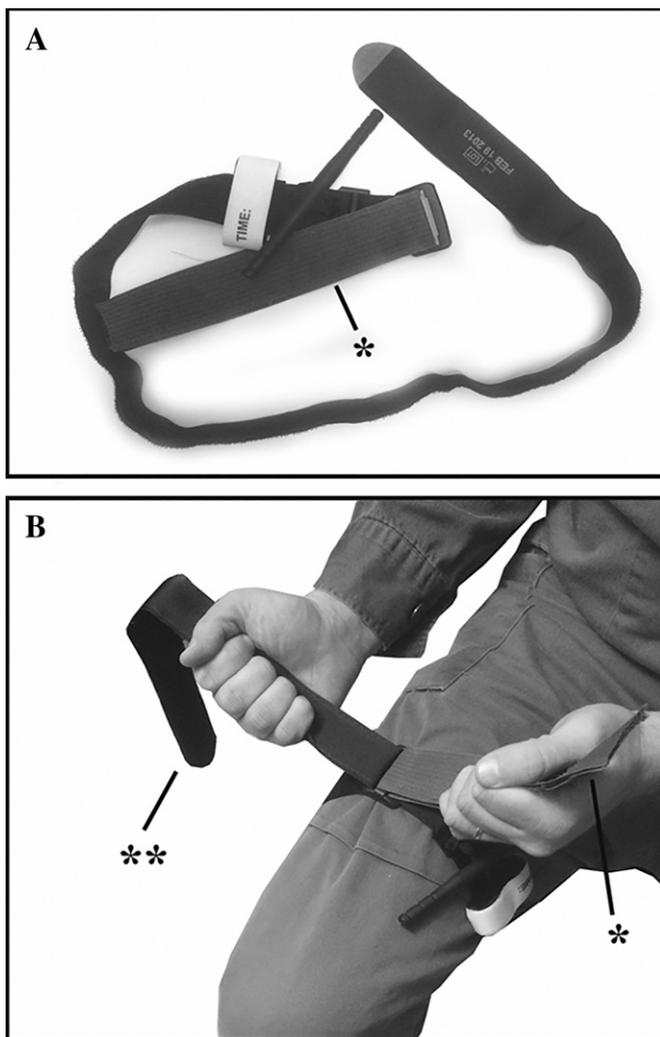
The HapMed Leg Tourniquet Trainer (CHI Systems, Fort Washington, PA) is a manikin simulating a bleeding amputation, proximal to the knee of the right thigh. The trainer has the ability to collect performance statistics such as time of application, time to stop bleeding, applied pressure, blood loss volume, and hemorrhage control status. The HapMed manikin was used in the last few years in several studies, examining tourniquet efficiency.<sup>16,17</sup> This study used injury scenario one, i.e., a casualty with a small build.

### Study Population and Setting

Tourniquet testing was performed by a total of 132 participants; all were active duty males, 18–21 years old. Sixty-one participants were combatants during basic military training (combatants group). Seventy-one participants were basic medics from the Special Forces of the IDF. Among them, 39 were 1 week after the completion of combat medic training course (Emergency Medical Technician Basic [EMT-B] beginners group), and 32 had additional 17 weeks of rigorous “in-unit” medical training (EMT-B advanced group). After completion of a short questionnaire regarding previous experience with tourniquet application and estimation of self-efficiency in a scale of 1 (the lowest) to 10 (the highest), the participants were block randomized to either modified ( $N = 67$ ) or conventional ( $N = 65$ ) CAT application, according to their previous medical training. Each group received an identical predefined explanation regarding the HapMed manikin and correct application of the modified or conventional CAT, respectively. Following the short explanation, all assigned participants applied the modified or conventional CAT once, as described in section “Study Protocol.”

### Study Protocol

The participants stood 10 ft (3 m) away from the HapMed manikin, with a CAT tourniquet held in their hand, so that the buckle of the CAT is free. The manikin was fixed on a table and the participants were given a start notification to begin CAT application. After applying the tourniquet, the participants announced the examiner when to stop the clock. Performance statistics was collected at the end of every application from the electronic controller of the HapMed. Participants were blinded to the specific investigated outcome variables, and were instructed to apply the tourniquet to the best of their ability to stop the bleeding. In addition, all the participants assigned to the modified CAT group, who also had previous experience with a conventional CAT, answered a preference questionnaire. Participants from the conventional CAT group were not requested to



**FIGURE 1.** The modified CAT with slack reducing band. (A) Photograph shows the CAT with the ad on slack reducing band (\*) attached to the buckle. (B) Photograph showing application of the modified CAT by pulling the slack reducing band (\*) to the counter direction of the CAT's original band (\*\*).

answer the preference questionnaire, since they were not experienced with the modified CAT.

### Sample Size Calculation

The study was designed to identify a 20 mm Hg increase of applied pressure. A sample size of 126 participants was calculated using WINPEPI (version 11.53, 2015; Brixton Health, Stone Mountain, Georgia), with a power of 80%, significance level of 5%, and SD of 40 mm Hg that was estimated from previous studies we have conducted on similar populations.

### Statistical Analysis

Descriptive statistics are presented as means and SD. Continuous data were compared using two-tailed Student's *t* test for independent groups. Pearson's  $\chi^2$  was used to compare parametric data. Correlation was assessed using Pearson's correlation coefficient. The probabilities of observing chance effects on the dependent variables of interest are presented as *p* values, with significant level set at 0.05.

## RESULTS

The CAT was applied by all 132 participants. The mean number of previous applications of the CAT ( $\pm$ SD) was 11.88 ( $\pm$ 15.14) for all participants, with no statistically significant difference between the conventional and the modified CAT groups (12.62  $\pm$  15.46 vs. 11.09  $\pm$  14.88, respectively, *p* > 0.05). The EMT-B advanced group had significantly more experience with CAT application relative to the combatants and EMT-B beginners group (28.27  $\pm$  5.11, 4.48  $\pm$  2.97, 4.33  $\pm$  0.95, respectively, *p* < 0.0001) (Table I).

Estimation of self-efficiency was evaluated using a scale of 1–10: 1–3 was considered low, 4–7 medium, and 8–10 high. Since only three participants had a self-efficiency estimation in the low group, we united the low and medium groups. A total of 69.7% of all participants had a high self-efficacy estimation, with no statistically significant difference between the conventional and modified CAT groups (72.3% vs. 67.2%, *p* > 0.05) (Table I). Participants with low

self-efficiency estimation achieved a pressure of 225.11  $\pm$  39.9 mm Hg, whereas participants with high self-efficiency estimation achieved a pressure of 221.32  $\pm$  44.7 mm Hg, that is to say that no relation was found between self-efficiency estimation and mean applied pressure.

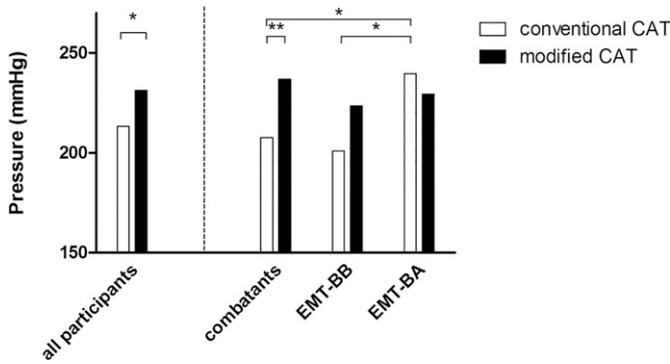
The combined mean applied pressure of all the subgroups using the modified CAT was significantly higher compared to the conventional CAT (231.49  $\pm$  37.84 mm Hg vs. 213.31  $\pm$  45.51 mm Hg, *p* < 0.05) (Fig. 2, Table II). In a subgroup analysis, the mean pressure applied by the conventional CAT was significantly higher in the EMT-B advanced group than the combatants group or the EMT-B beginners group (239.8  $\pm$  46.68, 207.81  $\pm$  41.1, 201.19  $\pm$  44.28 mm Hg, respectively, *p* < 0.05). Furthermore, the mean applied pressure using the modified CAT was significantly higher compared to the conventional CAT in the combatants group (237.17  $\pm$  32.57 vs. 207.81  $\pm$  41.1, *p* < 0.01), and a similar trend was identified in the EMT-B beginners group (223.61  $\pm$  35.2 vs. 201.19  $\pm$  44.28, *p* = 0.09). In contrast to the less trained subgroups, the EMT-B advanced group reached similar pressure values with both the conventional and the modified CAT (239.8  $\pm$  46.68 mm Hg vs. 229.6  $\pm$  49.68 mmHg, respectively). Of importance, when using the modified CAT, participants from both the combatants and the EMT-B Beginners subgroups reached high pressure values, similar to the EMT-B advanced group. That is to say, that insufficient previous training had no ameliorating effect once the modified CAT was used. Seven participants, four from the modified CAT group and three from the conventional CAT group, were excluded from the statistical analysis of the applied pressure because of a basic misunderstanding regarding the application of the CAT, such as skipping the windlass twisting phase, leading to 0 mm Hg applied pressure. Previous application number was positively correlated to applied pressure (*p* < 0.01) using the conventional CAT, but there was no such correlation using the modified CAT.

Tourniquet hemorrhage control rate for the modified CAT was significantly higher than with the conventional one (86.6% vs. 67.7%, *p* < 0.05) (Fig. 3, Table II). A similar trend was demonstrated in a subgroup analysis of the

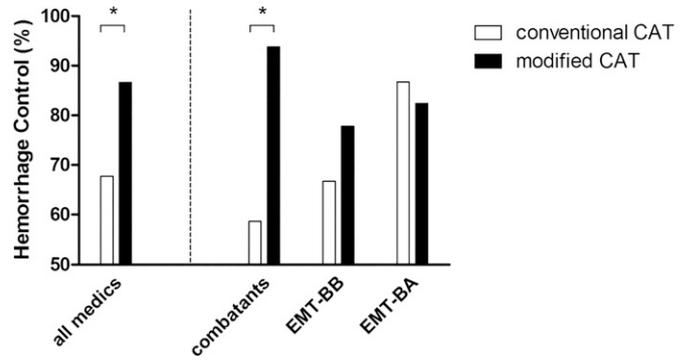
**TABLE I.** Characteristics of the Participants Applying the Tourniquets

Group	No. of Participants	Participants applying the Modified CAT N (%)	Previous CAT Applications (Mean $\pm$ SD)	High Self-Efficiency Estimation N (%)
All participants	132	67 (50.75)	11.88 $\pm$ 15.14	92 (69.7)
Conventional CAT	65	0 (0)	12.62 $\pm$ 15.46	47 (72.3)
Modified CAT	67	67 (100)	11.09 $\pm$ 14.88	45 (67.2)
Combatants	61	32 (52.45)	4.48 $\pm$ 2.97	34 (55.7)
EMT-B Beginners Group	39	18 (46.15)	4.33 $\pm$ 0.95	36 (92.3) <sup>b</sup>
EMT-B Advanced Group	32	17 (53.12)	28.27 $\pm$ 5.11 <sup>a</sup>	22 (68.7)

CAT, Combat Application Tourniquet; EMT-B B, Emergency Medical Technician-Basic Beginners group; EMT-B A, Emergency Medical Technician-Basic Advanced group, N, Number. <sup>a</sup>*p* < 0.0001 relative to combatants and EMT-B B (Student *t* test). <sup>b</sup>*p* < 0.05 relative to combatants and EMT-B A (Pearson's  $\chi^2$  test).



**FIGURE 2.** Mean applied pressure by the conventional and modified CAT. \* $p < 0.005$ , \*\* $p < 0.01$  (Student  $t$  test). CAT, Combat Application Tourniquet; EMT-B B, Emergency Medical Technician-Basic Beginners group; EMT-B A, Emergency Medical Technician-Basic Advanced group.



**FIGURE 3.** Tourniquet hemorrhage control rate by the conventional and modified CAT. \* $p < 0.005$  (Pearson's chi-square). CAT, Combat Application Tourniquet; EMT-B B, Emergency Medical Technician-Basic Beginners group; EMT-B A, Emergency Medical Technician-Basic Advanced group.

combatants and EMT-B beginners groups, but not in the EMT-B advanced group.

Analyzing only the applications that achieved hemorrhage control, there was no statistically significant difference found between the modified and conventional CAT groups in time to stop bleeding ( $27.5 \pm 11.25$  seconds vs.  $27.27 \pm 13.15$  seconds, respectively) and volume of blood loss ( $187.75 \pm 91.72$  mL vs.  $171.12 \pm 72.43$  mL, respectively).

All the participants applying the modified CAT ( $n = 67$ ) completed an additional survey after the application of the modified CAT, regarding their preferred tourniquet, conventional or modified. There was a clear preference of the modified device, with 97% ( $n = 65$ ) of the participants preferring it over the conventional CAT.

**DISCUSSION**

Tourniquet application is an essential, lifesaving skill that is taught by many different organizations worldwide. The CAT tourniquet has a track record as a lifesaver in battlefield trauma; however its effectiveness is greatly influenced by the previous training and experience of the applicator.<sup>18</sup> In the IDF, the CAT is issued to all front line medical personnel and combatants, a heterogenic population with variable training in bleeding control and CAT application.<sup>12</sup> In this

study, the combatants and EMT-B represent the point-of-injury first responders to battlefield trauma. This less trained population was the one to apply the majority of the tourniquets during recent conflicts, and therefore improving their CAT application effectiveness is a major concern.<sup>19,20</sup> This concern will probably be accentuated in future battlefields of urban environments, in which evacuation and advanced medical treatments might be delayed, leaving fellow combatants to provide point-of-injury bleeding control.

In the present study, we tested the effect of a modification of the CAT, which addresses slack reduction, a major drawback in CAT application. Applied pressure was selected as a main measure, since the pressure applied by a tourniquet is a major determinant for effective arterial occlusion, alongside tourniquet width that is fixed and limb girth that varies greatly between soldiers, leaving applied pressure as the only user-dependent variable.<sup>21</sup> The modified CAT, in comparison with the conventional CAT, allowed an 18.18 mm Hg improvement in mean applied pressure, almost similar to our predefined goal of an increase of 20 mm Hg. This improvement in applied pressure translates to an 18.9% increase in hemorrhage control rate, in the specific HapMed trainer scenario. A subgroup analysis revealed that the

**TABLE II.** Applied Pressure and Hemorrhage Control Rate by the Conventional and Modified CAT

Group	Mean Applied Pressure $\pm$ SD	Hemorrhage Control (%)
Conventional CAT, Overall	213.31 $\pm$ 45.51	67.7
Modified CAT, Overall	231.49 $\pm$ 37.84 <sup>a</sup>	86.6 <sup>a</sup>
Combatants Conventional CAT	207.81 $\pm$ 41.1	58.6
Combatants Modified CAT	237.17 $\pm$ 32.57 <sup>b</sup>	93.8 <sup>b</sup>
EMT-B Beginners Group Conventional CAT	201.19 $\pm$ 44.28	66.7
EMT-B Beginners Group Modified CAT	223.61 $\pm$ 35.2	77.8
EMT-B Advanced Group Conventional CAT	239.8 $\pm$ 46.68 <sup>c</sup>	86.7
EMT-B Advanced Group Modified CAT	229.6 $\pm$ 49.68	82.4

CAT, Combat Application Tourniquet; EMT-B B, Emergency Medical Technician-Basic Beginners group; EMT-B A, Emergency Medical Technician-Basic Advanced group, N, Number. <sup>a</sup> $p < 0.001$  relative to conventional CAT group. <sup>b</sup> $p < 0.01$  relative to combatants with conventional CAT group. <sup>c</sup> $p < 0.05$  relative to combatants and EMT-B B with conventional CAT (Student  $t$  test for mean applied pressure, Pearson's  $\chi^2$  for tourniquet effectiveness).

modified CAT had a substantial positive contribution to the ability of less experienced groups (the combatants and EMT-B beginners) to effectively apply the CAT. Such an effect was not demonstrated among the experienced group (the EMT-B advanced). That is to say, the modified CAT upgraded the pressure applied by combatants and EMT-B beginners to the level of the EMT-B advanced group, compensating for the differences in previous training and the complete lack of experience in the application of the modified CAT.

Surprisingly, while the application of the modified CAT was the first experience of the participants with this device, time to stop bleeding and blood loss were similar in both CAT types. The applications that did not stop the bleeding were excluded from this analysis, because time to stop bleeding is not relevant if bleeding had not stopped, and the volume of the blood loss is greatly influenced by the interaction of the user with the manikin. An application that has not reached hemorrhage control could lead to a very low blood volume loss if the participant decides to stop the application after a very short period of time. These results emphasize that the modification had not compromised the straightforward application flow of the CAT. In addition, a clear preference for the modified CAT over the regular one was shown among the participants who applied it. These results emphasize the potential of this intuitive modification, especially when applied by the less trained first responders, on whom we trust to perform lifesaving point-of-injury bleeding control.

A secondary conclusion arising from our findings is that, interestingly, the estimation of self-efficacy was not associated with the effectiveness of the application. This suggests that major personality confounders influence this variable and that the participants are unaware of their real capabilities. Integration of manikins with performance feedback during the training process might reduce this gap in self-awareness, leading to better training and application performance.

The present study has several limitations. Indeed, using the HapMed manikin to simulate above the knee amputation and bleeding allows for reproducibility, objective readings of physical and physiological parameters, and fewer ethical concerns. On the other hand, applying the CAT on a manikin does not simulate the physical and physiological variability of actual thigh amputations, such as blood loss, which is an extrapolated calculation made on the basis of the time of application and applied pressure. Furthermore, the settings of the study did not include a simulation of the stressful battlefield environment. Our study protocol allowed only one application attempt per participant, although in a real trauma scenario extensive manipulation (and reapplications) of a tourniquet may achieve better results. Another limitation of the present study is that the results are collected from the first application of the modified CAT, without previous training, although such training might have allowed for even better results with the modified CAT. We assumed that the modification we designed for the CAT improves application

by slack reduction, but slack was not assessed in order to not interfere with the application process. Being a pilot study, with a few dozen participants in every subgroup, it is possible that additional differences between the groups could be better detected with larger study groups.

## CONCLUSION

In this study, we have demonstrated the major contribution of a simple modification of the CAT, which significantly improves its hemorrhage control rate and pressure profile, without compromising its intuitive application. This could translate into more lives being saved, especially in the hands of less experienced first responders that without further training can achieve a similar hemorrhage control rate to the most experienced medics. Additional studies are needed to better understand the exact mechanism through which the modification achieves this improvement and the outcomes of further training.

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