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ORIGINAL ARTICLE

# Combat application tourniquet (CAT) eradicates popliteal pulses effectively by correcting the windlass turn degrees: a trial on 145 participants

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**Abstract**
*Introduction* We aimed to define an ideal range of windlass turn degrees for 100 % success rates within the study population.
*Methods* CAT was applied at mid-thigh level. Data included age, lower extremity circumference (LEC), body mass index (BMI), and mean arterial pressure (MAP). Windlass turn degrees were measured in failed and successful participants. The failed participants' windlass mechanisms were twisted until the popliteal artery was occluded. Failure to success and additional turn degrees to secure the windlass mechanism of CAT was determined. Doppler ultrasound was used to examine the popliteal artery blood flow.
*Results* 145 servicemen have participated in the study. Initially, 70 % successfully applied CAT. There was no statistically significant difference in BMI and MAP values between successful and failed participants. The mean LEC for failed and successful applications were 57.5 ± 4 and 56.8 ± 4, respectively. The required turn degrees for success ranged between 45° and 270°. After correction, the cumulative success rate of 93 and 100 % was reached at 990° and 1170° overall turn degrees.
*Discussion* In order to adequately stop limb hemorrhage, soldiers should be taught their optimal turn degrees.

**Keywords** CAT · Tourniquet · Lower limb · Injury

## Introduction

Extremity injuries remain the most common site of combat-related injuries [1]. Severe extremity injuries, which constitute up to 20 % of all combat injuries, may cause rapid blood loss and death [2]. Additionally, exsanguinating limb hemorrhage has been reported as the leading cause of preventable death in recent military conflicts [3]. Although data pertaining to civilian extremity hemorrhage-related pre-hospital deaths are not presented with exact statistics in the literature, some reports indicate that the percentage of deaths from isolated extremity trauma is low [4].

Emergency tourniquet application is a simple and life-saving intervention provided that the device is appropriately applied [5]. Various tourniquets with different designs (Emergency & Military Tourniquet®, SOF® Tactical Tourniquet, Improvised tourniquets, M2® Ratcheting Medical Tourniquet, Self-Applied Tourniquet System, One Handed Tourniquet, Surgical Tubing, CAT) have been used and investigated with variable success rates, by several

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countries' armed forces, such as United States, Canada, Israel, and United Kingdom [6, 7]. Currently, EMT (Emergency & Military Tourniquet) and CAT (Combat Application Tourniquet) are among the prominent tourniquet systems [8]. EMT is a pneumatic tourniquet system that has the highest reported effectiveness rate (92 %) [9]; however, it is not suitable for self-application by the wounded in the combat field. Military medics in an Afghanistan cave invented the CAT, and it is the standard device used in the US Military [7]. CAT is suitable for one-handed self-application in the combat field and issued for use by the Turkish Armed Forces (TAF). However, concerns center on the ability of CAT to control hemorrhage when applied at mid-thigh level and its effectiveness rate has been reported to range between 8.3 and 100 % [6, 9, 10].

Previously, as part of the TAF Tourniquet Research Program, controversies that swirl around the efficiency of CAT were addressed by a prospective randomized trial in training military personnel. The trial involved the changes in self-application success rates and application times in basic, after training and eyes-closed phases. The success rates were increased in successive phases that reached to 96 % for both upper extremities, 84 % for right lower and 88.9 % for left lower extremities in the eyes-closed phase [11].

In this study, our primary hypothesis was that CAT tourniquet was capable of successfully occluding lower extremity arterial flow (determined by a Doppler ultrasound) in 100 % of participants. We aimed to investigate the possibility of reaching an ideal range of windlass turn degrees for 100 % success rate within the study population.

## Methods

The study was designed as a prospective, randomized trial, and approved by Gulhane Military Medical Academy Research Ethics Committee. The prospective participants received a complete explanation sheet for the aim, risks, and details of the study. Written consent was obtained from each participant. Previously reported efficacy rates recommended a minimum of 24 participants to achieve a 95 % confidence interval [6, 7]. In order to decrease possible selection bias in the restricted randomization process, replacement randomization was used. All consenting participants were questioned about any recent medical problems and extremity trauma. Participants with history of pre-existing health conditions were excluded from the study.

The participants' age, presence or absence of participants' previous experience with any type of tourniquet, measurement of the randomized lower extremity circumference (LEC), body mass index (BMI), and mean arterial pressure (MAP) values were recorded.

Initially, the participants were briefed visually about the CAT® (Phil Durango, LLC, Golden, CO, supplied by Fenton Pharmaceuticals, UK). Mid-thigh level was selected for both lower extremity applications. The randomized selection of the lower extremity was assigned and the participants were instructed to tighten the tourniquet until it prevented any tourniquet movement over the limb controlled by the same instructor. Eradication of blood flow was confirmed by using mobile color Doppler Ultrasound device (GE, Logiq Book XP, USA) by a radiologist, and each successful participant's windlass turn degrees were recorded.

As the neutral position of windlass mechanism stays perpendicular to the locking mechanism, the successful application turn degrees were added another 90° while calculating the degrees. If the participant failed to successfully apply the CAT, the instructor continued to turn the windlass until the ultrasound probe showed no popliteal artery pulse. The windlass turn degrees were recorded using a goniometer (Fig. 1a, b).

All data were analyzed using SPSS Version 22 (IBM Corp. Armonk, NY). Pearson's $\chi^2$ test, Mann–Whitney $U$

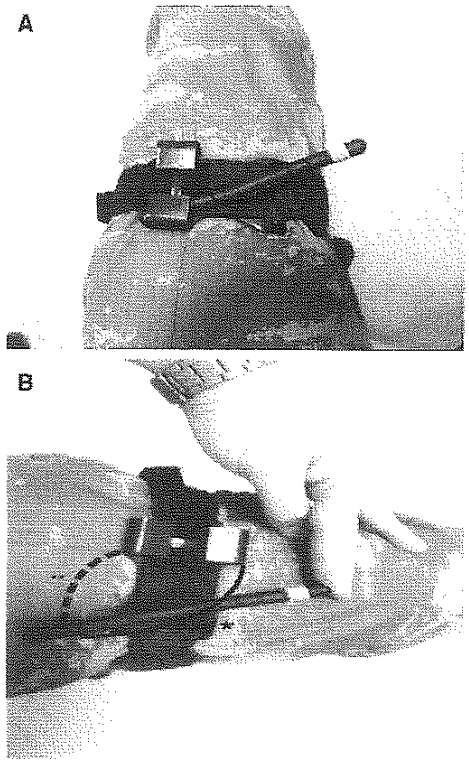


**Fig. 1** **a** Failed CAT application (before correction). **b** Failed application, required additional 120° windlass turn (*) and turn degrees to secure the windlass (**)

test and independent samples *t* test were used as appropriate. Power analysis was performed using Power Ax Version 1.4.0 (A&X Analytics, LLC–Cambridge, MA, USA). A power calculation with an 80 % power was set for determining the participant population.

## Results

This study was conducted as a prospective randomized trial, which involved 145 professional military and special police operations personnel. All participants were male. Seventy-four participants were randomized for left lower extremity, while 71 participants were for right lower extremity. All tourniquets were applied at mid-thigh level. The mean age was 32 ± 7 years. The participants reported no tourniquet-related complications.

Initially, 102 (70 %) of 145 participants successfully applied themselves the CAT. The mean turn degrees for successful participants were 570° ± 182.4°. There was no statistically significant difference between left and right lower extremity success rates ($p = 0.768$). The mean LEC for failed and successful applications were 57.5 ± 4 and 56.8 ± 4, respectively ($p = 0.331$). Turn degree scores for successful and failed CAT applications were not statistically significantly different ($p = 0.630$).

The mean LEC, BMI, and MAP were 56.8 ± 4 cm, 25 ± 1.8, and 88.7 ± 6 mmHg, respectively. None of the following differed between those who succeeded and those who failed: left or right side, BMI, MAP, LEC, and previous experience.

As the instructor undertook the failed applications to determine the required additional windlass turn degrees, the corrected participants' requirement was between 45° and 270° (mean 123° ± 52°) for attaining a 100 % success rate. The corrected participants' mean turn degrees were 745° ± 237° and significantly higher than successful participants' turn degrees (95 % CI 98 to 245.2, $p < 0.001$). The mean overall turn degrees were 624.4° ± 219°.

Overall, 66 % of participants successfully applied the CAT at 630°. The failed participants' cumulative success rate of 93 and 100 % was reached at 990° and 1170° overall turn degrees, respectively (Fig. 2). Overall cumulative turn degrees of both successful and corrected failed participants ($n = 145$) are shown in Table 1.

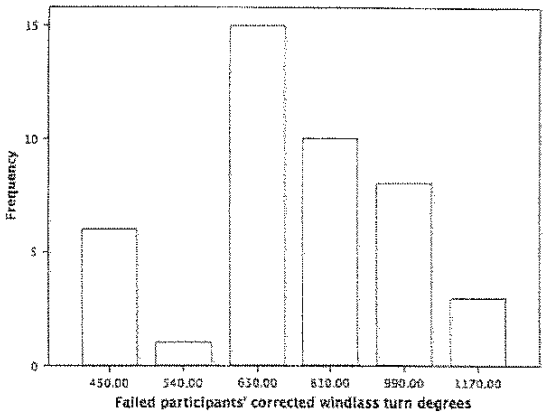


**Fig. 2** Frequency table of failed participants' corrected windlass turn degrees ($n = 43$)

**Table 1** Cumulative turn degrees of both successful and corrected failed participants ($n = 145$)

| Turn degrees | Frequency | Cumulative percent |
|---|---|---|
| 270.00 | 14 | 9.7 |
| 450.00 | 37 | 35.2 |
| 540.00 | 1 | 35.9 |
| 630.00 | 49 | 69.7 |
| 810.00 | 29 | 89.7 |
| 990.00 | 12 | 97.9 |
| 1170.00 | 2 | 99.3 |
| 1260.00 | 1 | 100.0 |
| Total | 145 | |

## Discussion

Traditionally, improvisation of tourniquets (i.e., rifle sling) in a combat environment was regarded as skills gained through military training. This paradigm in TAF has changed in the last decade. After 2000, the use of explosives has become the signature of terrorist attacks. Almost simultaneously, the same capacity has become a part of present national threat and injury patterns faced by Turkish Military personnel, civilian guards and civilian citizens have changed dramatically. TAF trauma statistics (2005–2007), which comprise casualties of combat and terrorist attacks, show that extremity injuries constitute 64 % of all combat-related injuries. Moreover, at least 16.4 % of all casualties incurred high velocity missile and blast effect related extremity injuries that required tourniquet application [11].

Tourniquet application is a simple task to prevent exsanguinating hemorrhage and "oversimplifying" pre-emptive action to provide essential tourniquet skills may lead to grave prognosis [2]. Holcomb et al. [12] reported that during the global war on terrorism (2001–2004), 13 % of casualties died of hemorrhage amenable to a tourniquet. It was also reported that in operation Iraqi Freedom, 18 of 35 (51 %) deaths incurred isolated extremity injuries and these

deaths were potentially survivable if an extremity tourniquet was applied [13]. In order to minimize this preventable source of death, our primary focus is establishing new training goals for self-application of an effective tourniquet in combat field.

Despite some initial success, there are concerns about this narrow windlass tourniquet's ability to control hemorrhage at mid-thigh level [6, 9]. The most challenging use of tourniquets is in the proximal lower limb since it has a large girth [9]. Taylor et al. [10] reported the arrival of casualties with two or even three CAT applied on the same lower extremity with active bleeding. Irrespective of the limb girth, an effective tourniquet device should be capable of exerting an adequate pressure to arterial occlusion. In the present study, 70 % of participants successfully applied CAT. These participants applied the CAT within a range of 270° and 990°. When the failed 43 (30 %) participants' windlass mechanisms were further twisted until the popliteal artery was occluded, the failed participants' popliteal artery pulses were occluded within a range of 45° and 270°. The overall 'corrected' windlass turn degrees were significantly higher than the successful participants. In the current study, the mean LEC values were similar between two groups and no statistical significance was found.

Slack removal before twisting the windlass is required for correct user application and device effectiveness. Kragh et al. [7] reported that when the tourniquet was applied loosely before windlass twisting began, too many twists (>540°, one twist was 180°) were required. The current study focused on success of self-applied CAT under fire and all the participants applied the CAT over their uniforms, which might explain the difficulty in providing the same level of CAT tightness on all extremities. However, authors of this study think that not all failures are attributable to inability to slack removal. During the application phase, the instructor eradicated the popliteal blood flow by further turning the windlass as low as 45°, but the participants chose to twist back the windlass to the securing point at 3 and 9 o'clock position. This may also be attributed to tourniquet-related pain perception of participants and the location of windlass locking mechanism in the horizontal plane.

This study has several weaknesses. The study design did not involve the effect of pain perception on the windlass turn degrees in failed and successful participants. The issue of as to how long the tourniquet should be left on and when should be evaluated. We were also unable to prevent slight differences in initial tourniquet tightness between different participants. Regardless of the differences in participants' LEC, pressure sensors applied at the mid-thigh level could increase the sensitivity and specificity of our results.

## Conclusion

To the best of our knowledge, this is the first prospective study that aims to provide an ideal range of windlass turn degrees within the study population. In the study, 70 % of the participants were successful in applying correctly the CAT, and 630° of windlass turns successfully impeded popliteal blood flow in two-thirds of the participants. Nevertheless, 1170° of windlass turns were necessary to achieve 100 % success rate. Due to differences in number of windlass turns necessary to achieve hemorrhage control in different people, individual soldiers should be taught and trained on their respective number of windlass turns.

### Compliance with ethical standards

**Conflict of interest** Aytekin Ünlü, Patrizio Petrone, Inanc Guvenc, Sahin Kaymak, Gokhan Arslan, Erkan Kaya, Soner Yilmaz, R. Aytac Cetinkaya, Tolga Ege, M. Tahir Ozer, and Selim Kilic declare that they have no conflict of interest.

**Ethical approval** The study was designed as a prospective, randomized trial, and approved by Gulhane Military Medical Academy Research Ethics Committee.

**Informed consent** The prospective participants received a complete explanation sheet for the aim, risks, and details of the study. Written consent was obtained from each participant.

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