

Original Article

Comparing the performance of tourniquet application between self-aid and buddy-aid: in ordinary and simulated scenarios

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Abstract: Objectives: Combat Application Tourniquet (CAT) is generally applied by self-aid or buddy-aid for exsanguinating extremity hemorrhage. The purpose of this study was to compare the accuracy, time and effectiveness between self-aid and buddy aid in ordinary and simulated scenarios. Methods: A total of 64 undergraduates from the Red Cross Commando of a military medical university participated in this study, which involved ordinary and simulated scenarios. In each scenario, every participant completed tourniquet application to upper and lower extremities by self-aid and buddy-aid, respectively. Measures of time, accuracy and effectiveness were assessed by an examiner identically after each application. Results: Compared with the performance of CAT application by buddy-aid, the time of application to upper extremities by self-aid increased by 8.39 s ($P<0.001$) and 3.24 s to lower extremities ($P<0.05$), and the percentage of pulse elimination by self-aid declined by 13.29% and 10.93% to both upper and lower extremities, respectively ($P<0.05$). Simulated combat performance showed longer time and lower accuracy ($P<0.05$). Conclusions: The hypothesized different performances between self-aid and buddy-aid, as well as between ordinary and simulated scenarios were verified in this study, indicating the need for superior tourniquet design for self-aid and rigorous deployment readiness training, especially for self-aid in tourniquet application.

Keywords: Tourniquet, tactical combat casualty care, training, self-aid vs. buddy-aid

Introduction

Hemorrhage remains a significant threat in both the military and civilian trauma systems. It is the first and second leading cause of preventable combat deaths [1-3] and civilian traumatic deaths, respectively [3]. Extremity injuries, as one of the most common combat injuries, may cause rapid blood loss and death. It is reported that extremity hemorrhage accounts for 13.5% of lethal hemorrhage among the casualties in Operations Iraqi Freedom and Operation Enduring Freedom [1]. Another study indicates that exsanguinating extremity hemorrhage contributes to the leading cause of potentially survivable deaths in recent military conflicts [4]. Despite various controversies over nearly two millennia [5], tourniquet application

has been evidently proved to be a simple and life-saving measure to stop limb arterial bleeding in the phase of tactical combat casualty care, especially before the onset of shock [5]. According to Tactical Combat Casualty Care (TCCC) Guidelines, Tourniquet application is the simple and effective first-aid intervention measure in the phase of Care Under Fire [6]. In regard to civilian trauma systems, tourniquets are gradually gaining acceptance due to their life-saving value of early hemorrhage control in mass casualty incidents, such as Boston marathon bombing and active shooter incidents [7, 8].

Combat Application Tourniquet (CAT) is now the standard first-aid device in the military forces of many countries. However, its success rate can

Tourniquet application between self-aid and buddy-aid

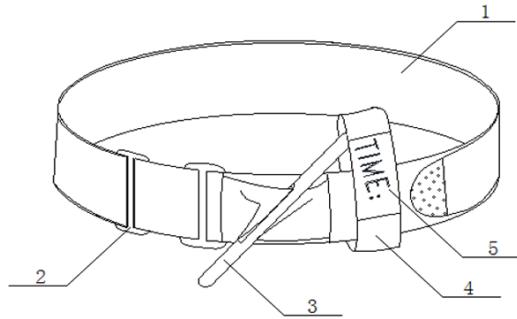


Figure 1. Combat Application Tourniquet. Note: 1. Omni-Tape Band; 2. Friction Adapter Buckle; 3. Windlass Rod; 4. Windlass Clip; 5. Hook-and-Loop Windlass Strap.

vary greatly arising from battlefield experience. A retrospective study of traumatic casualties from an Iraqi military campaign indicated a success rate of 70% regardless of caregiver level or extremity characteristics [9]. Another prospective study of tourniquet use and evaluation found that the CAT's effectiveness rate was 79% [10]. In contrast, an observational study identified that only 13% of the limbs with tourniquets in place were pulseless upon the arrival of a forward surgical team from the battlefield [11]. These surprisingly varied findings may be attributed to differences in the level of tourniquet training, which highlights the need for advanced training to optimize the performance of tourniquet application, including time, accuracy and effectiveness. Due to the gap between battle practice and classroom training, advanced training should involve combat-oriented and simulation-based design. Kragh et al. [12] emphasized the vital role of rigorous tourniquet training in simulated combat scenarios, especially for the novices without practical experience in the field. To identify the critical factors related to combat simulation design, some researchers have explored performance differences of tourniquet application between ordinary and simulated scenarios [13-15]. Unlu et al. simulated the low-light environment in CAT training, and compared the performance by self-aid between the ordinary and simulated phases [15]. In the studies of Richard et al. [16], the participants applied CAT to a standard casualty's thigh while wearing full body armor for avoiding simulated small fire in the simulated combat scenario, and the application time was significantly slower, the accuracy and effectiveness declined slightly com-

pared to the results of non-simulated practice. However, there are no published studies comparing the effects of self-aid versus buddy aid in tourniquet application under simulated conditions. Although the decision to use the buddy system or self-apply is not usually a choice, identifying the differences in performance between the two means has some implications for the improvement of tourniquet training and the modification of tourniquet design.

Therefore, the purpose of this study was to explore the differences in CAT application by self-aid and buddy-aid under classroom & simulated settings. It was hypothesized that the performance by buddy aid would be better than that by self-aid, while the performance in simulated setting was inferior to that in classroom setting.

Methods

Participants

Based on the results of our preliminary experiments including 10 participants, a calculation with 80% power recommended a sample of at least 44 participants to achieve a 95% CI. Therefore, the present sample size of 64 participants was considered adequate for testing the hypothesis of this study. The 64 participants were undergraduates from the Red Cross Commando of a military medical university in China and volunteered to participate in this study with consent. They were in the third-year grade or higher, with a relatively comprehensive construct of medical knowledge and skills. In addition, the participants had just completed a 5-day TCCC training course and passed the knowledge and skill tests, but none of them had active combat experience.

Research equipment

The CAT is a small and light-weight tourniquet, with an Omni-Tape Band, a Friction Adapter Buckle and a one-handed windlass system, which can completely occlude arterial blood flow in an extremity (**Figure 1**). The Windlass Rod provides true circumferential pressure on the extremity by using a free-moving internal band, which is then locked in place with the Windlass Clip and further secured by the Hook-and-Loop Windlass Strap. The application time can be ultimately recorded on the strap.

Tourniquet application between self-aid and buddy-aid

Esaote MyLab™One/Touch is a touch-screen portable color Doppler ultrasound machine with a SL3116 model probe at a frequency of 22 MHz. It was used for marking the pulse site and verifying the blood flow elimination before and after tourniquet application respectively.

Testing procedure

The study was conducted on the campus in June 2019. The 64 participants were randomly paired and 32 pairs were formed. In each pair, the two participants were named as A and B, respectively. Their left upper arms and thighs were selected for tourniquet application. Based on empirical evidence, the participants were asked to apply a CAT to the upper extremity and two CATs to the lower extremity, as the rate of pulse elimination could be improved by almost 17% when a second CAT was applied to the thigh of large girth [17].

The study involved two phases, i.e., ordinary and simulated scenarios. The 32 pairs were randomly assigned into two groups. One group went through the ordinary phase firstly and then went through the simulated phase, while the other group did that in opposite turn. There were four steps in each phase. Firstly, who acted as the medic carried out the tourniquet application to the upper and lower extremities of B who acted as the wounded (called buddy-aid). Secondly, B implemented the tourniquet application to his/her upper and lower extremities (called self-aid). Thirdly, A took the step of self-aid. Lastly, B as the medic completed the buddy-aid application to A. There was a ten-minute break between each step. When the participant finished the tourniquet application, measures of time, accuracy and effectiveness would be assessed by an examiner identically at each step.

Scenario settings

Ordinary scenario: The ordinary scenario was set in a low-stress classroom environment without interference. According to the buddy-aid steps, one participant sat on the ground while the partner took out a CAT from an individual first-aid kit (IFAK) and applied it in a squatting position. According to the self-aid steps, a participant sat on the ground to complete tourniquet application.

Simulated scenario: The simulated scenario was set in a field with bumpy ground. A partici-

part dressed in personal protective equipment and virtual weapon dipped his/her hands into simulated plasma and crawled through an obstacle passage (60 cm in height, 5 m in length and 2 m in width). At the end of the passage, the participant took out a CAT from an IFAK and then applied it to the wounded who was lying supine or to himself/herself by following buddy-aid and self-aid steps, respectively. During the whole process, the participant had to keep low and exposed to the simulated sound of gunfire on the stereo.

Measurements of key outcomes

Application accuracy: Application accuracy was defined as the percentage of correct procedures in the CAT application checklist (See Supplement), which was revised from the CAT skill sheet of the Committee on Tactical Combat Casualty Care and reviewed by experts in the field of combat rescue training. The checklist of upper-extremity and lower-extremity CAT consisted of 9 and 12 procedures, respectively, each of which was observed and recorded as correct or incorrect.

Application time: Application time was assessed as the time elapsed from the first contact of the participant with the IFAK to the time when the participant verbally declared the completion of the application. Application time was measured by a stop-watch accurate to 0.01 second.

Application effectiveness: Application effectiveness was verified as the absence of pulsatile blood flow at the distal end of the tourniquet, which was assessed by Doppler ultrasound machine. Pulse elimination was recorded as effective (coded as 1), otherwise as ineffective (coded as 0) (**Figure 2**). To guarantee reliability and validity, arteria radialis and dorsalis pedis were located and marked with a permanent marker.

The three above measurements were taken by three respective examiners, all of whom had been trained in a pilot study, so as to minimize measurement errors.

Statistical analysis

All data were analyzed using IBM SPSS V25. The difference in the application time was analyzed using a paired sample t test due to its normal distribution, while the application accuracy

Tourniquet application between self-aid and buddy-aid

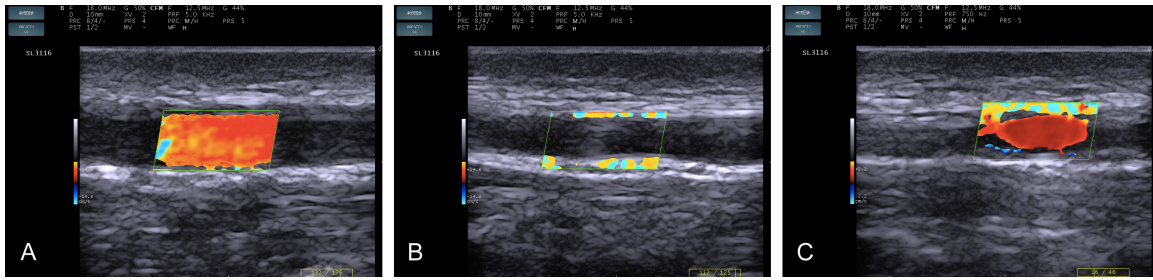


Figure 2. Effectiveness verified by CDFI: Normal blood flow of radial artery (A), elimination of pulsatile blood flow (B), presence of pulsatile blood flow (C).

Table 1. Summary table of outcome measures for self-aid and buddy-aid application

		Ordinary scenario			Simulated scenario		
		Self-aid	Buddy-aid	Chi square/ z/t values	Self-aid	Buddy-aid	Chi square/ z/t values
Upper-limb	Time (s)	47.70±12.96	39.36±11.98	6.093 ^{†**}	55.07±17.89	48.85±15.35	2.96 ^{†*}
	Accuracy (%)	98.06	97.78	0.409 [†]	96.24	96.24	-0.125 [†]
	Effectiveness (%)	75.38	93.85	6.05 ^{†*}	83.08	92.30	1.79 [#]
Lower-limb	Time (s)	76.93±15.22	74.32±14.92	1.32 [‡]	94.86±19.46	85.75±18.38	4.245 ^{†**}
	Accuracy (%)	97.79	97.95	-1.767 [†]	96.03	97.44	-0.692 [†]
	Effectiveness (%)	64.62	81.54	4 ^{†*}	63.07	84.62	0.375 ^{#*}

Notes: [†]Analysed by two-sample t test; [‡]Analysed by Wilcoxon signed-rank; [#]Analysed by Pearson Chi-square test. * $P < 0.05$. ** $P < 0.001$.

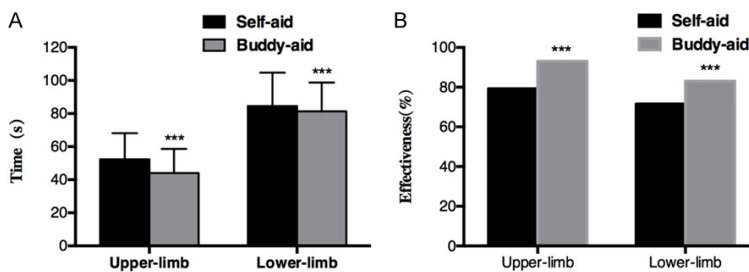


Figure 3. Multi-group bar chart of application time (A) and effectiveness (B). Note: * $P < 0.05$, ** $P < 0.001$, compared self-aid with buddy-aid.

was analyzed by Wilcoxon signed-rank test as a result of its abnormal distribution. Moreover, Pearson's χ^2 test was used to compare the rate of application effectiveness. The statistical significance level was set at $P < 0.05$.

Results

Demographic characteristics

The mean age of the participants was 21.3 years (range 19-24 years). 46 were males and 18 were females. The limb girth of the applied upper and lower extremities was measured with a mean of 27.4 cm (range 20.5-35.0 cm)

and 53.6 cm (range 46-64 cm), respectively, which would not affect the differences in performance of tourniquet application, as the study was self-controlled design.

Comparison between self-aid and buddy-aid

No differences in application accuracy: There were no significant differences in accuracy

measurements between self-aid and buddy-aid application for both the upper and lower extremities ($P > 0.05$) (Table 1).

Increased application time by self-aid: For the upper extremity, the buddy-aid application time was about 8.34 seconds shorter than the self-aid application time ($P < 0.001$) in ordinary scenario and 6.22 seconds in simulated scenario ($P < 0.05$). For the lower extremity, the time for self-aid application was increased by about 9.11 seconds in comparison with that for buddy-aid application in simulated scenario ($P < 0.001$) (Table 1; Figure 3).

Tourniquet application between self-aid and buddy-aid

Table 2. Summary table of outcome measures in ordinary and simulated scenario

		Ordinary	Simulated	Chi square/z/t values	p
upper-limb	Time (s)	44.53±13.47	51.96±16.96	-4.44	<0.001 [‡]
	Accuracy (%)	98.15	96.62	-2.78	0.006 [†]
	Effectiveness (%)	84.62	87.69	0.516	0.591 [#]
lower-limb	Time (s)	75.63±15.09	90.31±19.40	-9.54	<0.001 [‡]
	Accuracy (%)	97.88	96.73	-2.27	0.023 [†]
	Effectiveness (%)	73.08	81.54	2.65	0.138 [#]

[‡]Analysed by two-sample t test; [†]Analysed by Wilcoxon signed-rank; [#]Analysed by Pearson Chi-square test.

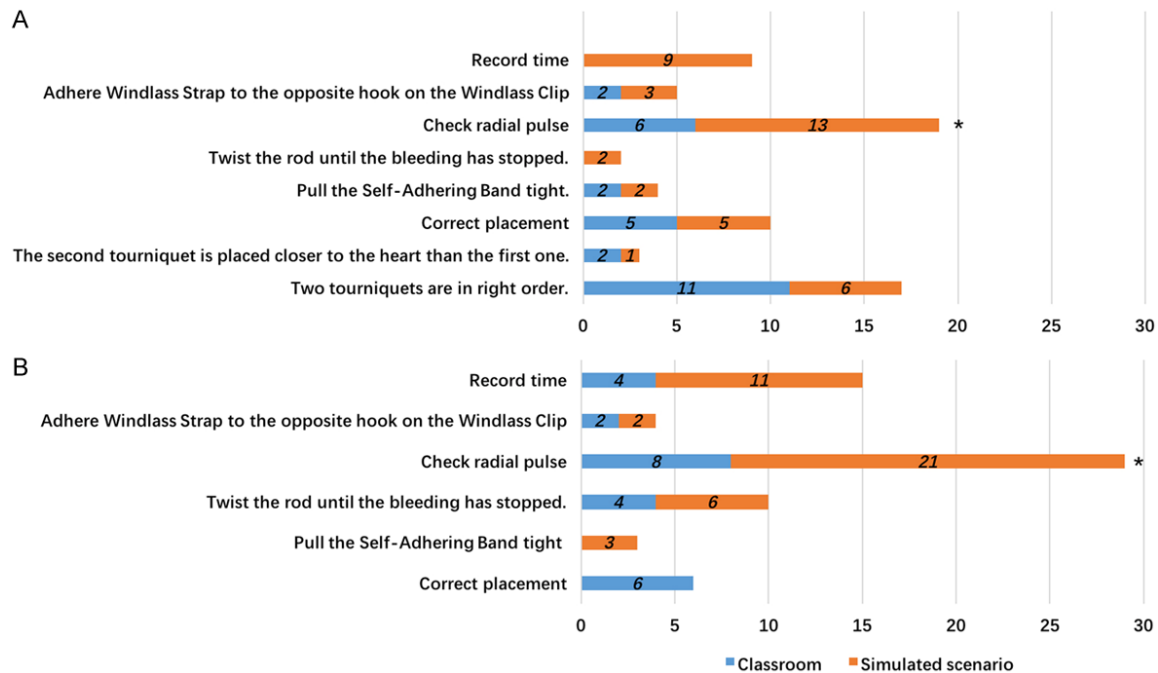


Figure 4. Operation errors in upper (A) and lower (B) extremity application and data were analyzed by means of Wilcoxon signed-rank. Notes: * $P < 0.05$, compared simulated scenario with classroom.

Declined application effectiveness by self-aid

In ordinary scenario, the percentage of pulse elimination for both the upper and lower extremities by buddy-aid (93.85% and 81.54%, respectively) was higher than that by self-aid (75.38% and 64.62%, respectively) ($P < 0.05$). In simulated scenario, the percentage of pulse elimination for lower extremities by buddy-aid was higher than that by self-aid ($P < 0.05$) (Table 1; Figure 3).

Comparison of ordinary scenario and simulated scenario

As hypothesized originally, compared with the results in the ordinary scenario, the application

time was slower and the application accuracy declined in the simulated scenario, and all the differences were statistically significant ($P < 0.001$ and $P < 0.05$, respectively). Interestingly, the application effectiveness in the simulated scenario was consistently better than that in the ordinary scenario, though the differences were not statistically significant ($P > 0.05$) (Table 2).

Frequencies of procedure errors

In order to provide references for future tourniquet training, we further analyzed the frequencies of incorrect procedures in the tourniquet application. As shown in the Figure 4, for the upper extremity, there were six procedures in

upper extremity application and eight procedures in lower extremity application, in which at least one participant made mistakes. Irrespective of for upper or lower extremity, the most frequent error was that the participants forgot to check the pulse before completing the application. Specifically, the frequency in the simulated scenario was statistically higher than that in the ordinary scenario ($P < 0.05$).

Discussion

CAT, as a replacement of Cargo-strap tourniquets, has been standardly deployed among the Chinese military service personnel since the year of 2018, but few studies reported the research of the CAT training in China. Therefore, this study contributes to the field by adding new facts, which can also be compared with other studies at the international level.

The most prominent findings of this study were the different effects of self-aid versus buddy-aid, which had not been adequately addressed in tourniquet application. Despite no statistical differences in the data of placement accuracy, overall findings supported the different application time and elimination of pulse. Specifically, on the one hand, the application time was longer by self-aid than that by buddy-aid, indicating that the participants were less proficient in tourniquet self-aid application; it was noticeable that the increased time for upper extremities by self-aid was much more than that for lower extremities, maybe because the participant could use only one hand to apply a CAT on an upper extremity by self-aid and thus one-hand application was more difficult and time consuming. Similar explanations were also addressed by Guo et al. who suggested that future tourniquet designs should take one-handed convenience into special consideration [18]. On the other hand, self-aid application scores showed a significant reduction in performance for effectively eliminating pulse compared to buddy-aid application. This was probably due to the fact that tourniquet application could be quite painful, which might limit the efficacy of windlass style tourniquets by self-aid [19]. Jaffer et al. found a trend that increased pain would be associated with applying tourniquet more tightly and effectively [20]. In terms of the implications of the above findings, it should be noted that although current tourniquets have played a critical role in reduc-

ing the combat mortality from extremity hemorrhage, there are still preventable deaths for this reason [21]. Therefore, it is necessary to enhance and improve tourniquet training as well as device designs. As soldiers are more likely to self-apply a tourniquet during combat, especially in the phase of care under fire, greater attention should be paid to self-aid training so as to make their self-aid performance better. Moreover, it is important to continuously innovate and promote the quality of combat tourniquet, for example, how to make the tourniquet easier for self-use, less painful and so on.

The difference in the performance of CAT application between ordinary and simulated scenarios was also compared. It showed the effect of the simulated scenario on significantly shortening application time and lowering application accuracy, which were consistent with the results of previous studies [16]. The elements for simulation, including bumpy ground, obstacle passages, virtual weapons, personal protective equipment, simulated plasma and noise of gunfire, were set to increase the fidelity of simulated battlefield conditions. High-level fidelity may increase task complexity to a point that students' cognitive resources become overloaded [22], which might take longer time for participants to complete the task with more procedure errors in the study. It was found that forgetting to check the pulse was the most frequent error and the frequency was significantly higher in the simulated scenario. Therefore, rigorous training in varied simulated combat scenarios will be needed to improve the speed and proficiency of CAT application. However, the difference in the effectiveness between ordinary and simulated scenarios was not found statistically significant in the study. This finding was similar with the studies of Schreckengaust et al. in which the percentage of pulse elimination was not significantly reduced under simulated combat compared to classroom training [16]. Whereas, Unlu et al. found that the effectiveness of CAT application was increased significantly in simulated scenario [15]. The disparities in these findings might be attributed to different levels of simulation fidelity. The study of Unlu only used blindfold to simulate low-light combat environment, while the studies of Schreckengaust et al. and our study set various simulation elements, such as irregular terrain, standardized patients, noise, fatigue, etc.

Tourniquet application between self-aid and buddy-aid

This study has many limitations. The study sample were healthy people who were different from the hemorrhage casualties often with hypotensive and tachycardia. Although the participants were undergraduates from military medical university with less medical experience, the findings of the study could not infer to the medics being deployed. Furthermore, pain perception was not measured in the study, which may be related to the degree of windlass turning and is therefore related to pulse elimination. Future study designs need to involve such consideration. Another limitation of this study is that there is still a gap between simulated and actual combat environments, for example, the simulation in this study could not reproduce the situation of actually being wounded, which indicates an improvement of simulation fidelity. It is necessary to follow up the efficacy of simulated training on the performance in actual combat.

Conclusion

Overall findings supported the differences in performance between self-aid and buddy-aid as hypothesized in this study, as well as between ordinary and simulated scenarios. It was highlighted that the time of application to upper extremities by self-aid increased, and the percentage of pulse elimination for both upper and lower extremities by self-aid declined. Simulated combat performance showed significantly slower application time and more procedure errors. All of the above suggest the need for superior tourniquet design for self-aid and rigorous deployment readiness training, especially for self-aid in tourniquet application and in simulated combat scenarios.

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Disclosure of conflict of interest

None.

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Tourniquet application between self-aid and buddy-aid

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