Simulation-based education improves military trainees' skill performance and self-confidence in tourniquet placement: A randomized controlled trial

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BACKGROUND: Tactical Combat Casualty Care (TCCC) is the standard of care for stabilization and treatment of military trauma patients. The Department of Defense has mandated that all service members receive role-based TCCC training and certification. Simulation education can increase procedural skills by providing opportunities for deliberate practice in safe, controlled environments. We developed and evaluated the effectiveness of a simulation-based TCCC training intervention to improve participants' skill performance and self-confidence in tourniquet placement.

METHODS: This study was a single-blinded, randomized trial with waitlist controls. Army Reserve Officers Training Corp cadets from a single training battalion comprised the study population. After randomization and baseline assessment of all participants, group A alone received focused, simulation-based TCCC tourniquet application training. Three months later, all participants underwent repeat testing, and after crossover, the waitlist group B received the same intervention. Two months later, all cadets underwent a third/final assessment. The primary outcome was tourniquet placement proficiency assessed by total score achieved on a standardized eight-item skill checklist. A secondary outcome was self-confidence in tourniquet application skill as judged by participants' Likert scale ratings.

RESULTS: Forty-three Army Reserve Officers Training Corp cadets completed the study protocol. Participants in both group A (n = 25) and group B (n = 18) demonstrated significantly higher performance from baseline to final assessment at 5 months and 2 months, respectively, following the intervention. Mean total checklist score of the entire study cohort increased significantly from 5.53 (SD = 2.00) at baseline to 7.56 (SD = 1.08) at time 3, a gain of 36.7% ($p < 0.001$). Both groups rated their self-confidence in tourniquet placement significantly higher following the training.

CONCLUSION: A simulation-based TCCC curriculum resulted in significant, consistent, and sustained improvement in participants' skill proficiency and self-confidence in tourniquet placement. Participants maintained these gains 2 months to 5 months after initial training. (*J Trauma Acute Care Surg.* 2022;93: S56–S63.)

LEVEL OF EVIDENCE: Therapeutic/care management; Level II.

KEY WORDS: Tactical Combat Casualty Care; tourniquet placement; simulation training; skills performance; self-confidence.

Tactical Combat Casualty Care (TCCC) is the standard of care for the stabilization and treatment of military trauma patients. There are many situational and environmental factors on the battlefield that affect individuals' ability to render "state of the art" TCCC care. The ability to perform, however, depends to a greater extent on whether individuals have undergone adequate training and assessment and can then employ the requisite knowledge and skills under extremely difficult circumstances. Therefore, any strategy to improve military medical readiness and clinical performance in the field should include a plan for strengthening TCCC training systems.

Accordingly, in the Spring of 2018 the Department of Defense (DoD) updated its "Medical Readiness Training" requirements (DoDI 1322.24),[1] stating that all service members (ASMs) must receive role-based TCCC training and certification as outlined in the Joint Trauma System's (JTS) TCCC Skill Sets.[2] In addition, the Instruction mandated development and implementation of new standardized curricula tailored to different roles elaborated across four tiers. By defining tier 1 to comprise ASMs (thereby including nonmedics), the new DoD directive significantly broadened TCCC training requirements.

In response to this mandate, and having previously conducted and reported a baseline survey of existing TCCC training, members of our research team, on behalf of the Defense Health Agency, created and piloted a new TCCC curriculum for ASMs.[3] As part of this process, we convened a multidisciplinary

Submitted: February 2, 2022, Revised: March 21, 2022, Accepted: May 9, 2022, Published online: May 23, 2022.

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DOI: 10.1097/TA.0000000000003702

group to develop multiple simulated task stations to facilitate training and assessment of TCCC skills focused on the leading causes of preventable death on the battlefield, including massive hemorrhage and airway compromise. These exercises were designed as capstone elements within a special TCCC-ASM course.[3]

We chose to deliver the training using simulation technology, which can increase procedural skills by providing opportunities for deliberate practice in a safe, controlled environment.[4,5] For example, previous research has demonstrated the effectiveness of simulation-based education to train medical residents to mastery skill levels in procedures such as central venous catheter insertion,[6,7] thoracentesis,[8,9] and advanced cardiac life support.[10,11] These previous studies often employed simulation in the context of a mastery learning model. Mastery learning is a stringent form of competency-based education that requires trainees to acquire a clinical skill measured against a fixed achievement standard. In mastery learning, educational practice time varies but results are uniform.[12]

The primary objective of this educational study was to evaluate the impact of a focused, simulation-based TCCC training intervention on participants' skill in applying a tourniquet to control massive hemorrhage. A secondary goal was to examine the effect of the simulation intervention on military trainees' self-confidence in tourniquet placement.

PATIENTS AND METHODS

Trial Design

Our study was a single-blinded, randomized educational trial that featured a waitlist control group with crossover.[13] [Fig. 1] With minor adaptations for this educational intervention study, this report follows the Consolidated Standards of Reporting Trials 2010 Statement[14] guidelines for reporting parallel group randomized trials and, where applicable, the extension guidelines for reporting of randomized crossover trials (Supplementary Digital Content 1, http://links.lww.com/TA/C586).[15]

Participants

We recruited Army Reserve Officers Training Corp (ROTC) cadets from a single training battalion based in Florida. Cadets wear rank corresponding to their training year in military science (MS) classes, and all ranks were eligible to participate. The only inclusion criterion was presence in class on the day of the baseline study occasion.

Research Team

The onsite study cadre included two physicians with prior military service and six paramedics. One physician with Critical Care Air Transport Team experience and expertise designing simulation training curricula and conducting educational outcomes research served as study lead. The other physician—with extensive clinical background and expertise as a member of the Committee on TCCC (CoTCCC) that established current standards for training and clinical care in this domain—served as principal instructor for all training sessions. Paramedics served as raters for assessments and instructors during tourniquet training; some also had prior military service, and all have significant operational experience in clinical trauma care/training as active paramedics and simulation instructors.

Timeline and Setting

We designed the study to occur across three separate, 1-day training and/or testing occasions: baseline, 3 months (time

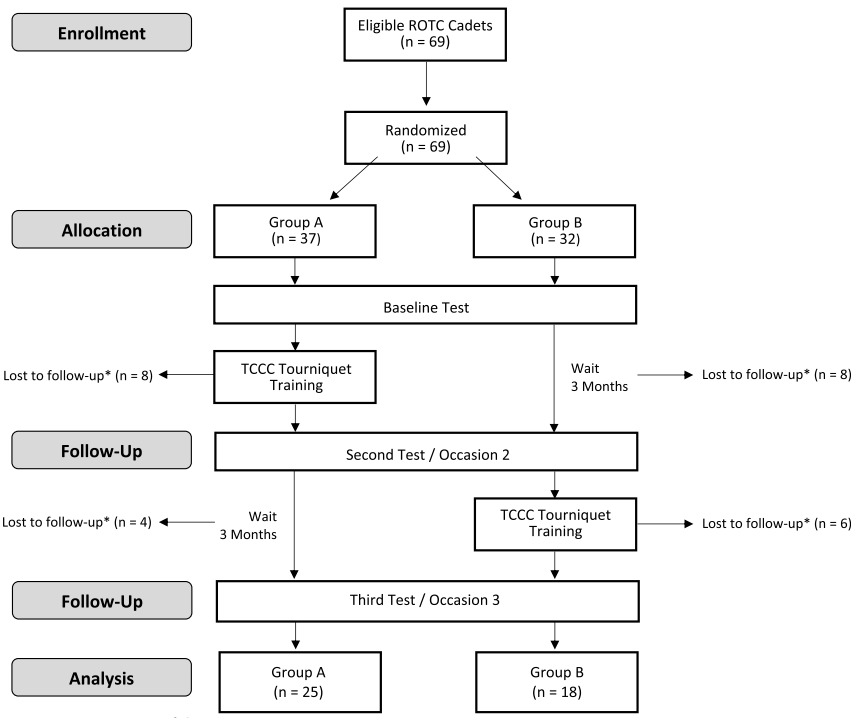

Figure 1. CONSORT 2010 flow diagram.[14] This figure illustrates the trial design and flow of participants through the study. *Due to illness, quarantine, or schedule conflict. CONSORT, Consolidated Standards of Reporting Trials.

2), and 6 months (time 3). All teaching and assessment sessions for the study occurred during one academic year (AY2020–2021), using classroom facilities in the ROTC building at the study site. Cadets of all ranks receive ROTC training once per week, consisting of didactic presentations in the morning—when underclassmen (MS1 and MS2 cadets) attend lectures separately from upperclassmen (MS3 and MS4 cadets)—and skills laboratories/other practical exercises in the afternoon.

Procedures

Study Flow

Figure 1 illustrates the trial design and flow of participants through the study. After randomization, both groups undergo baseline skills assessment. The intervention arm (group A) then participates in focused, simulation-based TCCC training in tourniquet placement, while the waitlist control (group B) receives usual MS training. After a second round of testing 3 months later, the control group B crosses over and receives the same educational intervention, while group A continues customary ROTC activities. After 3 months, all participants undergo a third/final round of testing.

Randomization

Training session logistics (e.g., classroom size and the need for social distancing) determined fixed block sizes that we used for block randomization. We generated four blocks of 20 participants from baseline testing session groupings of five cadets, who self-randomized to the intervention or waitlist control groups by choosing their initial assessment appointment slot without knowing the corresponding study arm assignment.

Informed Consent and Survey Procedures

Upon participants' arrival (in groups of five cadets), the onsite study lead provided the following:

- Verbal/written explanations of study procedures, risks/benefits of participation, and the voluntary nature of participation in the assessment portion of the study;
- Opportunities to ask questions for clarification and/or request written copies of the study protocol/consent documents; and
- Assignment of a study ID number.

After providing written informed consent, all participants used tablet computers to complete an online demographic questionnaire using software (Qualtrics; Provo, UT) that collected and stored in a secure database information about age, gender, ROTC training year, prior training in tourniquet placement, previous experience placing tourniquets in real-world trauma settings, and ratings of self-confidence in tourniquet placement (Supplementary Digital Content 2, http://links.lww.com/TA/C587).

Measurements

The primary outcome was proficiency in tourniquet placement as assessed by total score achieved on a skills checklist during a simulated Care Under Fire trauma scenario. A secondary outcome was confidence in tourniquet placement skills as judged by participants' self-ratings using a five-point Likert scale.

At each assessment occasion, the onsite study lead randomly assigned participants to one of five identical testing stations, where they demonstrated their tourniquet placement skills using a standard-issue Gen 7 Combat Application Tourniquet (C-A-T; North American Rescue LLC; Greer, SC) and a trauma task trainer (Z-Medica Hemorrhage Control Trainer; Z-Medica LLC; Wallingford, CT) that simulated a wounded lower extremity. Evaluators presented each participant with the following scenario: a fellow soldier had sustained multiple penetrating injuries to the thigh but was now safely behind temporary cover. Examiners provided spatial (cephalad-caudad) orientation to the position of the victim, indicated that one wound in particular was bleeding profusely, and instructed the participant to demonstrate (using a "think out loud" approach) how they would apply a tourniquet to control this hemorrhage.

Raters participated in a training session to standardize their interactions with study participants and to calibrate their assessments using a checklist consisting of eight equally-weighted items requiring dichotomous judgments: Pass (score = 1, done correctly) or Fail (score = 0, not done/done incorrectly). An interprofessional expert panel convened by the Defense Health Agency—including active duty/retired JTS/CoTCCC personnel and other multidisciplinary experts in TCCC/critical care/emergency medicine—developed the checklist items that enumerate critical steps in tourniquet application (Fig. 2). Raters were blinded to participants' training year, prior tourniquet experience, and study group assignment. The onsite study lead randomly assigned an ID number to each rater to be used throughout the study to enable post-hoc analysis of rater performance. We video-recorded all assessments for later quality control and calculation of interrater reliability using markings by a second blinded rater of a random sample (>50%) of assessments.

Intervention

At the initial study occasion (November 2020), after randomization and baseline testing, we divided participants in *group A only* into two separate sessions involving groups of up to 20 participants each, who then completed a 30-minute simulation-based training intervention on tourniquet placement that included the following:

- Instructions for downloading the free Deployed Medicine app that contains comprehensive resources related to TCCC training.[3]
- Review of selected videos describing principles of Care Under Fire and, in particular, control of massive hemorrhage through tourniquet placement. One military physician provided expert commentary and additional didactics using TCCC curriculum PowerPoint slides.
- Live demonstration of recommended techniques for application of a C-A-T tourniquet over the extremities of one of the instructor cadre. Large-group activities required approximately 15 minutes to complete.
- Participants spent the remaining 15 minutes in hands-on, deliberate practice using individual C-A-T tourniquets (provided for participants to keep after the training), a trauma task trainer (identical to the model used for the skills assessments), and printouts of the illustrated Skill Card on two-handed windlass tourniquet application (Supplementary Digital Content 3, http://links.lww.com/TA/C588).[3]

PERFORMANCE STEPS
TWO-HANDED (WINDLASS) TOURNIQUET APPLICATION IN CUF

"Participant should verbalize each step"

	Attempt	
	Pass	Fail
1. Inserted the wounded extremity in the loop of the self-adhering band (looped) or routed the band around the limb and passed the tip through the slit of the routing buckle.	○	○
2. Positioned the tourniquet above the bleeding site, high on the extremity over the clothing/uniform.	○	○
3. Ensured all the slack in the self-adhering band was pulled through the routing buckle before the band was fastened back on itself and the windlass was twisted.	○	○
4. Twisted the windlass rod until the bleeding stopped.	○	○
5. Completed steps 1–5 within 1 minute.	○	○
6. Locked the windlass rod in place with the windlass clip.	○	○
7. Routed the self-adhering band around the rod and between the clips.	○	○
8. Secured with the windlass safety strap.	○	○

Figure 2. Tourniquet placement skills checklist. This figure displays the scoring rubric used by raters to mark their assessments of participants' skill proficiency in tourniquet application. All raters marked their assessments using tablet computers running software that automatically initiated/displayed a timer (for those steps requiring completion within a set time limit) and stored performance data on a secure server.

- With low learner-to-instructor ratios (≤4:1) designed to optimize skill acquisition, instructors worked step-by-step with cadets, providing individualized feedback to aid in mastery of this critical lifesaving technique.

For the second study occasion at 3 months (February 2021), we repeated procedures as above, but at that time *only group B*, having originally been assigned to the waitlist condition, received the training intervention. For the third and final study occasion (originally planned at 6 months), we again reproduced procedures as above, but both groups A and B underwent *skills assessment only.* Exigencies of the COVID-19 pandemic necessitated conducting the third study occasion earlier than originally planned (April 2021 vs. May 2021).

Statistical Methods

Power Calculations

Based on the results of previous simulation-based training interventions,[16] we used G*Power[17] version 3.20 (Heinrich-Heine-Universität, Düsseldorf, Germany) to estimate that a total of 34 participants would be required in each group for an effect size of 0.5 with 80% power at a significance level of 0.05 on *t* tests. Therefore, to allow for attrition, we aimed to recruit 40 participants for each group.

Data Analyses

We compared demographic characteristics and self-confidence ratings between study groups using χ^2 and/or independent samples *t* tests. We used independent samples *t* tests to compare mean skills performance scores between groups at each study occasion. We used paired samples *t* tests to examine differences in performance scores and self-confidence ratings within groups across study occasions. We calculated interrater reliabilities of performance checklist scores using the kappa (κ) coefficient. We used SPSS Statistics version 26 (IBM; Armonk, NY) to perform the statistical analyses.

Ethics Approval

The University of Miami Institutional Review Board approved this study under protocol 20200250.

RESULTS

A total of 69 Army ROTC cadets were eligible to participate and provided consent at study outset. A total of 43 cadets (62.3%) completed the entire study protocol, while 26 cadets (12 originally assigned to group A and 14 originally assigned to group B) were lost to follow-up due to illness, quarantine, or scheduling conflicts. Figure 1 summarizes the study flow and results of random assignment to respective study groups: of the 43 cadets who completed the entire study protocol, 25 comprised group A and 18 comprised group B.

Table 1 shows baseline demographic data and comparisons of participant characteristics between study groups. There were no statistically significant differences between group A and group B related to participants' gender, how recently they had received tourniquet training, real-world experience with tourniquet application, or self-rated level of confidence in

TABLE 1. Baseline Demographic Data and Comparisons of Participant Characteristics in Both Study Groups

	Total (N = 43)	Group A (n = 25)	Group B (n = 18)	Statistics, *p*
Gender, n (%)				
M	28 (65.1)	19 (76.0)	9 (50.0)	χ^2 (1) = 3.11, p = 0.078
F	15 (34.9)	6 (24.0)	9 (50.0)	
Age				
(Mean, y)	20.2	19.5	21.2	t (41) = −2.43, p = 0.019*
Year/rank, n (%)				
MS1-MS2	24 (55.8)	18 (72.0)	6 (33.3)	χ^2 (1) = 6.34, p = 0.012*
MS3-MS4	19 (44.2)	7 (28.0)	12 (66.7)	
Prior training,† n (%)				
1	8 (18.6)	5 (20.0)	3 (16.7)	χ^2 (4) = 1.66, p = 0.797
2	1 (2.3)	0 (0)	1 (5.6)	
3	4 (9.3)	2 (8.0)	2 (11.1)	
4	3 (7.0)	2 (8.0)	1 (5.6)	
5	27 (62.8)	16 (64.0)	11 (61.1)	
Mean	3.93	3.96	3.89	t (41) = 0.14, p = 0.887
Experience,‡ n (%)				
1	33 (76.7)	18 (72.0)	15 (83.3)	χ^2 (2) = 1.85, p = 0.397
2	6 (14.0)	5 (20.0)	1 (5.6)	
3	4 (9.3)	2 (8.0)	2 (11.1)	
4	0 (0.0)	0 (0.0)	0 (0.0)	
5	0 (0.0)	0 (0.0)	0 (0.0)	
Mean	1.33	1.36	1.28	t (41) = 0.41, p = 0.685
Confidence,§ n (%)				
1	11 (25.6)	5 (20.0)	6 (33.3)	χ^2 (4) = 4.56, p = 0.336
2	4 (9.3)	1 (4.0)	3 (16.7)	
3	15 (34.9)	10 (40.0)	5 (27.8)	
4	11 (25.6)	7 (28.0)	4 (22.2)	
5	2 (4.7)	2 (8.0)	0 (0.0)	
Mean	2.74	3.00	2.39	t (41) = 1.63, p = 0.111

This table summarizes results of participants' answers to an online questionnaire. Statistics for between-group differences of means calculated using independent samples *t* tests, and for categorical data calculated using χ^2 analyses.

*Statistically significant difference at alpha = 0.05.

†Prior training: 1 = never; 2 = > 2 years; 3 = 1–2 years; 4 = 6–12 months; 5 = < 6 months ago.

‡Experience: 1 = never; 2 = rarely (1–4); 3 = occasionally (5–14); 4 = frequently (15–29); 5 = very frequently (>29).

§Confidence: 1 = not confident; 2 = a little confident; 3 = somewhat confident; 4 = fairly confident; 5 = very confident.

tourniquet application skills. Among study participants overall, there were nearly twice as many men (65.1%) as women (34.9%); despite the fact that this difference skewed more widely in favor of men in group A, it disappeared/equalized in group B, resulting in no statistically significant difference in sex between study groups. Mean age of all participants at study enrollment was 20.2 years, but on average group B was older than group A (21.2 years vs. 19.5 years, respectively); this difference was statistically significant. There were almost equal numbers of MS1 + 2 s (55.8%) and MS3 + 4 s (44.2%) in the total study cohort, but the respective ratios of underclassmen to upperclassmen were inverted between the two groups (i.e., more than 2:1 in group A, and exactly 1:2 in group B); these differences were statistically significant, consistent with the differences in age between the two groups. A sizeable majority (>60%) of all participants reported having received tourniquet training within the 6 months prior to study initiation, while another approximately 15% trained within the past 6 months to 2 years; almost 20% reported never having received such training. Mean level of all participants' experience placing a tourniquet in real-world settings was 1.33, categorized on a 5-point scale (1, "never"; 5, "very frequently"), with greater than 90% of all participants citing fewer than five past experiences of actual tourniquet placement, and none reporting greater than 15 such occasions in the past. Mean rating of all participants' self-confidence in tourniquet application was 2.74 on a 5-point Likert scale (1, "not confident"; 5, "very confident"), with ratings nearly equally distributed across the total study cohort: 34.9% "not" or "a little" confident, 34.9% "somewhat" confident, and 30.3% "fairly" or "very" confident, with no significant differences between study groups.

The upper panels in Table 2 and Figure 3 summarize comparative within- and between-group *performance* data as reflected by mean total score achieved (maximum = 8) on the tourniquet application skills checklist. Both groups performed similarly at baseline, with mean pre-test total checklist scores of 5.76 (standard deviation [SD] = 2.03) and 5.22 (SD = 1.99) for group A and group B, respectively. Group A was the first to receive training and showed significant improvement 3 months later (time 2), with mean post-test total checklist score of 7.44 (SD = 0.71), whereas the waitlist control group B showed no change on repeat testing, with mean total score of 5.11 (SD = 2.47). Group B then participated in the training intervention and showed highly significant improvement in tourniquet application skills from baseline to time 3, achieving on average nearly perfect scores (mean, 7.78; SD = 0.55) equivalent to the gains made initially by group A, who also maintained their improved level of skills performance (mean 7.40, SD = 1.32). The mean total checklist score of the entire study cohort increased from 5.53 (SD = 2.00) at baseline to 7.56 (SD = 1.08) at time 3 ($p < 0.001$). Calculation of interrater reliability of performance checklist scores using Cohen's kappa coefficient demonstrated moderate agreement[18] overall between pairs of blinded independent raters ($\kappa = 0.42$).

The lower panels in Table 2 and Figure 3 summarize comparative within- and between-group *self-confidence* data as reflected by mean Likert scale ratings (range, 1–5). Both groups rated their confidence similarly (and relatively low) at baseline, with mean pre-intervention ratings of 3.00 (SD = 1.23) and 2.39 (SD = 1.20) for group A and group B, respectively. Group A was the first to receive training and showed significant increases in self-confidence 3 months later (time 2), with mean post-training self-confidence ratings of 3.68 (SD = 1.03), whereas the waitlist control group B showed no change on repeat survey, with mean rating of 2.17 (SD = 1.20). Group B then participated in the training intervention and showed significant increases from baseline to time 3, rating self-confidence much higher (mean, 3.94; SD = 0.87) and equivalent to the gains made initially by group A, who also maintained their higher levels of self-confidence (mean 3.88, SD = 0.78). χ^2 Analyses of ordinal scale self-confidence ratings demonstrated similar trends (Supplementary Digital Content 4, http://links.lww.com/TA/C589).

DISCUSSION

Results of this study demonstrate that—compared with traditional (in this case, MS) training—Army ROTC cadets'

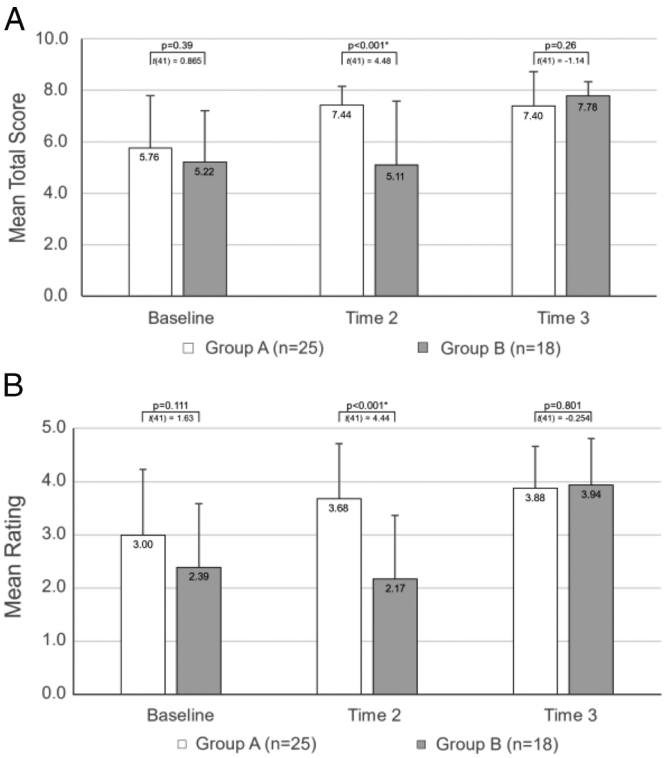

Figure 3. Between-group comparisons of skills performance and self-confidence by study occasion. (*A*) This panel summarizes *performance* data (means and standard deviations for total checklist score, range, 0–8) for participants in both arms of the trial at different study occasions. (*B*) This panel summarizes *self-confidence* data (means and standard deviations for Likert scale ratings, range, 1–5) for participants in both arms of the trial at different study occasions. Error bars denote standard deviations from the mean. The figure displays statistics for between-group differences calculated using independent samples *t* tests. *Statistically significant difference at alpha = 0.05.

performance of tourniquet application skills improved significantly after participation in a 30-minute blended learning experience that includes hands-on skills practice using a medical simulator and individualized feedback from instructors. Use of the simulated limb trauma task trainer in a structured educational program with opportunities for deliberate practice yielded large and consistent improvement with little decay over time. This approach to training incorporates features of the mastery learning model[12] that has proven effective for improvement and maintenance of procedural skills in multiple healthcare domains.[19]

For this study, we employed a robust research design[13] that is well suited to evaluating medical education interventions, including those used for military training. Participants randomly assigned themselves to the intervention or waitlist control group through self-selection of a baseline assessment appointment slot without knowing the corresponding study arm assignment. Randomization yielded equivalent groups in terms of tourniquet placement skill proficiency and self-confidence at baseline. All raters were blinded to participant rank and other demographic information, as well as study group assignment/intervention training status. The use of a waitlist control group has several advantages: it enables rigorous evaluation of the effects of educational interventions when it would not otherwise be feasible to train a large group of learners simultaneously. Moreover, because all learners ultimately receive the educational experience, it is a more ethical approach than using a no-intervention control, especially if the effects of training are anticipated to be beneficial to participants — as in this case of learning how to perform a potentially lifesaving skill.

Another strength of this research design is that all assessments beyond the baseline pre-test were conducted several months after the TCCC training sessions, in contradistinction to most simulation-based educational studies that usually administer post-tests immediately after the intervention. We would expect knowledge recall, familiarity with the simulation, and consequent skill performance to be maximal under the latter circumstances, but we gain little or no information about skill retention/decay from assessments that occur immediately post hoc. The fact that improvements in tourniquet placement skills persisted two (group B/time 3), three (group A/time 2), and even 5 months (group A/time 3) after the training highlights the large positive effects of this simulation-based intervention.

Several observations in this study reflect findings from similar research around procedural skills acquisition in other healthcare domains.[6–11,19,20] First, traditional training methods —often involving *passive* learning through lectures, watching videos, and/or observation of instructors demonstrating proper

TABLE 2. Within-Group Comparisons of Skills Performance and Self-Confidence by Study Occasion

Within-Group Performance (Paired Samples *t* Tests)				
Group	**n**	**Baseline to Time 2**	**Time 2 to Time 3**	**Baseline to Time 3**
A	25	$t(24) = 4.40$, $p < 0.001$*	$t(24) = -0.15$, $p = 0.882$	$t(24) = 3.28$, $p = 0.003$*
B	18	$t(17) = -0.28$, $p = 0.782$	$t(17) = 4.53$, $p < 0.001$*	$t(17) = 5.85$, $p < 0.001$*
Within-Group Self-Confidence (Paired Samples *t* Tests)				
Group	**n**	**Baseline to Time 2**	**Time 2 to Time 3**	**Baseline to Time 3**
A	25	$t(24) = 4.24$, $p < 0.001$*	$t(24) = 1.73$, $p = 0.096$	$t(24) = 6.06$, $p < 0.001$*
B	18	$t(17) = -1.07$, $p = 0.298$	$t(17) = 5.97$, $p < 0.001$*	$t(17) = 6.34$, $p < 0.001$*

This table displays statistics calculated using paired samples *t* tests to compare means, both for performance (total checklist score) and self-confidence (Likert scale ratings), within the same group across study occasions.
*Statistically significant difference at alpha = 0.05.

technique—are inadequate for mastering the competencies required in high-risk medical settings to ensure best patient outcomes. In developing the tourniquet placement skills checklist for use in TCCC courses, an expert panel deemed all eight steps essential to proper performance of this potentially lifesaving skill. Anything less than a near-perfect score (7/8 steps performed correctly) could pose a threat to patient safety. Fewer than 20% of all participants in this study reported no past training in tourniquet placement, whereas greater than 60% of study participants reported having received tourniquet training within the previous 6 months. Despite this, the baseline performance of both groups revealed inadequate preparation from traditional training, with total scores indicating that cadets on average missed more than two critical steps during simulated tourniquet placement.

In contrast to traditional training modalities, the substantial and sustained gains in performance after receiving the intervention in this study reflect the integration of evidence-based simulation methods that include features of deliberate practice[5] and mastery learning.[12,19] These educational models provide ample opportunities for *active* learning and deliberate practice of skills, plus *individualized* feedback that is guided by rigorous assessment and geared toward learner improvement and achievement of pre-determined (high) performance standards.[21] We found significant improvement and maintenance of tourniquet placement skills, demonstrating that even a brief (30 minutes), focused intervention using a simple task trainer—purposely designed to be feasible amid tight basic training schedules and high military operational tempos—can result in significant performance gains for ASMs. The mean total checklist score of the entire study cohort increased from 5.53 (SD = 2.00) at baseline to 7.56 (SD = 1.08) at time 3, a gain of 36.7%. This improvement is not only statistically significant, but also educationally and clinically significant. As noted earlier, these scores suggest that, prior to receiving the training intervention, study participants on average missed more than two essential steps in the procedure, risking tourniquet failure and poor patient outcomes, whereas after the training, they achieved near-perfect performance in placing a tourniquet, increasing the likelihood of success with this lifesaving technique. An additional result frequently observed after training in the mastery learning model is decreased variability in performance: we observed not only improvement in total scores, but also narrower standard deviations in both study groups after participating in the training intervention.

Similar to other studies, we observed that age and rank did not correlate with skill: group B consisted of cadets who, on average, were older and more advanced in their training than those in group A. It is likely that group B students had participated more often in past tourniquet training. Despite these differences, there was no difference in performance, when rigorously measured against established standards, between the two study arms at baseline. Moreover, after participating in the training intervention, the younger/lower rank cadets in group A significantly outperformed the more senior students in group B at time 2. These findings reinforce prior research reports[22] demonstrating that "experience" alone (or "time in grade") is not a proxy for competence.

As might be expected, overall trends in ratings of self-confidence—both in magnitude and direction—mirrored the effects of the training intervention on skills performance. Research has demonstrated poor correlation—typically overestimation—of trainees' (especially novices') self-assessments and actual competence, when objectively measured against established performance standards.[23,24] Nonetheless, the impact of educational interventions on self-confidence and other "reactions" (using the Kirkpatrick evaluation framework[25,26]) can influence, both positively and negatively, later "learning"—either through motivation for continued deliberate practice toward improvement of skills (if, as in the present study, self-confidence is bolstered) or avoidance behaviors and skills degradation (if self-confidence is threatened).

This research has several limitations. First, cadets from a single Army ROTC training unit comprised the entire study cohort. Therefore, although the age/sex distribution of our study population is representative of both officer candidates and enlisted recruits across the Services who would be required to undergo initial training including the Tier 1/TCCC-ASM course, we cannot generalize this study's findings to non-officer trainees, personnel with less than university-level education, or other Service branches. Prior research suggests another possible limitation to generalizability of this study's findings: a trial of the American College of Surgeons Bleeding Control Basic (B-Con) program for civilian bystander first aid demonstrated that skills acquired when training with a C-A-T tourniquet were not fully translatable to other commercial or improvised tourniquet types.[27] By design, however, this study employed the standard-issue tourniquet that ASMs carry in their Joint First-Aid Kit in the context of required TCCC-ASM training for military, not civilian, personnel.

Second, attrition was high after initial study enrollment: out of 69 cadets who provided consent at the outset of the trial and participated in baseline study activities, 26 (37.7%) were unable to complete the entire protocol. Because ROTC training for this cohort of cadets occurred only once per week and the research team traveled from a distance, study occasions comprised discrete one-day visits with no "make-up" opportunities if participants missed follow-up sessions due to illness, quarantine, or scheduling conflicts. A priori power estimates suggested a recruitment goal of at least 34 participants to each arm of the study, while the final cohorts included 25 cadets in group A and 18 cadets in group B. Nonetheless, we observed large, consistent, and sustained improvement attributable to the training, again demonstrating the powerful effect of simulation-based education that has been observed in similar prior research.[5] Moreover, post hoc analyses revealed no significant differences between the total groups present for a given study visit and the final cohorts who completed the study protocol (i.e., participated at all three occasions), with respect to past tourniquet training or real-world experience, self-confidence or, importantly, skill proficiency (Supplementary Digital Content 5, http://links.lww.com/TA/C590).

In addition, because the study occurred during AY2020–2021, shortening of the Spring semester due to the COVID-19 pandemic required slightly earlier testing for time 3 (at 5 months instead of 6 months from study initiation). It is possible that the performance of group B might not have been as high if more time had elapsed after participation in the training intervention. However, taken together, the findings of significant improvement in group A's performance after a full 3 months, the fact that these gains were sustained 2 months later, and the equivalence in performance (i.e., similar direction and magnitude of the

training effects) between group A and group B at time 3, suggest that there would not have been a significant decline in skill proficiency by group B had the full (planned) 3-month interval between time 2 and time 3 been possible.

CONCLUSION

This randomized controlled trial demonstrated that a focused, simulation-based TCCC training intervention—designed and taught according to the Tier1/TCCC-ASM curriculum—resulted in substantial, consistent, and sustained improvement in participants' skill performance and self-confidence in tourniquet placement with little decay over the 5-month time frame of the study. Future investigations can examine longer-term retention versus skill performance decline, which can inform the time interval required for refresher training.

AUTHORSHIP

R.J.S. participated in the design, data acquisition, analysis and interpretation of data, drafting and critical revision of the article. S.B.I. participated in the design, data acquisition, analysis and interpretation of data, drafting and critical revision of the article. M.H. participated in the design, data acquisition, analysis and interpretation of data, drafting and critical revision of the article. R.D.R. participated in the design, analysis and interpretation of data, drafting and critical revision of the article. A.A.B. participated in the data acquisition, drafting and critical revision of the article. M.G. participated in the data acquisition, drafting and critical revision of the article. J.J.G. participated in the design, data acquisition, drafting and critical revision of the article. C.I.S. participated in the design, analysis and interpretation of data, drafting and critical revision of the article.

ACKNOWLEDGMENTS

We wish to acknowledge the invaluable assistance of Donna Fye and Diego Waisman during manuscript preparation. We would also like to recognize SFC Maurice Cubas (Instructor), CPT Myra Novak (Assistant Professor of Military Science), LTC Christopher DeRuyter (Professor of Military Science), and especially the ROTC cadets of the 6th Brigade, U.S. Army Cadet Command, Fighting Knights Battalion at the University of Central Florida, without whose support, professionalism, and enthusiastic participation this study would not have been possible.
This study received support with funding through Defense Health Agency contract numbers W912CG19C0002 and W911NF18C0051.

DISCLOSURE

The authors declare no conflicts of interest.

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