Comparative Effectiveness of Telesimulation Versus In-Person Training for Teaching Tourniquet Application for Life-Threatening Hemorrhage: A Prospective Randomized Controlled Study

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Introduction: Hemorrhage continues to be the leading cause of preventable death in trauma, and tourniquet application has been associated with survival. The purpose of our study was to evaluate the efficacy of telesimulation (TeleSIM) versus in-person training (SIM) for teaching tourniquet application for life-threatening hemorrhage control.

Methods: We performed a prospective randomized study of participants enrolled in a Stop The Bleed course at a university medical school. The TeleSIM group completed the course with an instructor streaming live from an off-site location. The SIM group completed the course in the standard fashion with a live instructor present. The primary endpoint was the successful application of a combat application tourniquet to a bleeding extremity in a simulation scenario. We also evaluated the time for successful tourniquet application according to training modality. Participants' thoughts, feelings, and attitudes pertaining to their experience in the course were obtained via a postcourse survey.

Results: Ninety-four of 97 (96.9%) eligible subjects participated in the study. There was no difference in the proportion of participants in each group who successfully applied a combat application tourniquet during their simulation scenario: TeleSIM group, 100% (95% CI, 92.5–100.0); SIM group, 100% (95% CI, 92.7–100.0). We also observed no significant difference in the mean time it took the participants to apply a tourniquet regardless of their training modality. Both groups reported their learning modality as an effective way to learn hemorrhage control.

Conclusion: A telesimulation-based instructional delivery design is an effective way to teach tourniquet application for hemorrhage control.

Key Words: Telesimulation, tourniquet, hemorrhage control, Stop The Bleed, mass casualty incident

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Acts of terrorism threaten the health, safety, and well-being of communities worldwide. In recent decades, the incidence of active shooter events and mass casualty incidents (MCIs) has been rising in the United States.[1–3] In reviews of active shooter incidents produced by the US Department of Justice, the Federal Bureau of Investigation (FBI) reports that since 2000, there have been at least 484 active shooter incidents with more than 3,571 casualties.[4–7] The life-threatening injuries incurred from these acts of terrorism primarily result from penetrating injuries. Specifically, death from hemorrhagic shock is a preventable cause of death that can be reduced with simple resources and adequate training.[1,8,9]

Hemorrhage continues to be the leading cause of preventable death in trauma and can result from an active shooter event or detonation of an explosive device.[1,10] The application of a tourniquet in the prehospital setting can prevent death from hemorrhagic shock and has been associated with survival. It has been reported that in civilian trauma patients, delaying tourniquet application to a bleeding extremity was associated with a 4.5-fold increased odds of mortality from hemorrhagic shock.[8] Other benefits of prehospital tourniquet application have been described, and these include a decreased incidence of shock and increased mean systolic blood pressure on hospital arrival, decreased use of blood transfusions, and decreased hospital length of stay.[11–15] Owing to its conferred benefits, the tourniquet has become a critical resource used by first responders and prehospital care providers for the management of hemorrhagic shock. It has only been recently, however, where a significant and concerted effort to educate and train the public on tourniquet use has ensued.

Although also influenced by MCIs occurring during the previous years, it was the mass shooting at Sandy Hook Elementary School (in which 20 first-grade school children and 6 school staff were killed on December 14, 2012 in Newton, Connecticut) that catalyzed the cooperative effort of many stakeholders to take action to address this public health crisis.[16–18] In 2013, the "Joint Committee to Create a National Policy to Enhance Survivability from Intentional Mass Casualty and Active Shooter Events" was convened by the American College of Surgeons, in collaboration with the medical community and representatives from the federal government, the National Security Council, the US military, the FBI, and governmental and nongovernmental emergency medical response organizations.[19–21] The committee was assembled to create a protocol for a national policy to enhance survivability from active shooter and intentional mass casualty events. The committee's recommendations are called "The Hartford Consensus."[22,23]

In 2015, the White House launched the "Stop The Bleed" (STB) campaign, a national awareness campaign and call to action designed to encourage bystanders to become trained, equipped, and empowered to help in a bleeding emergency before professional help arrives.[24–27] Nationwide efforts have led to increased hemorrhage control education within schools, hospitals, law enforcement, public gathering venues, and workplaces. The STB courses have been shown to improve participant comfort, willingness to aid, and the correct placement of a tourniquet in hemorrhagic emergencies.[28–36] A major goal of the STB campaign is to train 200 million individuals.[26] Since the initiative launched in 2017, 2.4 million people have been trained.[26] Although with an increase in the number of individuals trained to STB, this rate of progress represents only a 1.2% completion of the goal over a 6-year period. Several challenges to scaling this public health campaign include (but are not limited to) access to subject matter experts to teach course content, limited geographic locations where the course is offered, time and distance barriers for both instructors and learners, and cost. The COVID-19 pandemic has served only to further constrain the dissemination of the content provided in the STB course. Furthermore, MCIs occur globally, in many areas around the world that have no access to subject matter experts or course materials. Telesimulation is a potential solution to address the implementation and scalability challenges faced by the STB campaign.

Telesimulation is the process by which telecommunication and simulation resources are utilized to provide education, training, and/or assessment to learners at an off-site location.[37] Studies in telesimulation have demonstrated its effectiveness in both the cognitive and psychomotor domains of learning.[37,38] Early studies using telesimulation to train healthcare providers at off-site locations in topics such as MCIs and active shooter events have also demonstrated the feasibility of this new educational delivery method.[39,40] Telesimulation is a new educational delivery method that has seen its adoption and implementation accelerate in the wake of the COVID-19 pandemic owing to its reported benefits. This educational delivery method can address the scalability challenges faced by the STB campaign, and more importantly, has the potential to save lives by reducing the incidence of preventable death from uncontrolled hemorrhage. To our knowledge, there are no prospective randomized controlled studies evaluating the effectiveness of telesimulation to teach tourniquet application for hemorrhage control. The objective of our study was to evaluate the comparative effectiveness of telesimulation (TeleSIM) versus standard in-person simulation training (SIM) for teaching learners tourniquet application for hemorrhage control.

METHODS

Study Design and Setting

We conducted a prospective, randomized, nonblinded study over a 12-month period in a simulation center at a University of California (UC) medical school. The UC Irvine Health Medical Education Simulation Center is located within a 65,000-square-foot state-of-the-art medical education center that provides telemedicine and simulation-based educational programs, and continuing medical education courses for thousands of healthcare providers each year.[41] Resources for education and training include, but are not limited to, a full-scale operating room, emergency department trauma bay, obstetrics suite, and a critical care unit. The simulation center has a complement of full-time staff, including full-time simulation specialists.

Selection of Participants

All medical students in their preclinical years and undergraduates of the university with an interest in health-related fields were eligible. Students who had previously taken the STB course were excluded from the study. Simulation-based education and training is integrated into the core curriculum during the preclinical years at the school of medicine. Students were offered voluntary participation in the study via communication through the school of medicine's Simulation Interest Group for the STB course being offered on the school of medicine campus. Use of the simulation center was not restricted to the study, and results of the study did not affect medical school or undergraduate course evaluations as the STB course is an independent course available to the general public. The study was approved by the university institutional review board, and subjects provided informed consent.

Study Protocol and Measures

Participants were randomized to either the simulation (SIM) group or telesimulation (TeleSIM) group with a computerized random-number generator. Participants in the SIM group were provided an in-person learning experience. The STB campaign is a national public health campaign that provides this course all throughout North America. Certified instructors are provided the educational content and materials to deliver the didactic and practical application sections of the course. The course includes a didactic component, tourniquet demonstration, and a practical application session where students apply a tourniquet to a procedural task trainer of a limb that has sustained a penetrating wound. Following the didactic component (which includes slides provided by the STB campaign) and live step-by-step tourniquet application demonstration by the instructor, the students were broken up into groups of 2 to 3 to practice tourniquet application with the course instructor available to provide in-person real-time feedback and answer questions. Educational delivery methods including rapid cycle deliberate practice (RCDP) were used to ensure skill mastery was achieved during the practical application component of the course. The average size of each STB course offered was approximately 12 students per session, lasting approximately 1 hour. The instructors in this study were certified STB course instructors and board certified in both emergency medicine and emergency medical services.

Participants in the TeleSIM group were provided the identical course as the SIM group, with the only exception being that the content was remotely delivered from an instructor at an off-site location. Both the instructor and participants had access to telecommunication resources for the course, which included a laptop computer with camera, a large flat screen wall-mounted TV/monitor, a smart tablet (iPad), and smartphone. The instructor used a camera-equipped laptop to deliver the didactics and provide the tourniquet demonstration. The simulation center conference room is equipped with audio/visual resources that allowed participants to see and hear the instructor through the large flat screen monitor. Communication was established using Zoom software (Zoom Video Communications, Inc, San Jose, CA). Zoom is a video communication application that allows users to conduct remote video and audio teleconferences, screen-share, and live chat with several users at once. Zoom had no part in the design or implementation of this project.

Similar to the SIM group, the TeleSIM group course included a didactic component, tourniquet demonstration, and a practical application session where students applied a tourniquet to a procedural task trainer of a limb that had sustained a penetrating wound. Following the real-time teleconferenced didactic component and live step-by-step tourniquet application demonstration by the instructor from an off-site location, the students were broken up into groups of 2 to 3 to practice tourniquet application with the course instructor available to provide real-time feedback and answer questions. This component of the course was facilitated with the use of audio/video equipment, including a large flat screen wall-mounted monitor, laptop, tablet device, and smartphone. A research assistant was available at the student site to set up the course materials, take student attendance, and troubleshoot any potential audio/visual issues as the course instructor was located at an off-site location.

After the practical application component of the course, the students were evaluated during a simulation scenario in which a patient sustained a penetrating extremity wound with a life-threatening bleed. The simulation scenario used the STB procedural task trainers to simulate a bleeding extremity. After the researcher/course assistant read the scenario introduction out loud, a timer was started and the students' task was to evaluate the patient and appropriately apply the combat application tourniquet (CAT). After tourniquet application, the students indicated to the course assistant that they had finished by placing their randomly assigned participant number on top of the procedural task trainer next to the tourniquet they had just applied. This action stopped the timer for their scenario.

Measures

The main outcome measure was the successful application of the combat application tourniquet to the bleeding extremity. The criteria for successful tourniquet application included recognition of the life-threatening penetrating wound, placement of the combat application tourniquet proximal (approximately 2 to 3 in) to the wound, adequate pressure such that the evaluator could not slide a finger underneath the tourniquet, locking the tourniquet in place with the windlass rod, and securing the rod with the windlass strap.[42–45] The data for each of the criteria were recorded in standardized data collection sheets. Data from each participant were independently assessed by 2 evaluators who were blinded to the students' assigned intervention group. The blinded assessments were conducted using a standardized assessment form that included pictures of the tourniquet applied during the simulated scenario (see document, Supplemental Digital Content 1, Tourniquet Application blind review data collection sheet, http://links.lww.com/SIH/B187). Each evaluator underwent training with regard to reviewing the specific outcome measures and completing the data collection sheet. The threshold for successful tourniquet application was 80% (4 of the 5 tourniquet application criteria). Any discrepancies between the 2 reviewers were resolved using a third reviewer where appropriate.

We also collected data to evaluate the time for successful tourniquet application. The simulation scenario was delivered in a standardized process to each participant, which included reading aloud the context for the scenario (a case of a patient experiencing a life-threatening penetrating extremity injury) and starting the timer after announcing "your case begins now." Students were informed beforehand to place their randomly assigned number on top of the wounded extremity to indicate they have completed their task. This action was the trigger to stop the timer. The times were recorded in seconds.

Our secondary outcome was a survey evaluating the perceptions and attitudes the participants had toward their experience with the standard in-person versus the telesimulation course. The survey was distributed directly after their simulation scenario and was available in either paper or digital format. The digital format was provided by an online survey, which was made accessible by QR codes placed on the walls for the participants to scan with their smartphone and to complete in real time.

Statistical Analysis

We calculated a sample size of 84 total subjects needed in this prospective randomized study to have a power of 80% for detecting an effect size of 5 percentage points on the tourniquet application completion checklist when comparing the TeleSIM and SIM groups. Discrete data are presented as count (%) and continuous data as mean scores with associated standard deviations. Mean evaluation scores were calculated (point estimates) along with 95% confidence intervals. We also present medians and interquartile ranges for data that are not normally distributed. Chi-squared analysis was used to evaluate the dichotomous variable of pass versus no-pass. A 2-tailed alpha (type I error rate) of 0.05 was used as the threshold for statistical significance. IBM SPSS statistics version 27.0 (Released 2020, IBM SPSS Statistics for Windows, Version 27.0: IBM Corp, Armonk, NY) was used for data analysis.

RESULTS

Of 97 eligible subjects, 94 participated in the study (96.9%) (Fig. 1). Participant demographic characteristics included those independent variables thought to have an impact on the primary outcome (Table 1).

For the primary outcome of the study, we found no significant difference in the proportion of participants in each group who successfully applied a combat application tourniquet during their simulation scenario: TeleSIM group, 100% (95% CI, 92.5–100.0), and the SIM group, 100% (95% CI, 92.7–100.0) (Table 2). We observed no significant difference in the mean time it took the participants to apply a tourniquet regardless of their training modality (Table 2). We also found no significant difference in quantitative scores between the groups on the 5-point tourniquet application performance checklist (Table 3). There were no discrepancies in outcome evaluation scores between the 2 blinded reviewers.

For our secondary outcome, we found no significant difference in the favorability of teaching modality (SIM versus TeleSIM) for learning tourniquet application for hemorrhage

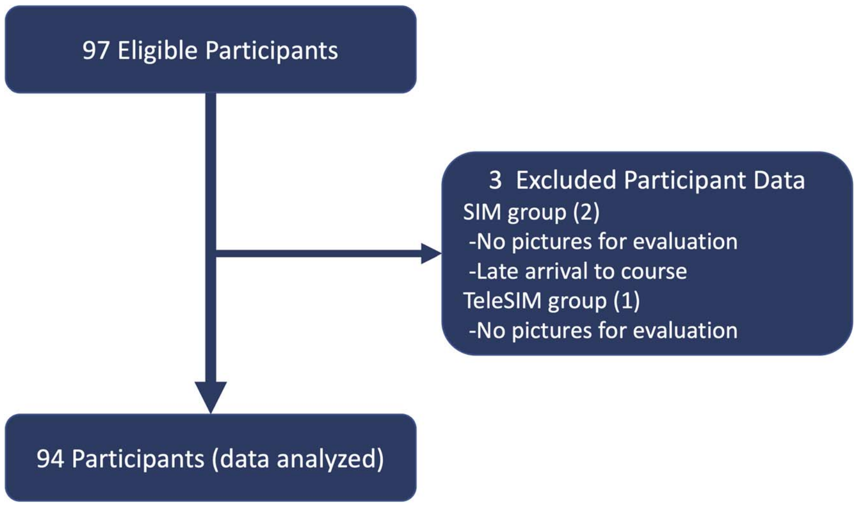

FIGURE 1. Flow diagram for participants in the study.

TABLE 1. Participant Demographics for Randomized Study of Telesimulation (TeleSIM) Versus Standard Simulation (SIM) for Teaching Tourniquet Application for Life-Threatening Hemorrhage

	Group					
	Simulation		Telesimulation		Total	
	Count	Column N %	Count	Column N %	Count	Column N %
Gender						
Female	27	56.3%	34	73.9%	61	64.9%
Male	20	41.7%	12	26.1%	32	34.0%
Nonbinary	1	2.1%	0	0.0%	1	1.1%
Age						
18–25	42	87.5%	43	93.5%	85	90.4%
26–30	4	8.3%	3	6.5%	7	7.4%
31–35	1	2.1%	0	0.0%	1	1.1%
36–40	1	2.1%	0	0.0%	1	1.1%
41–45	0	0.0%	0	0.0%	0	0.0%
46–50	0	0.0%	0	0.0%	0	0.0%
Education year						
First-year undergraduate	11	22.9%	7	15.2%	18	19.1%
Second-year undergraduate	9	18.8%	2	4.3%	11	11.7%
Third-year undergraduate	9	18.8%	6	13.0%	15	16.0%
Fourth-year undergraduate	3	6.3%	7	15.2%	10	10.6%
Fifth-year undergraduate	0	0.0%	1	2.2%	1	1.1%
First-year graduate	8	16.7%	13	28.3%	21	22.3%
Second-year graduate	8	16.7%	10	21.7%	18	19.1%
Third-year graduate	0	0.0%	0	0.0%	0	0.0%
Fourth-year graduate	0	0.0%	0	0.0%	0	0.0%
Previous experience with hemorrhage control course?						
Yes	10	20.8%	7	15.2%	17	18.1%
Previous experience with tourniquet placement?						
Yes	13	27.1%	10	21.7%	23	24.5%
Pass or fail from reviewer A						
Pass	48	100.0%	46	100.0%	94	100.0%
Pass or fail from reviewer B						
Pass	48	100.0%	46	100.0%	94	100.0%

TABLE 2. Proportion of Participants With Successful Tourniquet Application (%) and Mean Time for Tourniquet Application According to Training Modality

Training Modality	Successful CAT Application (%)	95% CI	Mean Time (s) for CAT Application	SD
SIM	100	92.5–100.0	35.0	13.3
TeleSIM	100	92.7–100.0	35.3	13.9

control on the postcourse survey (Fig. 2). Regardless of training modality, the learners reported that they believed this type of teaching was an effective way to learn about hemorrhage control and to practice skills such as tourniquet application. The learners also shared similar favorability responses regarding their belief that this type of teaching was beneficial to their learning and reported that they would participate in this type of learning modality in the future (Fig. 2).

DISCUSSION

In our prospective randomized parallel arm study evaluating the comparative effectiveness of telesimulation versus standard in-person training for teaching learners tourniquet application for hemorrhage control, we found no significant difference between the 2 groups. Specifically, we found no significant difference in the proportion of participants in each group who successfully applied a combat application tourniquet during a simulation scenario of a life-threatening hemorrhage from a penetrating extremity injury. We also found no significant difference in the mean time it took the participants to apply a tourniquet regardless of their training modality. To our knowledge, this is the first prospective randomized study evaluating the comparative effectiveness of telesimulation versus standard in-person training for teaching learners tourniquet application for life-threatening hemorrhage control.

The benefits of telesimulation have been described and include, but are not limited to, allowing for the education, training, and/or assessment of learners at an off-site location; eliminating time and distance barriers to educational content delivery; providing added convenience for both learners and educators; providing cost savings to individuals, programs, and institutions; and allowing for interinstitutional networking and collaboration.[37] Given that telesimulation is a relatively new niche in medical education, the evidence base supporting its use is limited in both quantity and methodologic rigor. Our findings support earlier research that has found telesimulation to be an effective delivery method for teaching healthcare providers in the psychomotor domain of learning.[46–50]

With specific regard to education and training in hemorrhage control for life-threatening penetrating injuries, our findings also support the early research demonstrating the benefit of simulation training. In a prospective evaluation of tourniquet application in law enforcement officers and private security personnel, Ali et al[28] employed a quasi-experimental study design to evaluate the effectiveness of an STB course given to 151 participants and found improved tourniquet application performance. The authors concluded that an STB course improved correct tourniquet placement, demonstrated improvements in application time, and increased levels of comfort.[28] In a prospective randomized study reported in *JAMA Surgery*, 465 laypersons were randomized into 4 arms (instructional flashcards, audio kits with embedded flashcards, B-Con [Bleeding Control] course, and control) to evaluate the effectiveness of different instructional point-of-care interventions and in-person training with no intervention for hemorrhage control and to assess skill retention 3 to 9 months after training.[33] The authors reported that for correct tourniquet application, B-Con (88% correct application) was superior to control (16% correct application), while instructional flashcards (19% correct application) and audio kit (23% correct application) were not.[33] All participants received B-Con training to later assess knowledge and skill retention, in which 54.5% were reported to be able to correctly apply the tourniquet 3 to 9 months after their initial assessment. The authors concluded that in-person hemorrhage control training for laypersons is currently the most efficacious means of enabling bystanders to act to control hemorrhage.[33] And in a prospective observational study of 298 nonmedical potential first responders (PFRs) that evaluated the effectiveness of STB training with and without a hands-on practical application component, the authors reported that the PFRs scored higher on the knowledge-based post-test. They concluded that knowledge related to hemorrhage control increased following the STB course and that participants who had hands-on practice for tourniquet and wound packing were more proficient than those who only saw the lecture.[36] These studies, along with other research in the field of education and training for hemorrhage control, have demonstrated the effectiveness of simulation-based training, from high school students to medical professionals.[51,52]

Our study adds a unique contribution to the evidence base that supports simulation-based training for life-threatening hemorrhage control. First, this is the first prospective randomized

TABLE 3. Quantitative Scores on 5-Point Tourniquet Application Checklist According to Intervention Group

	Count	Mean	Standard Deviation	95.0% Lower CL for Mean	95.0% Upper CL for Mean	Minimum	Maximum	Median	Percentile 25	Percentile 75
Group										
Simulation										
Total score for reviewer A	48	5	0	5	5	5	5	5	5	5
Total score for reviewer B	48	5	0	5	5	5	5	5	5	5
Telesimulation										
Total score for reviewer A	46	5	0	5	5	5	5	5	5	5
Total score for reviewer B	46	5	0	5	5	5	5	5	5	5

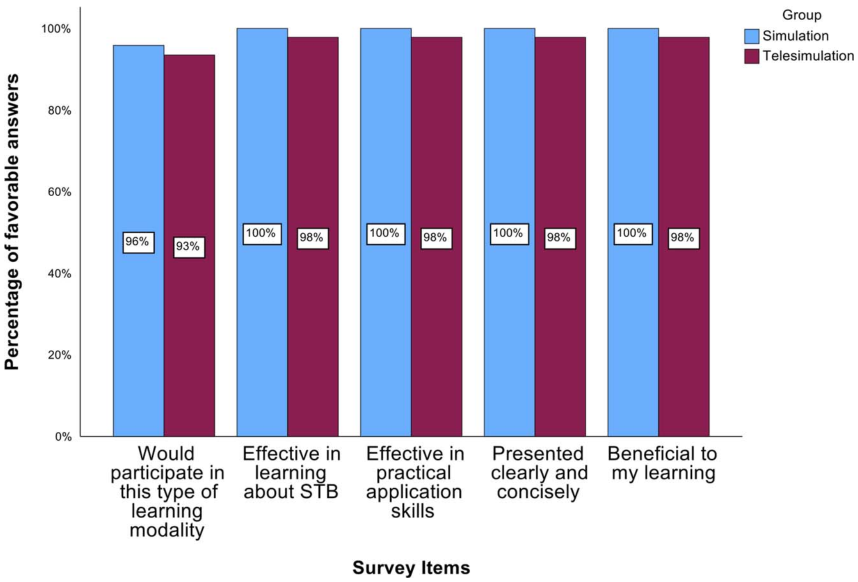

FIGURE 2. Percentage of favorable responses according to simulation modality. Survey questions: (1) I would participate in this type of learning modality in the future; (2) I believe this type of teaching was an effective way to learn about hemorrhage control; (3) I believe this type of learning was an effective way to practice application skills, such as tourniquet application; (4) I believe the educational material and skill demonstration was presented clearly and concisely; (5) I believe this type of teaching was beneficial to my learning.

study, to our knowledge, that evaluates the comparative effectiveness of telesimulation versus standard simulation (in-person training) for teaching learners tourniquet application for life-threatening hemorrhage control. The current literature in the field of hemorrhage control training (specifically for the national STB campaign content) has demonstrated that in-person simulation-based training is the most effective delivery method, when compared with other teaching modalities, which include, but are not limited to, lecture only, web-based training, and just-in-time instructional flash cards and audio kits.[28,33,36,51,52] Our study demonstrated no significant difference in successful tourniquet application or time to application between the telesimulation and in-person standard simulation groups.

Telesimulation has the potential to overcome the scalability challenges associated with in-person training that has been described in the literature.[33] Specifically, telesimulation may serve as a potential pathway to accelerate and reach the major goal of the STB campaign to train 200 million individuals, of which just more than 1% have been trained over the span of 6 years.[26] This potential lies in the benefits of telesimulation, which include allowing for the education, training, and/or assessment of learners at an off-site location; eliminating time and distance barriers to educational content delivery; providing added convenience for learners and educators; providing cost savings; and allowing for interinstitutional collaborative partnerships.

Our study is also unique in that we explicitly incorporated RCDP into our course protocol. RCDP is a type of simulation-based medical education where learners cycle between deliberate practice and direct feedback until skill mastery is achieved before progressing to subsequent learning objectives.[53–55] To our knowledge, we are the first to incorporate this type of educational delivery method into the practical application component of the STB course. We believe this to be a major contributing factor on why both groups had high tourniquet application success rates (all participants in both groups were able to successfully apply the tourniquet). The success rates of our learners are higher than that reported in the literature (high 80% to low 90%).[28,33] Although potentially time and labor intensive, we believe incorporating RCDP into courses teaching content in the psychomotor domain of learning maximizes the opportunity for skill mastery.

Our secondary outcome evaluated the learners' thoughts, feelings, and attitudes on their hemorrhage control course via a postcourse survey. We found no significant difference between the groups regarding their belief that this type of teaching was an effective way to both learn about and practice hemorrhage control, their belief in their teaching modalities' benefits, their perception of clarity of content, and their desire to participate in this type of learning in the future (Fig. 2). The dominant theme from the free text responses centered on the learner's enjoyment of the practical application component in which RCDP was implemented. Participants remarked, *"I liked how it was a hands-on experience. I enjoyed the hands-on aspect and how clear the presentation and instructions were,"* and *"Practicing the application of the tourniquet more than once was really helpful to remember the steps."* Our favorable results in the affective domain of learning are in concert with previous literature for education in hemorrhage control.[28,38,51]

Limitations

First, our study did not evaluate the educational intervention on actual patients experiencing life-threatening hemorrhage from a penetrating injury. As such, our study shares the limitation of educational studies with outcome metrics not specifically measuring actual patient data. To our knowledge, no studies exist that implement the educational modality we evaluated with the main outcome measured on real patients. Second, the participants in our study were not blinded to their treatment group (SIM versus TeleSIM). Owing to the nature of the educational modality, blinding of the participants was not possible. However, we believe that participants being aware of their treatment modality would not have any substantive impact on the objective outcome measure of successfully applying a tourniquet to an extremity sustaining a life-threatening hemorrhage. Some participants in our study reported prior exposure to the topic outside of the STB course. We felt this was an important independent variable to measure in the context of interpreting any differences in outcome between the groups. We noted that a few more individuals in the simulation group had prior exposure to the topic, yet no statistically significant difference between the groups was observed. We believe this observation further strengthens the notion that this topic could be learned from an off-site location. And last, our study did not measure (nor intend to measure) long-term retention of the skills learned during the educational session. Studies suggest that there is a knowledge and skill decay that occurs over time in the context of hemorrhage control training.[33] Our study is unable to provide estimates on the long-term retention of the skills learned during the course.

CONCLUSION

In our prospective randomized study evaluating the comparative effectiveness of telesimulation versus standard in-person training for teaching learners tourniquet application for life-threatening hemorrhage control, we found no significant difference in the proportion of participants in each group who successfully applied a combat application tourniquet. There was also no significant difference in the favorability of one teaching modality reported on a postcourse survey. Our data support and highlight the capability of telesimulation to scale the nationwide (and worldwide) efforts to increase hemorrhage control education, even to learners at off-site locations who may not have direct access to local STB courses. Further research is needed to establish the evidence base for telesimulation in hemorrhage control training.

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