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AEM Education and Training

ORIGINAL CONTRIBUTION

Effectiveness of a virtual reality trainer for retention of tourniquet application skills for hemorrhage control among emergency medicine residents

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Abstract

Background: With a rise in mass casualty incidents, training in hemorrhage control using tourniquets has been championed as a basic—and lifesaving—procedure for bystanders and medical professionals alike. The current standard for training is in-person (IP) courses, which can be limited based on instructor availability. Virtual reality (VR) has demonstrated the potential to improve the accuracy of certain medical tasks but has not yet been developed for hemorrhage control. The objective of this study was to evaluate the efficacy of a VR hemorrhage trainer in learner retention of tourniquet application when compared to traditional IP instructor teaching among a cohort of emergency medicine residents practicing in a Level I trauma center.

Methods: This was a prospective, observational study of 53 emergency medicine residents at an inner-city program. Participants were randomly assigned to either the control or the VR group. On Day 0, all residents underwent a training session (IP vs. VR) for the proper, stepwise application of a tourniquet, as defined by the American College of Trauma Surgeons. Each participant was then assessed on the application of a tourniquet by a blinded instructor using the National Registry Hemorrhage Control Skills Lab rubric. After 3 months, each resident was reevaluated on the same rubric, with subsequent data analysis on successful tourniquet placement (measured as under 90 s) and time to completion.

Results: Of the 53 participants, the IP training group had an initial pass rate of 97% (28/29) compared to 92% (22/24) in the VR group ($p = 0.58$). On retention testing, the IP training group had a pass rate of 95% (20/21) compared to 90% (18/20) in the VR group ($p = 0.62$). Stratifying the success of tourniquet placement by level of resident training did not demonstrate any statistically significant differences.

Conclusions: In this pilot study of emergency medicine residents, we found no significant differences in successful hemorrhage control by tourniquet placement between those trained with VR compared to a traditional IP course among emergency medicine

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residents. While more studies with greater power are needed, the results suggest that VR may be a useful adjunct to traditional IP medical training.

KEYWORDS
emergency medicine residents, hemorrhage control, resident education, Stop the Bleed, tourniquet, VR

INTRODUCTION

Since 2000, there has been a drastic rise in mass casualty incidents (MCIs) in the United States.[1,2] Among all causes of "preventable" deaths in these situations, uncontrolled hemorrhage was by far the most common.[3] In an effort to mitigate this alarming trend, tourniquet use was publicly championed as a basic procedure that should be taught to both medical professionals and laypersons for "on-field" hemorrhage control.[4] Although initial data supported an association with tourniquet use and increased survival,[4,5] subsequent research also found that if placed incorrectly, a tourniquet's effectiveness can significantly deteriorate and potentially worsen bleeding.[6]

The current standard for teaching tourniquet placement is through an in-person (IP) Bleeding Control Basic (B-Con) course, which teaches basic hemorrhage control by both tourniquet application and junctional wound packing.[7] Although presumed to be the most efficient way of teaching bystanders and medical providers, prior studies have shown that there is poor retention of tourniquet placement skills, with as many as 46% of participants failing to remember the appropriate steps three to 9 months post–B-Con course.[5] In addition, these lessons are cost-intensive and have limited availability, often precluding trainees from taking "refresher" courses to maintain skill retention.[8] Therefore, alternate trainings must be considered and evaluated.

There is a growing body of evidence to suggest that virtual reality (VR) can be used as an effective adjunct for medical training.[8] VR can significantly improve the accuracy and speed of medical tasks[9] and can provide similar learner outcomes in identifying critical actions when compared to traditional methods.[10] VR training provides a controlled, individualized learning environment, where users can repeatedly practice a task without utilizing precious resources while receiving real-time feedback to create a sequence-driven learning experience.[11]

Being that tourniquet placement is a crucial skill for medical professionals and given VR's utility in medical education has been gaining more interest, we sought to compare the retention of tourniquet placement skills between IP VR training to the current standard of IP lecture training among a cohort of emergency medicine residents practicing in a Level I trauma center. The objective of this study was to evaluate the efficacy of a VR hemorrhage trainer in learner retention of tourniquet placement compared to traditional IP instructor teaching. We hypothesize that developing a VR module that simulates proper tourniquet application can be an effective instrument to independently train emergency medicine residents and that there will be no significant difference in tourniquet placement and time to completion when comparing VR-trained to traditional IP instructor–trained participants.

METHODS

Study design and population

This was a single-blind, prospective, clustered randomized two-arm observational study of 53 first- to fourth-year (PGY-1 to -4) emergency medicine resident physicians at the Albert Einstein College of Medicine//Jacobi + Montefiore Medical Centers. After approval from the Albert Einstein College of Medicine Institutional Board Review, the study was conducted over the course of 3 months, with all participants joining voluntarily and informed consent was given. Any participants who had taken prior "Stop The Bleed"-specific hemorrhage control training were excluded from the project, and all residents had the option of withdrawing from the study at any time.

At the start of the program, all participants were explained the purpose of the research study. This included the intended outcomes of teaching proper tourniquet application for a life-threatening bleed and assessing VR's efficacy as a medical education tool for doing so. From there, residents were assigned an identification study number and randomized into one of two study arms: (1) control/IP lecture and (2) VR. IP hemorrhage control training was done in a large lecture hall using certified instructors within this research team, and VR headset–mediated training was conducted in a separate breakout room proctored by other members of the research team who were familiar with the coded modules.

At Day 0, all participants underwent an initial training session (IP vs. VR) for stepwise application of tourniquet placement for an actively hemorrhaging wound, as agreed upon by the nationally recognized guidelines from the American College of Trauma Surgeons and Stop the Bleed campaign.[13] Each participant was then scored on a physical assessment of tourniquet application by blinded evaluators using the standardized, National Registry Hemorrhage Control Skills Lab rubric (considered the criterion standard for testing).[14] Three evaluators were utilized during the study; all were emergency medicine board–certified physicians trained in tourniquet placement and blinded to the study protocol and interventions. Raters were calibrated with the standardized scoring checklist prior to the initial assessment of residents using multiple scenarios, and raters were asked to strictly adhere

to the printed copy of the New York State (NYS EMT) tourniquet skills rubric as the assessment tool to ensure inter-rater reliability. This initial data was recorded as baseline characteristics for each participant.

At Day 90, each participant was again reevaluated on the same scored physical assessment of tourniquet application by the same blinded evaluators. Raters were again unaware of assignments for graded participants and asked to adhere to the same NYS EMT tourniquet skills rubric. Final assessment scores were collected, analysis was run on skills and retention of each group, and comparisons were made to test for differences in tourniquet application between the two groups.

Key outcomes measured

The main objective of this study was to evaluate the efficacy of a VR hemorrhage trainer in learner retention of IP tourniquet skills compared to traditional IP instructor teaching. The primary outcome of interest was successful tourniquet placement in under 90 s. PGY training level was controlled for when measuring this. Secondary outcomes included time to completion of tourniquet placement after 3 months posttraining and analyzing general trends in time differences and success rates between the two groups when comparing the initial and final assessment.

Interventions

Participants in the IP arm received a 0.5-h, hemorrhage control lecture by certified instructors within the research team adhering to the nationally standardized guidelines provided by the American College of Trauma Surgeons and Stop the Bleed campaign.[13] This course included hands-on training on how to apply PPE, how to assess victims, how to identify scene safety, how to identify the location of a life-threatening bleeding, how to apply pressure while packing a wound, and how to apply a tourniquet. Proper tourniquet technique and correct tourniquet application sequence were particularly emphasized during the discussion and real-time feedback was provided to each participant as needed.

Participants in the intervention arm received VR training through a module that mirrored the standardized guidelines for tourniquet application. The VR program was developed by TrainXR in partnership with the researchers and was coded with the intention to utilize sequence-driven learning to teach proper hemorrhage control in a photorealistic interactive training environment. There was no cost incurred by the research team for its development and no financial agreements or interests were made with TrainXR for this study. The VR program consisted of two modes: (1) tutorial and (2) training. The participants in the intervention group trained in both modes once. The tutorial mode allowed the trainee to follow a virtual instructor step-by-step for the same necessary steps of PPE application, assessing victims, identifying scene safety, identifying the location of life-threatening bleeding, applying pressure while packing a wound, and eventual tourniquet application. The training mode provided an opportunity for repeat practice without the virtual instructor and displayed prompts when mistakes were made. The two modes, on average, would take a participant who was unfamiliar with VR roughly 25 min to complete. All participants were made aware of the critical steps in the scored assessments that would result in failure if missed: correctly applying PPE, applying the tourniquet in an incorrect location, not tightening the tourniquet adequately, or not verbalizing when the bleeding had stopped.

Data analysis

All statistical analysis was performed using STATA v16.1. Baseline characteristics are reported as mean ± SD or median (IQR) if not normally distributed. Dichotomous variables are reported as *n/N* (%). Significance is defined as $p < 0.05$. The association of IP versus VR training with successful tourniquet placement is reported using Fisher's exact test. The associations of resident training level (dichotomized to junior residents and senior residents) and gender with successful tourniquet placement is reported using Fisher's exact test. Results were stratified by resident training level, with PGY-1 and PGY-2 residents defined as junior residents; PGY-3 and PGY-4 residents were defined as senior residents.

RESULTS

Eighty-three resident physicians were eligible for participation, of whom 53 (63.8%) were enrolled and underwent training and initial evaluation. Thirty residents were excluded due to timing conflicts, but all enrolled participants completed training successfully. No residents required exclusion due to their inability to tolerate VR headsets or reported side effects such as nausea or headaches while interacting with the software. Thirty-one of 53 (61%) were junior residents in the cohort. Follow-up at 3 months was completed for 41/53 (77%) participants, with only 12 residents being lost to follow-up due to time constraints. Twenty-four of 41 (59%) were junior residents. The study flowchart of control and intervention groups is shown in Figure 1.

The rate of successful tourniquet placement (pass rate) after initial evaluation for all participants was 94% (50/53). Among participants randomized to the IP training group, the initial pass rate was 97% (28/29); the rate was 92% (22/24) in the VR group ($p = 0.58$). At the 3-month follow-up, the pass rate among all respondents was 93% (38/41). Among participants who were randomized to the IP training group, the pass rate was 95% (20/21); the pass rate was 90% (18/20) in the VR group ($p = 0.61$; Table 1).

After being stratified by level of training, 94% (16/17) of juniors in the IP group and 87% (13/15) in the VR group initially successfully placed a tourniquet, compared to 100% of senior residents in both groups. At 90 days, 92% (11/12) of juniors in both IP and VR groups

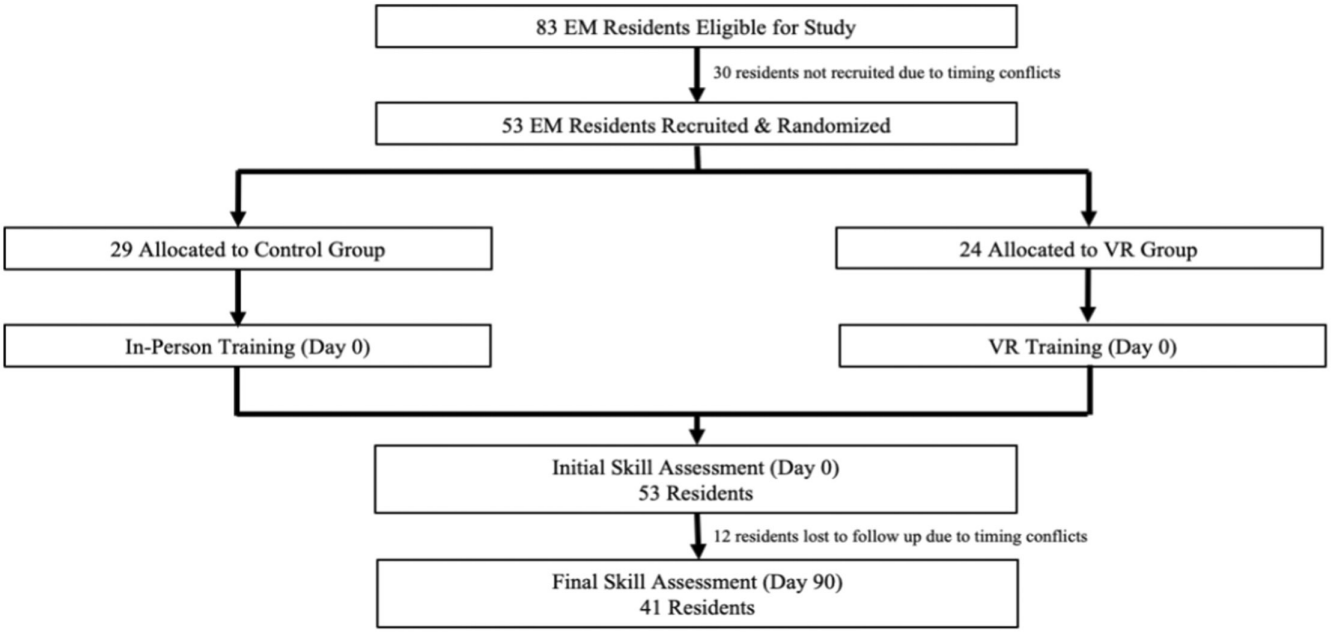

FIGURE 1 Study flowchart of control and intervention groups. VR, virtual reality.

TABLE 1 IP versus VR tourniquet placement training.

	Initial			90 days		
	IP	VR	*p*-value	IP	VR	*p*-value
Successful placement	97% (28/29)	92% (22/24)	0.58	95% (20/21)	90% (18/20)	0.61
Time to placement (s)	51 ± 19.35	52 ± 25.92	0.91	62 ± 50.14	60 ± 23.11	0.19
Called 9-1-1	79% (23/29)	92% (22/24)	0.27	38% (8/21)	55% (11/20)	0.35
Scene safety	83% (24/29)	96% (23/34)	0.2	38% (8/21)	45% (9/20)	0.75

Abbreviations: IP, in person; VR, virtual reality.

TABLE 2 IP versus VR training stratified by training level.

	Initial				90 days			
	Junior resident		Senior resident		Junior resident		Senior resident	
	IP	VR	IP	VR	IP	VR	IP	VR
Successful placement	94% (16/17)	87% (13/15)	100% (12/12)	100% (9/9)	92% (11/12)	92% (11/12)	100% (9/9)	88% (7/8)
Time to placement (s)	48 ± 18.88	50 ± 27.04	54 ± 20.29	57 ± 24.97	71 ± 62.14	61 ± 20.27	52 ± 26.34	57 ± 28.65
Called 9-1-1	88% (15/17)	93% (14/15)	67% (8/12)	89% (8/9)	17% (2/12)	50% (6/12)	67% (6/9)	63% (5/8)
Scene safety	94% (16/17)	93% (14/15)	67% (8/12)	100% (9/9)	42% (5/12)	42% (5/12)	33% (3/9)	50% (4/8)

Abbreviations: IP, in person; VR, virtual reality.

successfully placed a tourniquet, compared to 100% of senior residents in the IP group and 88% (7/8) in the VR group. Stratifying the success of tourniquet placement by the level of resident training did not demonstrate any statistically significant differences (Table 2).

On the initial evaluation, two participants in the VR group failed to place the tourniquet too loose while one also did not perform the steps in the appropriate sequence. The participant who failed in the IP group also placed the tourniquet too loose and did not in the appropriate steps. Similarly, two VR participants and one IP participant failed the 90-day evaluation by placing the tourniquet too loose and not performing the steps in the appropriate sequence. The National Registry Hemorrhage Control Skills Lab rubric is shown in Figure 2

DISCUSSION

Tourniquet placement is a critical skill in combating the increasing trauma and mass casualty–related morbidity and mortality. Proper

Assessment Rubric			
Was 9-1-1 called immediately on entry of scenario	Yes	No	
Did the participant assess his or her own safety prior to proceeding? (i.e. Scanned scenario, verbalized where the shooter was, requested door be closed or barricaded)	Yes	No	
Did the participant identity which wound was the life threatening wound? (has to verbalize)	Yes	No	
When asked, what describes life threatening wound, the participant answered (any answer is correct, if they say more than one, you can circle)	• Blood that is spurting out of the wound • Blood that won't stop coming out of the wound • Blood that is pooling on the ground • Clothing that is soaked with blood • Bandages that are soaked with blood • Loss of all or part of an arm or leg • Bleeding in a victim who is now confused or unconscious	Wrong Answer	
	The following is regarding tourniquet placement		
Time to Placement (seconds)		If above 420 seconds (7 minutes), participant fails	
Correct placement (unable to place finger under tourniquet and it indents mannequin)	**Yes**	**No**	
If not correct placement, please circle which causes (can circle more than one)	**1. Too loose** (can place finger under tourniquet)	**2. Doesn't complete steps** (review image below)	**3. Incorrect Location** (less than 2" proximal to wound, too far away, on a joint)
	4. Time greater than 7 minutes	**5. Participant requested to stop early**	

FIGURE 2 National Registry Hemorrhage Control Skills Lab rubric.

application is particularly important for those practicing in receiving trauma centers, where medical providers are annually in-serviced on the procedure and may require or encounter its use during resuscitations. The current standard of IP courses to teach tourniquet use can be expensive, time-consuming, limited in availability, and ultimately still lead to poor retention of skills.[5,7] Meanwhile, VR's utility in medical education has been gaining more interest. Given the exciting applications of VR, we decided to explore its use as an effective teaching modality in educating emergency medicine residents on the proper tourniquet application. We sought to compare the retention of tourniquet placement skills between IP VR training to the current standard of IP lecture training.

In this study, we found no difference in both initial pass and retention rates between emergency medicine residents trained through certified instructors compared to those trained through VR. There are a number of potential reasons why performance after VR training was comparable to the current standard of training. VR provides on-demand and standardized training with immediate real-time feedback on all sequential steps of the procedure. Participants also had the ability to learn at their own pace and repeat any steps as often as needed. This degree of individualized learning is much more challenging to do in a traditional classroom setting and may have contributed to VR training having similar results to the more familiar teaching methods.

There is a growing body of evidence that VR may be a useful adjunct to medical training.[8] Our research team has previously demonstrated a decrease in PPE donning and doffing errors among emergency medicine residents through the use of VR.[12] While tourniquet placement and donning and doffing PPE are relatively simple procedures in the scope of medical practice, there is precedence that VR can assist in learning more complicated skills. It has previously been found that novice trainees retained laparoscopic surgical skills 6 months after VR simulator training.[15] It is therefore reasonable to imagine a training program having VR headsets available to residents to repeatedly practice a wide range of critical skills on their own time. While more studies are needed, our research adds to the already existing body of literature that suggests VR may be a useful adjunct to medical training by providing an effective, individualizable, and repeatable learning tool for trainees.

LIMITATIONS

There were several limitations to our study. The study groups were a convenience sample recruited from residents in a single emergency medicine residency. As this was a single-site study, the results may not be generalizable to other populations. While consisting of various PGY training levels, all participants were medical school graduates with a higher medical proficiency than the average person, which limits generalizability. Even though the participants were from a single residency, only 41/53 (77%) of participants were able to complete the 90-day reevaluation to assess for retention of tourniquet placement skills. In part due to lack of retention, the study was underpowered to test for true noninferiority or perform a logistics regression calculation. Additionally, the impending departure of numerous participants from the residency as they graduate limited our ability to test for retention of skills at a longer time point such as at 6 months. Finally, the VR program was performed IP whereas in a non-study setting, it would likely be performed asynchronously at the participant's home. Future research should consider performing VR programs outside of the educational setting along with testing it on non-medical professionals to fully develop the impact of such an educational platform for hemorrhage control training.

CONCLUSIONS

In this study, we found no significant differences in successful hemorrhage control by tourniquet placement between those trained with virtual reality compared to a traditional in-person course among emergency medicine residents. These findings were consistently seen when stratifying for junior and senior residents. While more studies with greater power are needed, this suggests virtual reality may be a useful adjunct to traditional in-person medical training for tourniquet placement.

AUTHOR CONTRIBUTIONS

Vinay Saggar: study concept and design, acquisition of the data, analysis and interpretation of the data, drafting of the manuscript, critical revision of the manuscript for important intellectual content, study supervision. Philip O'Donnell: study concept and design, acquisition of the data, analysis and interpretation of the data, drafting of the manuscript, critical revision of the manuscript for important intellectual content; study supervision. Hillary Moss: study concept and design, acquisition of the data, analysis and interpretation of the data, drafting of the manuscript, critical revision of the manuscript for important intellectual content, study supervision. Andrew Yoon: study concept and design, acquisition of the data, critical revision of the manuscript for important intellectual content, study supervision. Carlo Lutz: analysis and interpretation of the data; drafting of the manuscript, critical revision of the manuscript for important intellectual content, statistical expertise. Andrew Restivo: study concept and design, acquisition of the data, analysis and interpretation of the data, drafting of the manuscript, critical revision of the manuscript for important intellectual content, study supervision. Oark Ahmed: acquisition of the data, critical revision of the manuscript for important intellectual content, study supervision. Debayan Guha: analysis and interpretation of the data, drafting of the manuscript, critical revision of the manuscript for important intellectual content. Farrukh Jafri: drafting of the manuscript, critical revision of the manuscript for important intellectual content. Maninder Singh: study concept and design, acquisition of the data, analysis and interpretation of the data, drafting of the manuscript, critical revision of the manuscript for important intellectual content, study supervision.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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