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Abstract

Objectives: Team-focused cardiopulmonary resuscitation (TFCPR) is a choreographed approach to CPR in which responders know and practice their role in resuscitation, with prioritization on minimally interrupted chest compressions and early appropriate defibrillation. To determine the feasibility of virtual reality (VR) for large-scale educational deployment at a regional medical campus (RMC), we developed a pilot VR training module and examined its effect on resuscitation knowledge acquisition among clinicians of various learner levels.

Methods: Three separate cohorts were included in the investigation: third-year medical students at our RMC, emergency medicine (EM) residents, and board-certified EM attending physicians. Participants were administered an iPad-based, de-identified pre-test, which assessed knowledge of 12 critical resuscitative tasks. All learners received a two-minute orientation to the VR headset fit and operation. Learners then completed training on the VR platform using two cardiac arrest clinical scenarios: one with an initial shockable rhythm and another with a non-shockable initial rhythm. After completion of VR training, participants completed a post-test, again assessing knowledge of the 12 critical action resuscitative tasks, as well as a questionnaire determining metrics related to participants' overall experience with VR training.

Results: All participants demonstrated statistically significant increases in post-test scores after VR training with the combined median improvement of 12.5% (CI 12.5–17.0; p <0.0001). Medical students demonstrated the greatest median pre-post score improvement (17%; CI 12.5–25.0; p <0.0001]. Study participants reported the VR training platform to be enjoyable, realistic, immersive, and a good way to learn. Additionally, participants reported having a good visual-sensory tolerance to VR and it being a satisfying training method.

Conclusions: At our RMC and single hospital, pre- and post-test analysis, knowledge acquisition of critical resuscitation skills improved after VR TFCPR training for all learners. Additionally, participants demonstrated a high level of satisfaction with VR as a training methodology. VR may represent a feasible adjunct or alternative to traditional cardiac arrest resuscitation training for knowledge acquisition.

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Introduction

Sudden cardiac arrest (SCA) occurs in approximately 1,600 people each day in the United States, with survival less than 6% for out-of-hospital cardiac arrests (OHCA) and 24% for in-hospital cardiac arrests (IHCA).[1] Team-focused cardiopulmonary resuscitation (TFCPR) is a choreographed approach to CPR in which responders understand and practice their role in resuscitation, with prioritization on minimally interrupted chest compressions and early appropriate defibrillation. TFCPR implementation in the pre-hospital and hospital setting has led to substantial improvements in survival with good neurologic outcomes.[2-3] However, skill and knowledge decay is a known challenge in education, with prior studies demonstrating degradation of advanced cardiac life support (ACLS) skills in SCA responders.[4,5] This degradation increases incrementally the further a learner is from their initial ACLS training. Frequent retraining of SCA responders, however, carries many logistical challenges. Additionally, lecture-based learning is inadequate for the adult learner.[6] As a result, simulation-based education has emerged as an integral learning strategy with studies demonstrating that full-scale simulation is superior to interactive problem-based learning for teaching critical skills.[6,7] Despite the demonstrated advantages, simulation-based education presents its own challenges. TFCPR is traditionally taught using simulation, which can be time-consuming and resource-intensive for frequent training of providers whose schedules are difficult to coordinate. Simulation training is also cost prohibitive on a large scale.[8] To mitigate these logistical barriers, we developed a pilot study of virtual reality (VR) as a novel training method to improve the feasibility of TFCPR education with hopeful, resultant knowledge acquisition.

The use of virtual reality (VR) in healthcare has demonstrated a rapid growth in recent literature and has shown tremendous application, particularly in surgical skills education and training.[9] VR technology is steadily becoming integrated in both medical practice and medical education as evidenced by its use in stroke rehabilitation, mass casualty training, triage implementation, surgical and clinical skill acquisition, and medical student education.[10-16] In Sweden, multiplayer virtual training in CPR, similar to avatar gaming, was shown to be beneficial for medical students,[16] although only student-user perceptions and feelings regarding the tool were investigated and outcomes were not assessed. Additionally, immersive education, such as VR, has demonstrated benefits in knowledge retention and skills acquisition compared to traditional lectures,[17] and higher levels of learner engagement than two-dimensional (2D) video formats.[18] Despite its use in both clinical practice and medical education, VR's impact and role in the acquisition and dissemination of information is still in its infancy. To enhance TFCPR education to various learner levels within our institution, we developed a pilot VR training module. The aim of this study was to evaluate the feasibility of VR implementation, while also investigating the potential efficacy for this new intervention.[19]

Methods

We conducted a pre- and post-test study at a 900-bed, level 1 cardiac resuscitation teaching hospital, which also serves as regional clinical campus of a medical school. This study was reviewed and approved by our institutional review board.

Construction of a High-Fidelity Virtual Reality TFCPR Training Video

Video design and construction were done in conjunction with our Area Health Education Center (AHEC). A GoPro 360° camera rig (GoPro, Inc, San Mateo, CA, USA) was used to record a VR training video that showcased a team of physicians, nurses, and emergency department (ED) technicians providing TFCPR utilizing a Laerdal SimMan® Essential (Laerdal Medical AS, Stavanger, Norway). The VR TFCPR module was developed with post-production editing through Adobe Premiere® and stitching with AutoPano® and VideoPro®. Audio post-production editing was achieved using Adobe Audition®, and Adobe Photoshop® was used for post-production graphics editing. We adhered to a previously published process for quantifying content validity to select critical action items,[20] which were embedded within the module. Videos were edited for content and length with each being less than five minutes. Two cardiac arrest clinical scenarios were produced in this manner: an arrest with an initial shockable rhythm and another with a non-shockable initial rhythm. Study subjects viewed videos using either a Samsung Gear VR headset (Samsung Electronics Co., Ltd, Samsung Digital City, Suwon, South Korea) plus Samsung Galaxy S6 smartphone (Samsung Electronics Co., Ltd, Samsung Digital City, Suwon, South Korea) or Oculus Go all-in-one VR headset (FaceBook Technologies, LLC, Menlo Park, CA, USA).

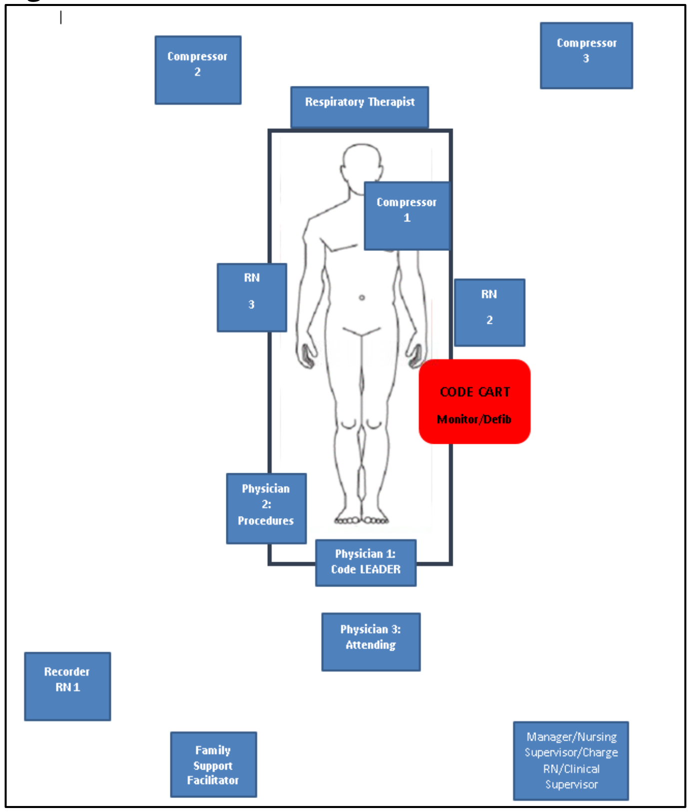
Subject Selection and Learner Groups

Three separate study subject cohorts were investigated. Eligible subjects included all third-year medical students at our hospital's regional campus, emergency medicine (EM) residents, and full-time board-certified EM attending physicians actively involved in ED resuscitations as SCA responders. Exclusion criteria were individuals not involved in ED resuscitations and any individual physically unable to provide high-quality chest compressions. No exclusions were made based on sex, race, or age. Study subjects were divided into separate groups based on their prior exposure to TFCPR. EM residents and attending physicians had received previous education on TFCPR as part of formal lecture-based residency education and ACLS training. In contrast, medical students had no prior exposure to TFCPR.

Virtual Reality Training Sessions

Medical students were introduced to TFCPR concepts via a lecture-based five-minute voiceover PowerPoint detailing TFCPR. **Figure 1** has been included for reference to TFCPR roles and functions.

Figure 1. TFCPR roles and functions



All materials were developed previously and used to orient learners without previous exposure to TFCPR. Neither EM residents nor attending physicians received this initial orientation, as they had previous exposure to TFCPR in the clinical setting and they received previous lecture-based education on TFCPR. All learners (students, residents, and attendings) were administered an iPad-based, de-identified pre-test, which assessed knowledge of 12 critical resuscitative tasks **(Figure 2)** derived from a previously published multistep content validation process.[20]

Figure 2. Critical Resuscitation Actions for TFCPR

1. Delivery of high-quality, minimally interrupted chest compressions.
2. Chest compressions consistent with rate of 100-120.
3. Pulse check duration of <10 seconds with delivered compressions if pulseless.
4. Defibrillator charged at 180th compression in preparation for energy delivery.
5. One cycle of TFCPR consists of 200 compressions.
6. One breath delivered every 20 compressions.
7. A backboard always used to achieve optimal compression quality.
8. The preferred airway is a supraglottic device.
9. Defibrillator pads should immediately be placed upon the patient.
10. Defibrillation occurs immediately after pad placement and shockable rhythm identified.
11. The leader stands at the foot of the bed.
12. Closed loop communication (repeating all verbal orders) is used in TFCPR.

All learners received a two-minute orientation to the VR headset fit and operation. Learners then completed training on the VR platform using the previously described shockable and non-shockable arrest scenarios. After completion of VR training, learners completed a post-test, assessing the exact same knowledge of the 12 critical action resuscitative tasks. Learners also completed a questionnaire on their VR experience using a Likert scale to evaluate user friendliness, realism, immersive experience, visual-sensory tolerance, perceived effectiveness of the VR training module, and overall satisfaction with the VR training tool.

Data Analysis

The number of learners who initiated and successfully completed the VR TFCPR training, time to VR training completion, and responses regarding the VR training experience were collected. Descriptive statistics, including means, standard deviations, medians, and interquartile ranges (IQRs) were calculated for each measure. Knowledge summary scores of pre-VR training and post-VR training were compared using the Wilcoxon signed rank test. Based on the available study population, we estimated a sample of 84 paired test results would give us 95% power to detect a mean difference of 1.0, assuming a standard deviation of 2.5 and a significance level (alpha) of 0.05. The power was calculated using PASS 15 Power Analysis and Sample Size Software 2017 (NCSS, LLC, Kaysville, Utah, USA). Statistical analysis was conducted using the latest version of StatsDirect (StatsDirect Ltd, Cheshire, UK).

Results

In total, 26 medical students, 42 EM residents, and 33 EM attendings were eligible for enrollment. Of 101 eligible clinicians, 96 participated in VR training. Complete paired pre- and post-test data were available for 86 (90%) of the 96: 26 medical students, 32 residents, and 28 EM attendings. Participant age varied given the study included a range of learner levels. **Table 1** demonstrates the sex and age range of each of the participant cohorts. Training sessions lasted approximately 12 minutes for EM resident and attending cohorts and 22 minutes for the medical student cohort (given the additional TFCPR introductory presentation). Ninety survey responses were available for analysis.

Table 1. Demographics

	Age Range (years)					
Participant	20–30	30–40	40–50	> 50	Male	Female
Medical Student	23	2	0	0	11	14
EM Resident	28	13	0	0	22	19
EM Attending	1	13	10	6	21	9
All	52	28	10	6	54	42

Knowledge summary scores of pre-VR training and post-VR training performance are shown in **Table 2**. Median pre- and post-test scores for all participants were 83% (IQR 75%–92%) and 100% (IQR 92%–100%), respectively. The median difference in post-test scores was 12.5% for all participants [95% confidence interval (CI) 12.5%–17.0%; p <0.0001]. Median pre- and post-test scores in the medical student cohort (N = 26) were 75% (IQR 67%–83%) and 92% (IQR 92%–100%), respectively. The median difference in improvement of post-test scores was 17% (95% CI 12.5%–25.0%; p <0.0001). Median pre- and post-test scores in the EM resident cohort (N = 32) were 92% (IQR 83%–92%) and 100% (IQR 92%–100%), respectively. The median difference in improvement of post-test scores was 8.3% (95% CI 4.2%–12.5%; p <0.0001). Median pre- and post-test scores in the attending physician cohort (N = 28) were 83% (IQR 75%–92%) and 100% (IQR 92%–100%), respectively. The median difference in improvement of post-test scores was 12.5% (95% CI 8.3%–16.7%; p <0.0001).

Table 2. Pre-Post Virtual Reality TFCPR Tests

Participant	N	Pre	Post	Median Change	95% CI	p-value
Medical Student	26	75% [IQR 67%–83%]	92% [IQR 92%–100%]	17%	12.5%–25.0%	<0.0001
EM Resident	32	92% [IQR 83%–92%]	100% [IQR 92%–100%]	8.3%	4.2%–12.5%	<0.0001
EM Attending	28	83% [IQR 71%–92%]	100% [IQR 92%–100%]	12.5%	8.3%–16.7%	<0.0001
All	86	83% [IQR 75%–92%]	100% [IQR 92%–100%]	12.5%	12.5%–17.0%	<0.0001

Responses regarding the VR training experience are shown in **Table 3**. Upon evaluation of the VR training platform, participants agreed or strongly agreed VR demonstrated three dimensions very well (96%), VR was a good way to learn (94%), they enjoyed the experience (96%), and they were satisfied with the VR platform as a learning tool (96%). Additionally,

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learners perceived the code team directly in front of them (89%), felt immersed within the experience (84%), reported the experience as realistic (86%), and had good visual-sensory tolerance (94%).

Table 3. VR Experience: Median Likert Scale 1–5 (1 = strongly disagree, 5 = strongly agree) with 95% Confidence Intervals

	Medical Student (N = 25)	EM Resident (N = 38)	EM Attending (N = 27)	All (N = 90)
It was easy to wear and use the VR headset.	4 (4–5)	5 (4–5)	4 (4–5)	5 (4–5)
Instructions for use of the VR headset were easy to understand.	5 (4–5)	5 (4–5)	5 (4–5)	5 (4–5)
I had the feeling that the team was really present in front of me.	4 (4–5)	4 (4–5)	4 (4–5)	4 (4–5)
I had the feeling that I was present with the other team members.	4 (4–4)	4 (4–5)	4 (3–5)	4 (4–5)
I had the impression that I was in a real code situation.	4 (3–4)	4 (4–5)	4 (3–5)	4 (3–5)
The perception of the three-dimensional space was very good.	4 (4–5)	5 (4–5)	4 (4–5)	4 (4–5)
The environment was realistic.	4 (4–4)	4 (4–5)	4 (4–4)	4 (4–5)
I felt immersed in the code.	4 (4–4)	4 (4–5)	4 (3–4)	4 (4–5)
I was comfortable wearing the VR device.	4 (4–5)	5 (4–5)	4 (4–5)	4 (4–5)
I tolerated the visual sensory components of the experience well.	4 (4–5)	5 (4–5)	4 (4–5)	4 (4–5)
I did NOT have motion intolerance/sickness.	4 (4–5)	5 (4–5)	5 (4–5)	5 (4–5)
This was a good way to learn.	4 (4–5)	5 (4–5)	4 (4–5)	4 (4–5)
I enjoyed the VR training experience.	4 (4–5)	5 (4–5)	4 (4–5)	5 (4–5)
I was satisfied with this training tool.	5 (4–5)	5 (4–5)	5 (4–5)	5 (4–5)

Discussion

We piloted an effective, feasible, and generalizable VR TFCPR training module for educating sudden cardiac arrest responders in the hospital setting. Our study demonstrated VR is a useful training tool for clinicians of various learner levels at our RMC. It significantly increased knowledge acquisition of critical action items and was well tolerated by all study subjects based on responses to our post-training questionnaire.

All study subject cohorts exhibited statistically significant increases in their post-test scores after VR training. Medical students demonstrated the greatest median score improvement. At our institution, the TFCPR model is currently utilized in the emergency department, as well as in non-ICU inpatient settings for all adult medical cardiac arrests. We attribute the higher pre-test scores of EM residents (92%) and attending physicians (83%) compared with medical students (75%) to their prior exposure to TFCPR. The lack of prior exposure to TFCPR also explains the greatest median improvement by medical students. Despite the disparity in initial knowledge, the statistically significant increase in post-test knowledge observed in all cohorts demonstrates our novel VR TFCPR training provides an effective means of knowledge acquisition for all learner levels. Furthermore, this VR TFCPR training module could subsequently address the known issue of skills and knowledge decay by providing a feasible platform for repetitive cognitive practice and consequent retention of knowledge of critical resuscitative skills.

VR training is practical from a logistic standpoint. As discussed previously, traditional simulation-based education requires prolonged time, an instructor, physical space, manikins, and other specialized equipment. In comparison, our VR training sessions lasted between 12 minutes for EM residents and attending participants and 22 minutes for medical students (given the five-minute voiceover PowerPoint detailing TFCPR). Additionally, the VR TFCPR training runs autonomously, allowing learners to use the device in isolated environments, thus mitigating scheduling challenges and eliminating the need for group education and instructor time. After development of the VR TFCPR training module, the only human interactions required in the implementation of our study were during the administration of the devices and providing a two-minute introduction to their fit and use. This process could be further streamlined in the future by allowing devices to be independently checked out while providing device orientation via email, pamphlet, or video, as their operation is relatively simple. As such, VR provides an excellent opportunity to scale repetitive training for large learner numbers while limiting instructors.

Minimal resources were required to administer the VR training and module as compared to traditional simulation-based education. Despite our initial study including 96 subjects, all training was completed using only six VR devices. Given the relatively brief length of training and autonomous nature of VR simulation, only a small number of VR devices are needed at any given time. The six VR headsets cost approximately $2,400 as compared to an approximate $75,000 for a high-fidelity manikin commonly used at our simulation center for TFCPR training. Compared to the resources required for traditional simulation-based education, this educational modality potentially allows for fiscal savings, while providing the opportunity for more frequent training sessions and ease of educational coordination based on learner schedules, thus making this training generalizable

Given the increased demands on learners and clinical educators, modalities of training that make education more efficient rather than large in-person group gathering, such as VR, are increasingly necessary. Evaluating through Moore's lens of pilot study, we were able to demonstrate the feasibility of VR implementation, while also investigating the potential efficacy for this new intervention.[19] As we have demonstrated pilot success in using VR at our RMC, we will be sharing the results of our study and our training module within our system for study in a larger context.

Limitations
This pilot was conducted at a regional medical campus and single emergency department with funding to support the purchase and administration of VR education. The cost of VR headsets does represent a small challenge for generalizability for education, however minimal when compared to traditional simulation-based education. Being an RMC, the medical student cohort is smaller than the main campus.

Skills and knowledge decay are known challenges in medical education and often confound assessments of the efficacy of a given educational intervention. Skill decay has been reported as early as two weeks after an educational intervention.[21] Our study assessed knowledge acquisition within minutes of a VR TFCPR training module; thus, future work should include collection of post-training knowledge assessment data over longer interval time periods.

Additionally, whether virtual education is an adjunct and/or acceptable substitute for hands-on, simulation-based, or traditional classroom education remains a subject of debate.[22,23] Most certainly, measured effectiveness of VR education is dependent on the educational domain (psychomotor, cognitive, or affective) being measured. Our study measured only cognitive resuscitative knowledge changes after VR education. Whether these improvements translate into actual clinical practice will need to be studied. Arguably, since traditional simulation-based education more closely approximates clinical practice for TFCPR, future work should compare these two educational modalities.

Conclusions

In this pre-and post-test analysis, knowledge acquisition of critical resuscitation skills improved after VR training for all learners at our RMC. These results support the use of VR for inpatient cardiac resuscitation cognitive training. High learner satisfaction, excellent visual-sensory tolerance, and highly rated realism and immersion further support the use of VR for training purposes. VR is a feasible adjunct and may represent an alternative to knowledge acquisition in traditional or simulation-based cardiac arrest resuscitation training. Future studies should directly compare the educational modalities and examine long-term knowledge retention on a larger scale.

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