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Efficiency of virtual reality for cardiopulmonary resuscitation training of adult laypersons

A systematic review

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Abstract

Background: Virtual reality (VR) is an interesting and promising way to teach cardiopulmonary resuscitation (CPR) to adult laypersons as its high immersive characteristics could improve the level of skills and acquired knowledge in learning basic life support (BLS).

Methods: This systematic review assesses current literature about BLS training with VR and its possible effect on CPR-quality parameters, self-efficacy, perceived learning, and learners' satisfaction and short and long-term patients' outcome. We screened the Cochrane Library, PubMed, CINAHL, MEDLINE Ovid, Web of Science, and Scopus databases and included only clinical trials and quasi-experimental studies published from inception to October 1, 2021, which analyzed adult laypersons' BLS training with the use of VR. Primary outcomes were CPR parameters (chest compression rate and depth, Automated External Defibrillator use). Secondary outcomes were self-efficacy, perceived learning and learners satisfaction, and patients' outcomes (survival and good neurologic status). The risk of bias of included study was assessed using the Cochrane Handbook for Systematic Reviews of Interventions tool to evaluate randomized control trials and the transparent reporting of evaluations with nonrandomized designs checklist for nonrandomized studies.

Results: After full article screening, 6 studies were included in the systematic review (731 participants) published between 2017 and 2021. Because of the heterogeneity of the studies, we focused on describing the studies rather than meta-analysis. The assessment of the quality of evidence revealed overall a very low quality. Training with VR significantly improved the rate and depth of chest compressions in 4 out of 6 articles. VR was described as an efficient teaching method, exerting a positive effect on self-efficacy, perception of confidence, and competence in 2 articles.

Conclusion: VR in BLS training improves manual skills and self-efficacy of adult laypersons and may be a good teaching method in a blended learning CPR training strategy. VR may add another way to divide complex parts of resuscitation training into easier individual skills. However, the conclusion of this review suggests that VR may improve the quality of the chest compressions as compared to instructor-led face-to-face BLS training.

Abbreviations: BLS = basic life support, CPR = cardiopulmonary resuscitation, OHCA = out-of-hospital cardiac arrest, RCT = randomized control trials, ROB = risk of bias, ROSC = return of spontaneous circulation, TREND = transparent reporting of evaluations with nonrandomized designs, VR = virtual reality.

Keywords: cardiopulmonary resuscitation, extended reality, systematic review, virtual reality

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The datasets generated during and/or analyzed during the current study are publicly available.

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1. Introduction

Out-of-hospital cardiac arrest (OHCA) is a major global health problem, with more than 3,00,000 cases occurring annually in Europe and the United States.[1,2] The early recognition of the problem and early initiation of cardiopulmonary resuscitation (CPR) is one of the most important steps to improve outcomes for patients with OHCA.

Cardiac arrest is often witnessed by family members or people without basic life support (BLS) training, which delays the initiation of care until the arrival of emergency medical services. Less than 50% of OHCA patients receive bystander CPR,[3,4] although increased CPR training in the population is associated with increased survival after CPR, including improved neurological outcomes.[5–8] It is therefore important to provide PCR training to the general population. According to the European Resuscitation Council Guidelines 2021, every citizen should learn to provide life-saving BLS skills.[9]

BLS training has become more important in recent decades, creating opportunities for mass training that has the potential to significantly reduce sudden cardiac arrest deaths.[10,11] Classical BLS training has typically consisted of instructor-led theoretical training. A recent systematic review reported that instructor-led CPR training with real-time or delayed feedback improved psychomotor CPR skills in lay adults, but these skills are lost over time, at approximately 3 to 6 months.[12] The need for retraining, as well as the need for specific spaces and schedules, together with the lack of realism and immersion of traditional feedback devices, are some of the limitations found in traditional CPR training system.

However, many new technologies for teaching CPR have become available in recent years and have been shown to overcome these limitations.[13] But their actual impact on teaching and learning is not very clear.[14] An ILCOR CoSTR evidence update supports the idea that simulation-based education of resuscitation in situ (directly at the workplace of individuals), or in a dedicated simulation center, may be included within the continuous education programs of life support courses.[14]

In this sense, virtual reality (VR) implementation in cardiopulmonary resuscitation (CPR) training might be a tool that could be used to teach an ever-increasing number of persons, to improve the level of skills and acquired knowledge, and to provide more convenient and more frequent learning opportunities for the learners who seek to be competent in BLS.[15] VR may be a good education method and resource that could be used to achieve these objectives, and was supported in 2018 by the American heart association, which highlighted the role of immersive technologies and gamified learning in the advancement of CPR education strategies to improve the learning experience of users.[16] Recently, the 2021 European Resuscitation Council Guidelines recommended the use of virtual learning environments for all levels of CPR training as part of a blended learning, as well as a self-learning approach.[9]

VR is a simulation created by a computer, and it includes scenarios of the real or imaginary world, which offer opportunities for interaction in real-time.[17] Through the use of hardware, such as VR-goggles and haptic controllers, an immersive experience is provided to the users, which result in improvements in procedural memory,[18] speed, precision, and the transfer of knowledge to real-world scenarios, as compared with instructor directed training.[19] As it provides a strong feeling of immersion, VR is a new, interesting and promising way of teaching health care, and its use is rapidly spreading.[20] VR has been used to simulate clinical settings that allow both individuals and groups to learn specific techniques and to improve teamwork.[20,21] VR was described successful to teach echocardiography,[22] or the placement of a central venous catheter.[23]

Despite its advantages, virtual reality has serious limitations for teaching BLS. In a virtual reality environment, procedures such as chest compressions, ventilation and defibrillation cannot be performed with the same characteristics as they would be in a real environment, as VR uses haptic controls to perform the actions. These limitations can be eliminated by incorporating extended reality and/or augmented reality, with the use of full-scale mannequins and other simulation objects (e.g., simulation AEDs).[24] In the case of BLS, VR would simulate a real cardiac arrest scenario so that the user learns to identify it and perform the steps in the chain of survival until the arrival of emergency medical services.

Several studies on VR for CPR training have been published in the past few years[25–28] and analysis of simulators based on VR, XR and AR[24] but no systematic review has systematically analyzed and summarized this training strategy for the general population. The objective of the present study is to systematically review current publications on VR in BLS training of adult non-healthcare professional laypersons. The aim is to assess if CPR training with VR improves CPR-quality markers (depth and frequency of chest compression, use of AED), and the short and long-term outcome of patients after cardiac arrest (return of spontaneous circulation [ROSC], survival at discharge, favorable neurological outcome).

2. Methods

The review was conducted according to the Cochrane Handbook for Systematic Reviews[29] and the preferred reporting items for systematic reviews and meta-analyses statement.[30] The systematic review protocol was registered at the International Prospective Register of Systematic Reviews (PROSPERO: CRD42021249502). Ethical approval was not necessary for the review.

2.1. Data sources and search strategy

A sensitive search strategy using relevant search terms that were developed from MeSH and keywords were used. See Appendix 1, Supplemental Digital Content, http://links.lww.com/MD/I353, to find search strategies. Three researchers (PMAA, MPR and LRP) independently searched the databases: PROSPERO, Cochrane Library, PubMed, CINAHL, MEDLINE Ovid, Web of Science and Scopus from the inception of the investigation to October 2021. Manual searches within the references of the included studies were carried out to identify other studies that could potentially be included. That search was cross-checked, and it was helpful to identify studies that were missed during the electronic search. The references were exported, and duplicates were removed manually.

2.2. Eligibility criteria and study selection

We planned to include experimental studies that assessed educational innovations strategies with VR in BLS to improve CPR quality parameters, in comparison to instructor-led face-to-face education, of adult laypersons.

The population, intervention, comparator, and outcome (PICO) structure was[17]:

- Population: laypersons, aged > 18 years in any education setting of BLS training.
- Intervention: VR in BLS teaching or training.
- Comparator: instructor-led face-to-face BLS teaching or training.
- Outcome: Improve CPR quality parameters (compression and depth rate, use of AED) after the training, and self-efficacy, perceived learning, learners' satisfaction, as well as short and long-term patient outcomes (ROSC, survival to discharge, and survival with favorable neurological outcome).

We included randomized controlled trials or quasi-experimental studies published in any language, providing full text availability. We excluded abstracts, systematic reviews, observational studies, letters to the editor, studies assessing training in pediatric or neonatal CPR or healthcare personnel. During the full-text assessment, we became aware that studies found before the year 2017 include virtual learning environments based on serious gaming, manikin simulation, or video games, but these studies did not include VR as a technique to teach CPR. As VR is an innovative technology that has expanded in recent years and continues to evolve, the included studies are very recent.

All the studies identified with the search strategy underwent titles and abstracts screening against the inclusion and exclusion criteria by 2 reviewers (PMAA and MPR) followed by a second screening based on the full text of all the studies whose titles and abstracts fully met the inclusion criteria. In cases of disagreement, a decision was made by consensus or, when necessary, a third reviewer (LRP) was consulted. Figure 1 display the study selection process.

2.3. Data analysis

From the full texts of possibly eligible studies, a narrative synthesis of the characteristics and results of the included studies was summarized in Table 1. We defined that the heterogeneity of the studies, and the variable results were needed to synthesize a meta-analysis. If that was not possible, we summarized the results regarding the relationship between innovative CPR educational strategies and outcome variables as mentioned above. Data extraction was performed by 2 authors independently. Disagreements were resolved by discussion between the 2 evaluators, or if consensus was not possible, further opinions were sought.

The primary outcome variables analyzed were: compression rate (minute) and depth (mm), as well as AED use. Secondary variables were self-efficacy, perceived learning and learners' satisfaction using Likert scales. We assessed whether the included studies had performed analyses of short- and long-term patient outcomes (ROSC, survival to discharge, survival with favorable neurological outcome). The outcomes included where: chest compression depth and rate, CPR performance score, median flow chest compression fraction, proportion of compressions with full release, post-survey with questions relating to VR and CPR or 7-value Likert scale. The other variables for which data were sought were: author, country, year of publication, sample size, sex, age, number of participants, follow-up, intervention, measurement instrument used, and results (Table 1).

2.4. Risk of bias assessment

Two reviewers (PMAA and LRP) evaluated the risk of bias (ROB) for each included study, using the Cochrane ROB tool for randomized trials (see Table 2)[31] to evaluate randomized control trials (RCT) and the transparent reporting of evaluations with nonrandomized designs checklist for nonrandomized studies. Allocation, blinding, incomplete outcome data, selective reporting, and other potential sources of bias are shown in Figures 2 and 3.

See Appendix 3, Supplemental Digital Content, http://links.lww.com/MD/I355, to find the quality of evidence was assessed according to the grading of recommendations assessment, development, and evaluation.

3. Results

We found a total of 241 articles in the databases, and 1 additional study at Google Scholar. Of these 242 articles, 181 were excluded due to methodological reasons, duplicate records, and after reading the titles and abstracts (Fig. 1). In the end, 6 articles met the inclusion criteria: 4 RCT,[20–23] and 2 quasi-experimental studies,[24,25] including a total of 731 participants, aged between 19 and 57 years, 389 (53.2%) were men. Two studies reported the level of higher education (university): 45%[20] and 19%.[21] The percentage of participants who had received BLS training in the last 2 years in the studies was 16%,[20] 17%,[21] 26% in the intervention group versus, 29% in the control group,[22] 20% in the intervention group versus 16% control group,[23] 43%,[25] and 0%.[24]

General characteristics of the studies are described in Table 1. The studies were conducted in the Netherlands,[20] China,[24] the USA,[21] Spain,[22] Italy,[23] and the UK.[25]

3.1. Evaluation of ROB

The risks of bias (ROB) of the RCT are shown in Figures 2 and 3 and Table 2. Due to the type of study, blinding of the participants was not possible, but it did not have an influence on the subsequent evaluation and was therefore deemed as low ROB. In the case of the quasi-experimental studies, the quality of the studies was more difficult to determine, as the scores obtained with the TREND checklist varied widely. In this sense, some weak aspects were common to both articles, especially in the methodology (participant eligibility criteria, method of recruitment, determination of the sample size, where and who performed the intervention), as well as the time utilized and the measures adopted to optimize the compliance or the adherence. In general, the best areas were: Title, abstract, and results (that is, specific objectives and hypotheses, method of data collection, and information on validated instruments, as well as their psychometric and biometric properties). See Appendix 2, Supplemental Digital Content, http://links.lww.com/MD/I354, it's shown the verification list of ROB in quasi-experimental studies. See Appendix 1, Supplemental Digital Content, http://links.lww.com/MD/I355, it's shown the grading of recommendations assessment, development, and evaluation evidence profile table displaying the quality of evidence assessment shows very low quality for all randomized controlled trials and quasi-experimental studies.

3.2. Results by outcome measures

3.2.1. Quality of the CPR. For the important outcome of chest compression rate we found reports in the 6 studies.[20–25] Cerezo-Espinosa et al,[22] showed in their RCT improved compressions of $97.5 \pm 9.7\,\mathrm{min}^{-1}$ in the VR group but $80.9 \pm 7.7\,\mathrm{min}^{-1}$ in the control group ($P = .003$).

Nas et al,[20] showed non-inferiority of VR for compression rate compared to face-to-face instructor training. The 2 quasi-experimental articles reported improvements.[24,25] Bench et al,[25] reported that 65% of participants scored in the 90% of the chest compression performance scale.

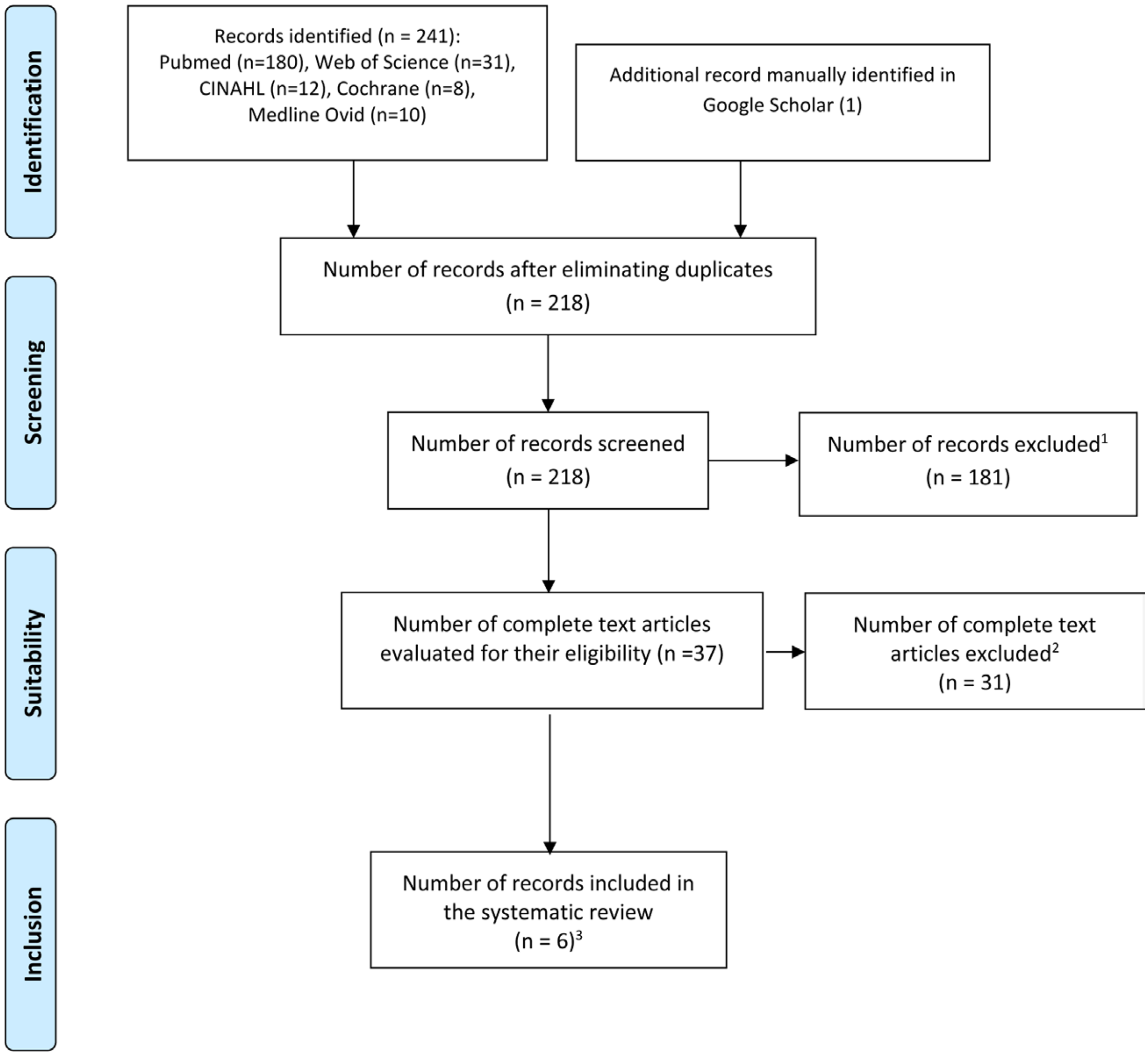
Yang et al,[24] reported with VR significantly higher chest compression scores and a shift of 90% of failures to 16% ($P < .001$).

Buttussi et al,[23] reported improved chest compression after repetition with VR, although the differences were not significant compared to face-to-face training. Leary et al,[21] did not find a significant differences for chest compression rate.

For the important outcome of depth of chest compressions we found results in the 6 studies.[20–25] In the 2 RCT of Nas et al,[20] and Leary et al,[21] VR was reported as inferior compared to face-to-face training.

In contrast, the RCTs by Cerezo Espinosa et al,[22] and Yang et al,[24] reported improvements in chest compression depth for the use of VR.

For the CPR-outcome of compressions with full release Nas et al,[20] reported improvements after training with VR ($P = .002$) as well as Buttussi et al,[20] at the second repetition ($P < .005$).



Exclusion criteria:

1 Type of study (abstracts, systematic reviews, observational studies, letters to the editor).
Language not English or Spanish
Studies assessing training in paediatric or neonatal CPR
Healthcare personnel
Studies published before 2017

2 Type of study (systematic reviews).
No virtual reality training (augmented reality or serious games).
Rate and/or depth of chest compression not evaluated.
No adult laypersons.

Studies included in the systematic review

3 Nas et al 2020 (17); Leary et al, 2019 (18); Cerezo et al, 2019 (19); Buttussi et al, 2020 (20); Yang et al 2020 (21); Bench et al 2019 (22)

Figure 1. PRISMA flow diagram. PRISMA = preferred reporting items for systematic reviews and meta-analyses.

3.2.2. Self-efficacy, perceived learning, and learners' satisfaction. Cerezo Espinosa et al,[22] reported from a questionnaire higher ratings for the VR experience ($P < .001$).

Buttussi et al,[23] reports in a before-and-after questionnaire improved self-efficacy after the VR CPR training ($P > .001$). The pairwise comparisons showed that self-efficacy before training ($M = 3.24 \pm 1.47$) was lower than after training ($M = 4.88 \pm 1.15$) $P < .001$.

Bench et al,[22] report a positive effect on self-efficacy, the perception of confidence, and competence (especially for chest compressions).

Leary et al,[21] assessed in a before-and-after questionnaire knowledge about CPR, AED, and the chain of survival. Participants trained with VR knew significantly more about the use of an AED ($P = .05$), however, no difference was found for other knowledge questions.

Table 1

Main characteristics of included studies.

Study	Country	Design	Follow-up period (mo)	Sample size (n) Sex n (%) Age (yr), mean ± SD or (range)	Subject characteristics	intervention and control group	Risk of bias (ROB)	Outcomes evaluated	Measurement instruments	Results
Nas et al, 2020 [17]	Neth-er-lands	RCTa	6	☐ n = 381 intervention group: 190 control group: 191 • women = 216 (57%) • Age 26 (22–31)	Exclusion: participants who were deemed not capable of performing either the training or the post-training CPRb test. participants with elevated alcohol levels (≥0.5‰) who failed a tandem gait test (a walk test).	intervention group: VRc training with VR goggles and headphones Control group: standardized CPR training with certified instructor	Low risk: complied with all the items of the checklist that evaluated ROB.	1. chest compression depth (mm) 2. chest compression rate (min^{-1}) 3. CPR performance score. 4. median flow chest compression fraction. 5. proportion of compressions with full release. 6. average chest compression depth and rate within the guideline endorsed range.	1. certified CPR manikins (Resusci Anne QCPR; Laerdal Medical) with operating device (SimPad; Laerdal Medical). 2. European resuscitation council endorsed CPR checklist.	1. VR training is non-inferior in compressions rate vs face-to-face mean ± SD: VR: 114 ± 12 min^{-1} vs face to face: 109 ± 12 min^{-1}; mean difference [95% CI] 6 [3 to 8] min^{-1} ($P < .01$). 2. VR was inferior to face-to-face training; mean depth of compressions in VR training was 49.1 ± 10mm and 56.8 ± 5.4mm in the control, a difference of -7.7mm [95% CI, -9.4 to -6.0mm ($P = .99$)] 3. Proportion of compressions with complete release improved after VR training (98% [IQR, 59%–100%] vs 88% [IQR, 55%-99%] ($P = .002$).
Leary et al, 2019 [18]	USA	RCT	_	n = 105 intervention group: 52 control group :53 • men = 68 (66%) • Age 46 ± 16 (19–23)	Exclusion: -unable to use VR device. -unable to complete skills checks. subjects recruited from public locations.	intervention group: digital CPR training with VR CPR training mApp (smartphone with a VR cardboard viewer) Control group had digital CPR training with established CPR training mApp (video-only training methods).	intermediate risk on three items: creation of randomized sequences, blinding of allocation and blinding of the evaluation of the results.	1. pre-survey. 2. intervention: ☐ bystander response data (call 911, perform CPR, ask for an AED). ☐ CPR quality data (chest compression, rate and depth compressions). 3. Survey post-intervention.	1.CPR recording manikin (ResusciAnne, Leardal Medical). 2.post-survey with questions relating to VR, the sequence of bystander response actions, and CPR.	1.VR was inferior to face-to-face training. Mean ± SD depth of compressions in VR training was 38 ± 15mm and in face-to-face training 44 ± 13mm ($P = .05$). 2.Mean ± SD chest compression rate was 104 ± 42 min^{-1} in VR vs 112 ± 30 min^{-1} in face to face training (p = NS). 3.In the VR group, 84% knew how to use an AED as compared to 60% in the control group ($P = .05$).
Cerezo Espinosa et al, 2019 [19]	Spain	RCT	_	n = 92 intervention group: 50 control group: 46 • men = 55 (57%) • age mean ± SD = 28 ± 11	Exclusion: -wearing corrective goggles. -dropping out of the study.	intervention group had CRP training via VR viewing device (360° video of a CPR simulation scenario. control group had no prior training.	Low risk: complied with all the items of the checklist that evaluated ROB	1.multiple-choice questionnaire. 2.rate and depth compressions. 3.CPR quality.	1.theoretical questionnaire used in the Kids Save Lives Study (the maximum score was 10 and the minimum 0). 2.CPR manikin (Resusci Anne Simulator) with SIMPAD. 3.SIEVCA-CPR 2.0d	1.Compressions min^{-1} VR: 97.5 ± 9,7; Control:80.9 ± 7.7; $P = .003$ 2.Depth of compressions 34.0 ± 6.5mm VR; 27.3 ± 4.9 control ($P < .001$) 3.Theoretical questionnaire mean for VR: 9.3 ± 0.9; Control 7.78 ± 1.63 [mean difference 1.5 (95%CI 1.0-2.0), $P < .001$].

(*Continued*)

Table 1

(Continued)

Study	Country	Design	Follow-up period (mo)	Sample size (n) Sex n (%) Age (yr), mean ± SD or (range)	Subject characteristics	intervention and control group	Risk of bias (ROB)	Outcomes evaluated	Measurement instruments	Results
Buttussi et al, 2020 [20]	Italy	RCT	_	n = 30 intervention group: 15 control group: 15. • men = 28 (93%) • age 22 ± 1	undergraduate computer science students	intervention group had training using VR with the manikin (HTC Vive Pro headset and two HTC wrist trackers) control group had training using VR only (6-DOF trackers on the wrists).	high risk in two items: Creation of random sequences and blinding of the assignment were not conducted	1. self-efficacy questionnaire with 5 items: i) I feel sure about my ability to perform CPR, ii) I would be able to verify if a person can breathe autonomously, iii) I can perform cardiac massage correctly, iv) I would be able to understand when a person has regained normal vital functions, and v) I can perform cardiac massage without wasting time. 2.training trials. ☐ compression depth. ☐ Cpme ☐ error in Cpm ☐ correct compressions ☐ compressions too deep ☐ compressions too shallow ☐ compressions with incomplete release 3.final assessment. ☐ transfer of procedural knowledge	1. 7-value Likert scale. 2. CPR manikin (Resusci Anne) with two sensors on the internal Arduino board. 3. Videotaping and assignment of the codes by the experimenter.	1.Main effect of repetition on compressions min^{-1} [F (1.8, 51.7) = 25.5, $P < .001$, $n_p^2 = 0.48$]. 2. No significant differences when comparing the VR group with the face-to-face training group ($P > .05$) 3.Main group effect on compression depth F (1,3) = 10.6, $P < .005$, $n_p^2 = 0.27$ and compressions too deep (F 1,3) = 15.6, $P < .001$, $n_p^2 = 0.36$ being higher in the VR group 4.The proportion of compressions with complete release improved with repetition of training (F1,3) = 5.6, $P < .005$, $n_p^2 = 0.17$ 5.Self-efficacy before training (M = 3.3 ± 1.5) was lower than after training (M = 4.9 ± 1.2) $P < .001$.
Yang et al, 2020 [21]	China	Quasi-experimental	_	n = 100 • men = 60 (60%) • age range [19–23]	undergraduate students majoring in information-related fields without any previous CPR training	1. pre-intervention learning: questionnaire and CPR chest compression simulation. 2.intervention: chest compression with VR-CPRs device. 3.post-intervention: post-test and satisfaction questionnaire	Items weak on TRENDf checklist: participant eligibility criteria, method of recruitment, determination of the sample size, clearly defined primary and secondary outcome measures, time utilized and the measures adopted to optimize the compliance or adherence and where and who performed the intervention.	1. learner's compression force. 2. Chest compression frequency. 3. Level of satisfaction of the VR-CPRs learning system.	1.Force-sensitive model (FlexiForce A401). 4.Satisfaction questionnaire (five-point scale).	1.better overall scores after VR. Decrease in failures from 90% to 15% (T = -16.4, $P < .001$). 2.reduction in insufficient depth of compressions after VR training (reduction from 23% to 10% in women and from 25% to 0% in men). 3. 87% of participants were satisfied or very satisfied with VR CPR learning 4.Errors in chest compressions rate: percentage of insufficient rate of compressions reduced from 38% to 5% for women, and from 30% to 2% in men.

(*Continued*)

Table 1

(*Continued*)

Study	Country	Design	Follow-up period (mo)	Sample size (n) Sex n (%) Age (yr), mean ± SD or (range)	Subject characteristics	intervention and control group	Risk of bias (ROB)	Outcomes evaluated	Measurement instruments	Results
Bench et al, 2019 [22]	UK	Quasi-experimental		n = 23 • men = 14 (61%) • age 41 (26–57)	adult staff members from a range of departments. ten declared previous resuscitation training.	intervention: standardized 5-minute VR experience called Code Blue (HTC corporation vive headset, wrist trackers and a low-end physical manikin).	items weak on TRENDf checklist: method of recruitment, determination of the sample size, time utilized and the measures adopted to optimize the compliance or adherence and where and who performed the intervention.	1. Anonymized paper-based questionnaires pre- and post-intervention. 2. audio-recorded focus group discussions the day after VR experience ☐ experience and expectations ☐ performance and feedback ☐ interaction and Immersion ☐ potential	1. 7-point Likert scale: (1 completely disagree, and 7 completely agree). 2.inductive thematic analysis.	1. 65% of participants scored over 90% on the chest compression performance scale. 2.positive effect on self-efficacy as well as on the perception of confidence and competence (mean rating of participants before intervention = 2; after intervention = 6).

CPR = cardiopulmonary resuscitation, RCT = randomized control trials, VR = virtual reality.

[a] Randomized clinical trial.

[b] Cardiopulmonary resuscitation.

[c] Virtual reality.

[d] SIEVCA-CPR 2.0: tool for the evaluation of the quality of Cardiopulmonary Resuscitation.

[e] Number of compressions performed divided by the time.

[f] Checklist specifically developed to guide standardized reporting of non-randomized controlled trials.

Yang et al,[21] was the only study that reported higher satisfaction for VR teaching from a questionnaire.

None of the included studies reported results on the following predefined outcomes: short and long-term patient outcomes (ROSC, survival to discharge, survival with favorable neurological outcome). No side effect of VR, like vertigo or nausea was described in the studies.

The follow-up intervals of the studies were 6 months in the Leary et al[21] and Nas et al[20] study. No outcomes were reported after follow-up. The rest of the studies did not report follow-up intervals.

Although the objective of this study was to perform a meta-analysis, the heterogeneity of the studies and the variable results made this impossible.

The assessment of the quality of evidence shows very low quality for all outcomes assessed, so the recommendation for these outcomes is weak.

4. Discussion

Out-of-hospital cardiac arrest remains a global health problem. Despite the fact that an increasing number of countries offer assisted CPR (80% in Europe),[1] and have AED registration and policies focused on CPR training,[9] survival to discharge remains very low, between 6% and 8%.[1,38] As we know, increased CPR training of the population also increases survival after CPR[5–8] but we do not know how new VR technologies systematically influence CPR training.

After screening the current literature, this systematic review included 4 RCT and 2 quasi-experimental studies that assessed how adult laypersons (none-health care providers) who learned through BLS-VR training, improved CPR-quality parameters and the cardiac arrest patients' outcome. Overall moderate improvements in CPR-quality parameters, such as compression rate and depth, were found. None of the studies reported results about the short and long-term patient outcomes. VR CPR training was associated with positive effects on self-efficacy, perception of confidence, higher learners' competence (especially for chest compressions), and satisfaction. Due to the heterogeneity of the studies and the ROB of the variable results, a formal meta-analysis was impossible to be conducted.

4.1. Quality of the CPR

The present systematic review confirms that VR training improved the rate and depth of compressions in 4,[34–36,37] of the 6 articles analyzed as compared to instructor-led face-to-face BLS training. Previously-published studies in school children found that the application of virtual and augmented reality during CPR training increased CPR-skills [39,40]. In contrast to reports about a greater improvement in skills due to the use of virtual and augmented reality in CPR training in the classroom (41), Nas et al[32] described an inferior performance as compared to face-to-face training for depth of chest compressions in laypersons after VR CPR training. On the other hand, about 50% of the study participants who trained on CPR with VR, met current guidelines on depth and frequency of chest compression.[9,42] This indicates that VR CPR training as an initial teaching approach for adult laypersons in any educational setting is a valid option, as suggested by Wong et al [43]. CPR-instructors expressed their opinions about VR CPR training and considered this educational strategy as a potential combined learning tool, for both novice health professionals and experienced ones.

Interestingly, the review confirms that VR reduces errors in the rate and depth of chest compressions after a brief learning exercise,[36] which were even more pronounced with repetitions of such VR training sessions.[35] As "rapid cycle deliberate training" [44–46] has been shown to be a very efficient educational strategy to improve team performance when learning with simulated

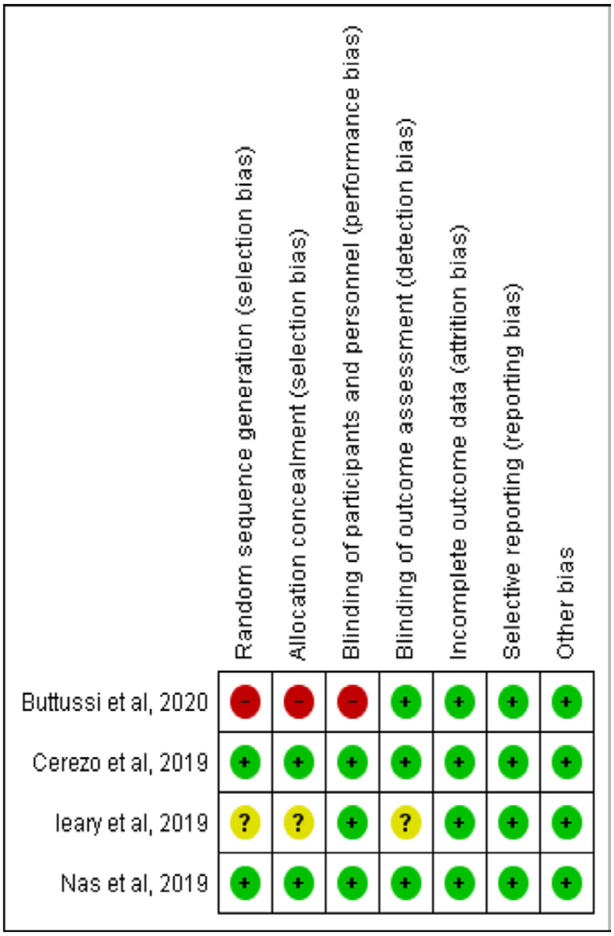
Table 2

Risk of bias of randomized clinical trials included and evaluated through RoB 2.0.

Author	Randomization process	Deviations from intended intervention	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall bias
Cerezo et al	Low	Some concerns[b]	Low	Low	Low	Low
Nas et al	Low	Some concerns[b]	Low	Low	Low	Low
Leary et al	Some concerns[a]	Some concerns[b]	Low	Low	Low	Low
Buttussi et al	High	Some concerns[b]	Low	Low	Low	Low

[a] Method of sequence generation not specified.

[b] Low risk of bias in Part 1 but some concerns in Part 2. Appropriate analysis to estimate the effect of assignment to intervention not used.



	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Buttussi et al, 2020	-	-	-	+	+	+	+
Cerezo et al, 2019	+	+	+	+	+	+	+
leary et al, 2019	?	?	+	?	+	+	+
Nas et al, 2019	+	+	+	+	+	+	+

Figure 2. Risk of bias summary: review of authors' judgements about each risk of bias (ROB) item for each included study. ROB = risk of bias. Buttussi et al, 2020[20]; Cerezo et al, 2019[19]; Leary et al, 2019[18]; Nas et al 2020.[17]

resuscitation, VR may add another way to divide complex parts of resuscitation training into easier individual skills.

4.2. Learning of resuscitation and self-efficacy.

This systematic review revealed that VR used to support the learning of CPR was efficient, exerted a positive effect on self-efficacy, the perception of confidence, and competence.[34,35] This is in agreement with reports on better knowledge retention with the reproduction of virtual scenarios as compared to face-to-face training [47], the learning of non-technical skills in new situations [48], and with the reported increase in the participants' skill performance confidence when utilizing VR for CPR training [40]. Buttussi et al[35] described this improvement in confidence independently of the presence of the manikin. This finding may be explained by the fact that VR seems to be less threatening as a training method, which may improve the acquisition of skills, as suggested by Plessas in 2017.[33]

During the review process, one of the limitations found was the lack of homogeneity of the studies in the design of the VR simulators used for BLS training, which may be the cause of the heterogeneity of the results. A recent systematic review that analyzed new technologies for BLS training, reported that it is necessary to define which type of tools are used for training and which are used for evaluation, to better design specific simulators for VR training.[24] The ROB (blinding, information) was another limitation found.

One of the most important limitations of this review was the scarcity of studies that assessed CPR training with VR in adult laypersons, as most studies excluded focused on CPR-skills of health care professionals. Therefore, some important planned questions on medium and long-term follow-up of learning outcomes could not be answered, such as the retention of knowledge and skills, and overall on short and long-term patient outcomes, such as the ROSC, survival after discharge, or outcome with favorable neurological outcome. That is in line with a recent review that evaluated VR to improve CPR training, which concluded that this field was both diverse and immature.[13]

The 2021 European Resuscitation Guidelines, in their chapter on education for resuscitation, point out the lack of high-quality research on resuscitation education to demonstrate if CRP training improves the quality of the process and overall patients' outcome.[9] This systematic review answers some educational questions, but many are still not answered: Questions clarifying the optimum manner of teaching with the help of VR, and which role VR may play in the frequency of re-training to maintain competencies and knowledge, and lastly, how this educational strategy might prevent deterioration of CPR-skills and knowledge.[14] A new field to study is the evaluation of CPR education in laypersons, as limited high-quality data from very heterogeneous designed studies prone to biases exist.[13] Therefore, CPR education research shall not only limit their focus on educational outcomes and results, but equal efforts need to be made to investigate education strategies that lead to improved patient outcomes after a cardiac arrest, which is still the highest priority.

The general population needs more and better training to be able to deal with emergency medical situations such as cardiac arrest without the immediate help of a professional. New technologies make it easier for this training to reach more people, but they are not conclusive when it comes to reporting improvements as compared to face-to-face BLS training. To this end, new lines of future research are needed to address the study of specific VR systems and extended reality in BLS training to eliminate heterogeneity in the studies and to be able to obtain long-term outcomes and to overcome other research gaps such as the return to spontaneous circulation, survival or neurological outcome at discharge.

5. Conclusions

This systematic review of current literature provides very low certainty scientific evidence suggesting that VR benefits the learning of CPR knowledge, and the training of CPR manual

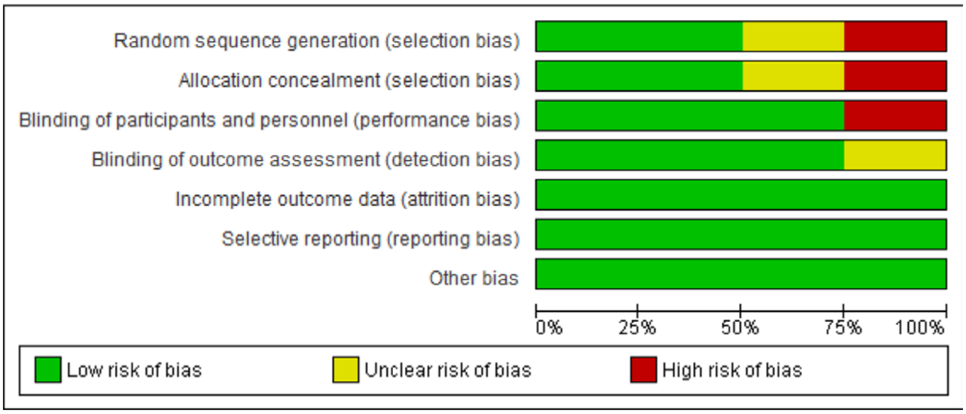


Figure 3. Risk of bias graph: review of authors' judgements about each risk of bias (ROB) item presented as percentages across all included studies. ROB = risk of bias. Buttussi et al, 2020[20]; Cerezo et al, 2019[19]; Leary et al, 2019[18]; Nas et al 2020.[17]

skills to none-health care laypersons. This may be due to the paucity of existing studies and their heterogeneity. New studies are needed to define which tools are used for training and which are used for evaluation of BLS training. In spite of this, the very weak evidence suggests that VR may improve the quality of the chest compressions' frequency and depth as compared to instructor-led face-to-face BLS training. No data on real patients' outcomes or side effects of VR were reported. However, the conclusions from this review should be considered with caution, due to the low quality of many of the included studies.

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References

[1] Perkins GD, Graesner JT, Semeraro F, et al. European resuscitation council guidelines 2021 resumen ejecutivo. Resuscitation. 2021;80:60.
[2] Merchant RM, Topjian AA, Panchal AR, et al. Part 1: Executive summary: 2020 American heart association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation. 2020;142(16_suppl_2):S337–57.
[3] Brady WJ, Mattu A, Slovis CM. Lay responder care for an adult with out-of-hospital cardiac Arrest. N Engl J Med. 2019;381:2242–51.
[4] Deakin CD. The chain of survival: not all links are equal. Resuscitation. 2018;126:80–2.
[5] Sayre MR, Berg RA, Cave DM, et al. Hands-only (compression-only) cardiopulmonary resuscitation: a call to action for bystander response to adults who experience out-of-hospital sudden cardiac arrest: a science advisory for the public from the American heart association emergency cardiovascular care committee. Circulation. 2008;117:2162–7.
[6] Kragholm K, Wissenberg M, Mortensen RN, et al. Bystander efforts and 1-year outcomes in out-of-hospital cardiac arrest. N Engl J Med. 2017;376:1737–47.
[7] Malta Hansen C, Kragholm K, Pearson DA, et al. Association of bystander and first-responder intervention with survival after out-of-hospital cardiac arrest in North Carolina, 2010-2013. JAMA. 2015;314:255–64.
[8] Nakahara S, Tomio J, Ichikawa M, et al. Association of bystander interventions with neurologically intact survival among patients with bystander-witnessed out-of-hospital cardiac arrest in Japan. JAMA. 2015;314:247–54.
[9] Greif R, Lockey A, Breckwoldt J, et al. European resuscitation council guidelines 2021: education for resuscitation. Resuscitation. 2021;161:388–407.
[10] Rea TD, Helbock M, Perry S, et al. Increasing use of cardiopulmonary resuscitation during out-of-hospital ventricular fibrillation arrest. Circulation. 2006;114:2760–5.
[11] Bagai A, McNally BF, Al-Khatib SM, et al. Temporal differences in out-of-hospital cardiac arrest incidence and survival. Circulation. 2013;128:2595–602.
[12] Riggs M, Franklin R, Saylany L. Associations between cardiopulmonary resuscitation (CPR) knowledge, self-efficacy, training history and willingness to perform CPR and CPR psychomotor skills: a systematic review. Resuscitation. 2019;138:259–72.
[13] Kuyt K, Park SH, Chang TP, et al. The use of virtual reality and augmented reality to enhance cardio-pulmonary resuscitation: a scoping review. Advances in Simulation. 2021;6:11.
[14] Greif R, Bhanji F, Bigham BL, et al. Education, implementation, and teams: 2020 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Resuscitation. 2020;156:A188–239.
[15] Taplin J, McConigley R. Advanced life support (ALS) instructors experience of ALS education in Western Australia: a qualitative exploratory research study. Nurse Education Today. 2015;35:556–61.
[16] Cheng A, Nadkarni VM, Mancini MB, et al. Resuscitation education science: educational strategies to improve outcomes from cardiac arrest: a scientific statement from the American heart association. Circulation. 2018;138:e82–122.
[17] Gaddis T. Using virtual reality to bring your instruction to life. League Innovat Conf Inform Technol. 1997;1:27.
[18] Kim BR, Chun MH, Kim LS, et al. Effect of virtual reality on cognition in stroke patients. Ann Rehabil Med. 2011;35:450–9.
[19] Gurusamy KS, Aggarwal R, Palanivelu L, et al. Virtual reality training for surgical trainees in laparoscopic surgery. Cochrane Database Sys Rev. 2009;1:63.
[20] Semeraro F, Ristagno G, Giulini G, et al. Virtual reality cardiopulmonary resuscitation (CPR): comparison with a standard CPR training mannequin. Resuscitation. 2019;135:234–5.

[21] McGrath JL, Taekman JM, Dev P, et al. Using virtual reality simulation environments to assess competence for emergency medicine learners. Acad Emerg Med. 2018;25:186–95.

[22] Mahmood F, Mahmood E, Dorfman RG, et al. Augmented reality and ultrasound education: initial experience. J Cardiothorac Vasc Anesth. 2018;32:1363–7.

[23] Huang CY, Thomas JB, Alismail A, et al. The use of augmented reality glasses in central line simulation: 'see one, simulate many, do one competently, and teach everyone'. Adv Med Educ Pract. 2018;9:357–63.

[24] Ricci S, Calandrino A, Borgonovo G, et al. Viewpoint: virtual and augmented reality in basic and advanced life support training. JMIR Serious Games. 2022;10:e28595.

[25] Balian S, McGovern SK, Abella BS, et al. Feasibility of an augmented reality cardiopulmonary resuscitation training system for health care providers. Heliyon. 2019;5:e02205.

[26] Jaskiewicz F, Kowalewski D, Starosta K, et al. Chest compressions quality during sudden cardiac arrest scenario performed in virtual reality: a crossover study in a training environment. Medicine (Baltimore). 2020;99:e23374.

[27] Mather C, McCarthy R. Exploring the effects of a high-fidelity environment on nursing students' confidence and performance of CPR. Nurs Stand. 2021;36:76–82.

[28] Issleib M, Kromer A, Pinnschmidt HO, et al. Virtual reality as a teaching method for resuscitation training in undergraduate first year medical students: a randomized controlled trial. Scand J Trauma Resusc Emerg Med. 2021;29:27.

[29] Higgins JP, Green S. Cochrane Handbook for Systematic Reviews of Interventions : Cochrane Book Series. :674.

[30] Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. PLoS Med. 2009;6:e1000100.

[31] Sterne JAC, Savović J, Page MJ, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. BMJ. 2019; 366:l4898.

[32] Nas J, Thannhauser J, Vart P, et al. Effect of face-to-face vs virtual reality training on cardiopulmonary resuscitation quality: a randomized clinical trial. JAMA Cardiol. 2020;5:328–35.

[33] Leary M, McGovern SK, Chaudhary Z, et al. Comparing bystander response to a sudden cardiac arrest using a virtual reality CPR training mobile app versus a standard CPR training mobile app. Resuscitation. 2019;139:167–73.

[34] Cerezo Espinosa C, Segura Melgarejo F, Melendreras Ruiz R, et al. Virtual reality in cardiopulmonary resuscitation training: a randomized trial. Emergencias. 2019;31:43–6.

[35] Buttussi F, Chittaro L, Valent F. A virtual reality methodology for cardiopulmonary resuscitation training with and without a physical mannequin. J Biomed Inform. 2020;111:103590.

[36] Yang CH, Liu SF, Lin CY, et al. Immersive virtual reality-based cardiopulmonary resuscitation interactive learning support system. IEEE Access. 2020;8:120870–80.

[37] Bench S, Winter C, Francis G. Use of a virtual reality device for basic life support training: prototype testing and an exploration of users' views and experience. Simulation in Healthcare. 2019;14:287–92.

[38] Craig-Brangan KJ, Day MP. Update: AHA guidelines for CPR and emergency cardiovascular care. Nursing. 2020;50:58–61.

[39] López-Belmonte J, Sánchez S, Belmonte G. La eficacia de la realidad aumentada en las aulas de Infantil: un estudio del aprendizaje de SVB y RCP en discentes de 5 años. Pixel-Bit, revista de medios y educación. 2019;157–78.

[40] Gent L, Sarno D, Coppock K, et al. Abstract 396: successful virtual reality cardiopulmonary resuscitation training in schools: digitally linking a physical manikin to a virtual lifesaving scenario. Circulation. 2019;140(Suppl_2):A396.

[41] Khanal P, Vankipuram A, Ashby A, et al. Collaborative virtual reality based advanced cardiac life support training simulator using virtual reality principles. J Biomed Inform. 2014;51:49–59.

[42] Kleinman ME, Brennan EE, Goldberger ZD, et al. Part 5: adult basic life support and cardiopulmonary resuscitation quality: 2015 American heart association guidelines update for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation. 2015;132(18 suppl 2):S414–35.

[43] Wong MAME, Chue S, Jong M, et al. Clinical instructors' perceptions of virtual reality in health professionals' cardiopulmonary resuscitation education. SAGE Open Med. 2018;6:2050312118799602.

[44] Hunt EA, Duval-Arnould JM, Chime NO, et al. Integration of in-hospital cardiac arrest contextual curriculum into a basic life support course: a randomized, controlled simulation study. Resuscitation. 2017;114:127–32.

[45] Hunt EA, Duval-Arnould JM, Nelson-McMillan KL, et al. Pediatric resident resuscitation skills improve after "rapid cycle deliberate practice" training. Resuscitation. 2014;85:945–51.

[46] Lemke DS, Fielder EK, Hsu DC, et al. Improved team performance during pediatric resuscitations after rapid cycle deliberate practice compared with traditional debriefing: a pilot study. Pediatric Emergency Care. 2019;35:480–6.

[47] Tekedere H, Göke H. Examining the effectiveness of augmented reality applications in education: a meta-analysis. Int J Environ Sci Educ. 2016;11:9469–81.

[48] Kleinert R, Wahba R, Chang DH, et al. 3D immersive patient simulators and their impact on learning success: a thematic review. J Med Internet Res. 2015;17:e3492.