Virtual Reality Simulation Training for Cardiopulmonary Resuscitation after Cardiac Surgery: Face and Content Validity

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Abstract

Background: Cardiac arrest after cardiac surgery commonly has a reversible cause, where often emergency re-sternotomy is required for treatment, as recommended by international guidelines. We have developed a virtual reality (VR) simulation for training of CPR and emergency re-sternotomy procedures after cardiac surgery, the CardioPulmonary resuscitation VR-simulator (CPVR-sim). In this prospective study, we researched face validity and content validity of this CPVR-sim.

Objective: We designed a prospective study to assess the feasibility and to establish the face and content validity of CPVR-sim in a group of novices and experts in performing CPR and emergency re-sternotomies in patients after cardiac surgery.

Methods: Thirty clinicians (staff cardiothoracic surgeons, physicians, surgical residents, and nurse practitioners) participated as either an expert or novice, based on experience with emergency re-sternotomy. All performed the simulation and completed the questionnaire rating the simulator’s usefulness, satisfaction, ease of use, effectiveness, and immersiveness to assess face validity and content validity.

Results: Responses towards face validity and content validity were predominantly positive in both groups. Most participants felt actively involved (97%), in charge of the situation (73%), it was easy to learn how to interact with the software (80%), and the software responded well (70%). Almost all expert-participants preferred VR training as a substitute to conventional (100%) and digital (60% agreed and 40% was neutral) training. Moreover, 86% of the expert-participants would recommend VR training to other colleagues, and 93% found that CPVR-sim is a useful method to train infrequent CPR-cases after cardiac surgery.

Conclusions: We developed a proof-of-concept of a VR simulation for CPR training after cardiac surgery, which participants found was immersive and useful. By proving the face validity and content validity of CPVR-sim, we present a first step towards a cardiothoracic surgery VR training platform.

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Virtual Reality Simulation Training for Cardiopulmonary Resuscitation after Cardiac Surgery: Face and Content Validity

Running head: VR training for CPR post cardiac surgery

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Abstract

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Conclusions: We developed a proof-of-concept of a VR simulation for CPR training after cardiac surgery, which participants found was immersive and useful. By proving the face validity and
content validity of CPVR-sim, we present a first step towards a cardiothoracic surgery VR training platform.

**Keywords:** cardiac surgery; cardiopulmonary resuscitation; emergency re-sternotomy; Virtual Reality; simulation training

**Introduction**

Every year, around 2 million patients undergo cardiac surgery worldwide [1]. The incidence of cardiac arrest after cardiac surgery ranges between 0.7% to 8% with a survival rate of approximately 50% [2-5]. This relatively high survival rate can be explained by a high incidence of reversible causes precipitating the arrest, such as ventricular fibrillation (VF) (25-50%), cardiac tamponade, hypovolaemia, and tension pneumothorax [2,4-6]. Notably, aside from VF, external massage is often ineffective in these cases because of reduced diastolic filling of the heart, resulting in inadequate tissue and brain perfusion [2]. In light of these findings, The Society of Thoracic Surgeons Taskforce on Resuscitation After Cardiac Surgery published an expert consensus in 2017 to provide guidelines for developing local protocols for cardiopulmonary resuscitation (CPR) after cardiac surgery [2]. As reported in the guidelines, early recognition is essential of the clinical signs and symptoms indicating that emergency re-sternotomy is required [2,5]. The majority of post-operative cardiac surgery emergencies requiring CPR will involve re-opening of the sternum [2,5]. Several studies have shown that training and practising based on a structured protocol improves the time to recognise the need for re-sternotomy and the time to actually re-open the thorax [2,7]. Early re-sternotomy reduces complications and improves outcomes for patients with cardiac tamponade, hypovolaemia, or tension pneumothorax [2,7]. However, the paucity of these cases limits the possibilities of clinical training for clinicians [8]. CPR training allows clinical staff to acquire theoretical knowledge on the protocol, together with the ability to physically perform the steps described within the protocol [9]. This is
commonly taught in instructor-led training sessions, requiring multiple team members and supplies [2]. Moreover, these classroom sessions are currently restricted by precautionary measures taken during the coronavirus 2019 pandemic [10].

Simulation training enables training of multiple cases with unlimited practice (and possible errors), without compromising patient safety or the need for setting up training sessions [8]. Virtual Reality (VR), with 360-degree scenarios, can recreate a fully immersive, interactive, and reality-like scenario in which the user is able to repeatedly train without the need for other supplies or participants. Moreover, it is possible to use VR in a multi-user setting, allowing different users to be present in the same scenario while physically distanced [11]. Multiple studies have shown that simulation training effectively improves knowledge, confidence, motivation, and satisfaction with the training versus standard training methodology[8,9,12,13].

Quantifying outcomes and the validity of simulations is a difficult task. It is essential that a VR simulator is valid, in the sense that it resembles a realistic situation and reinforces the appropriate skills and knowledge [14]. This validity consists of several subtypes, including face validity and content validity. Face validity relates to the realism of a simulator, or in this case how well the simulation resembles real-world clinical practice [14,15]. This can be assessed informally by experts (referents) and non-experts (novices/trainees) in the field [16-19]. Content validity judges the usefulness of the simulator as a training method [14,15]. This can be assessed by an evaluation of experts in the subject matter of the training [16-20]. The implementation of a new protocol and limited incidence of emergency re-sternotomies after cardiac surgery highlight the need to develop a high-fidelity training method, that follows the expert consensus protocol for CPR and re-sternotomy for patients after cardiac surgery [2]. To facilitate medical staff training at our cardiothoracic surgery (CTS) department, we have developed a dedicated VR-based post-cardiac surgery CPR simulation:
CPVR-sim (CardioPulmonary resuscitation Virtual Reality-simulator). We designed a prospective study to assess the feasibility and to establish the face and content validity of CPVR-sim in a group of novices (e.g. surgical residents, junior-physicians and nurse practitioners) and experts (e.g. cardiothoracic surgeons and senior residents).

**Methods**

**Study participants**

A total of thirty participants were included in this study. To assess the face validity and content validity of CPVR-sim, the participants were assigned to the novice or expert group. Staff-cardiothoracic surgeons and certified CPR-training instructors were categorised as expert, while the remaining participants were classed as novices (e.g. junior physicians, nurse practitioners, and surgical residents).

All participants completed written consent forms for their participation in this study. The research protocol was approved by the Erasmus Medical Center Medical Ethical Review Committee (MEC-2020-0989).

**Simulator**

The simulation was designed by a multidisciplinary team consisting of physicians, researchers, software developers, digital transformation experts, VR experts, and cardiothoracic surgeons from the CTS department located at Erasmus Medical Center (Rotterdam, the Netherlands), Zan Mitrev Clinic (Skopje, Republic of North Macedonia) and Distant Point LTD (Skopje, Republic of North Macedonia). Unreal Engine (Epic Games, Cary, North Carolina) software was used for software
development. An Oculus Quest 2 (Oculus, Irvine, California, USA) head-mounted display (HMD) in combination with two VR-controllers and a high-performance laptop (MSI, New Taipei City, Taiwan) was used to run the CPVR-sim.

In order to study the feasibility of CPVR-sim, we developed an immersive VR simulation resembling CPR-scenario after cardiac surgery, based on a fictive patient case (Supplementary Video). The patient scenario recreated in the simulation was a fictive case of a patient three days after undergoing cardiac surgery via median sternotomy. This patient was found to be unresponsive on the surgical ward, determined to be in cardiac arrest and requiring CPR, as a result of cardiac tamponade leading to PEA. Before running the simulation, each participant was given a short briefing on the scenario, how to use the VR HMD, and how to interact with the controls and software to perform the CPVR-sim. When the simulation started, the user of the CPVR-sim was placed as a team leader of the CPR team. The team leader was able to assign tasks to the other participants in the simulation or was able to execute several tasks him/herself to manage the cardiac arrest situation. Figure 1 shows multiple screen captures of the team leader’s view during the simulation. The team leader was able to instruct the virtual colleagues by choosing between different menu options (Figure 1B) with the joystick on the controller. Additionally, a participant wearing the HMD and performing the simulation is shown (Figure 1D). The menu options were shuffled each time the simulation started, so the user did not know the order of the menu-options beforehand. When the correct command was given, it was followed by visual and auditory feedback of the instruction. This means, for example, that when "Start Chest Compressions" was chosen at the correct moment, the virtual nurse confirmed the instruction and started chest compressions.

**Questionnaire**

After finishing the simulation, all participants completed a questionnaire consisting of participant characteristics questions, including their experience with emergency re-sternotomy, gaming, and VR.
Subsequent, questions were scored on a five-point Likert-scale, ranging from 1 (fully disagree) to 5 (fully agree). The Likert-scale questions were divided into the following categories: usefulness, satisfaction, ease of use [21], effectiveness, and immersiveness [12,22-24] as described in previous studies. Finally, the questionnaire concluded with open questions to assess the advantages and disadvantages of the simulation. The questionnaire can be found in Supplementary file S1. To determine face validity, we used questionnaire results on the ease of use, effectiveness, and immersiveness of all participants. To assess content validity, we looked at the results from the expert-group, regarding usefulness and satisfaction.

**Statistical analysis**

Statistical analysis was performed using IBM SPSS Statistics for Windows, version 26.0 (IBM Corp., Armonk, New York, USA). We used a Mann-Whitney U test to perform statistical analyses of non-normal numerical data such as the Likert-scale results. For non-normally distributed categorical data, such as the participant characteristics, we used the Chi-squared test. Continuous data are presented as median with interquartile range (IQR) and categorical data, including Likert scales, are presented as percentages.

**Results**

**Participant characteristics**

All thirty participants performed the simulation and completed the questionnaire. Participants were divided into two groups, 15 experts (staff cardiothoracic surgeons and certified CPR instructors) and 15 novices (physicians, residents, and nurse practitioners). The median age of the expert group was 43 (IQR 38, 55.5) years and of the novice group 30 (IQR 30, 42.5) years (p<0.05). Furthermore, the median work experience in cardiothoracic surgery was 17 (IQR 9.5, 26.5) years in the expert group.
and 1 (IQR 0.5, 4.5) year in the novice group (p<0.05). The participant characteristics are shown in Table 1.

**Questionnaires**

The face validity of CPVR-sim was assessed first, from the ease of use, effectiveness, and immersiveness questions in the questionnaires. The results of the questionnaires are displayed in **Figure 2**. Most participants (87%) felt actively involved and in charge (77%) of the situation suggesting an predominant positive opinion regarding the face validity in both groups. Simulation software responded adequately and did not lag according to 70% of the participants, and 80% of the participants reported that it was easy to learn how to interact with the software.

Subsequently, the content validity was assessed from the results of the expert group (n=15) from the satisfaction and usefulness outcomes of the questionnaire (**Figure 3**). All of the expert-participants (100%) agreed that this VR training method is useful as a supplement to conventional training methods and 60% (40% was neutral) as a supplement to current digital training methods. Notably, some of the expert-participants did not prefer VR training instead of conventional (43%) or digital training (36%). Conversely, 86% of the expert-participants would recommend VR training to other colleagues and 93% of them reported that CPVR-sim is a useful method to train for infrequently occurring CPR-cases after cardiac surgery. 43% of the expert group and 80% of the novice group stated that they learned a lot from CPVR-sim (**Supplementary file S2**).

Finally, participants were asked for general advantages and disadvantages of the CPVR-sim. The most commonly reported advantages were the broad applicability of the VR simulation on various CPR scenarios, the possibility of a repetitive, personal, and quick practice session without being restricted by logistical challenges, and that CPVR-sim is a beneficial method for step-by-step sequence training. The most important disadvantages of the current CPVR-sim version were the limited freedom of decision making, lack of team-training and interaction with a team, and the absence in the CPVR-sim of the pressure and hectic environment during such an emergency.
situation, which made it feel occasionally artificial. Results of the face and content validity questionnaire can be found in Supplementary file S2, and a complete overview of the advantages and disadvantages filled in by the participants can be found in Supplementary file S3.

| Table 1: Participant Characteristics | Experts (n = 15) | Novices (n=15) | Total (n=30) | P value *
|--------------------------------------|-----------------|----------------|-------------|---------|
| **Sex**                             | n (%)           | n (%)          | n (%)       |         |
| Male                                | 12 (80)         | 10 (67)        | 22 (73)     | 0.409   |
| Female                              | 3 (20)          | 5 (33)         | 8 (27)      |         |
| **Profession**                      |                 |                |             | <0.05   |
| Cardiothoracic Surgeon             | 13 (87)         | 1 (7)          | 14 (47)     |         |
| CTS Resident                        | 1 (7)           | 4 (27)         | 5 (17)      |         |
| CTS Junior Physician               | 0 (0)           | 6 (40)         | 6 (20)      |         |
| CTS Nurse practitioner             | 1 (7)           | 4 (27)         | 5 (17)      |         |
| **Experience with post cardiac surgery CPR** |                 |                |             | <0.05   |
| No experience                       | 0 (0)           | 1 (7)          | 1 (3)       |         |
| 1 to 5 times                        | 1 (7)           | 8 (53)         | 9 (30)      |         |
| 6 to 10 times                       | 1 (7)           | 4 (27)         | 5 (17)      |         |
| More than 10 times                  | 13 (87)         | 2 (13)         | 15 (50)     |         |
| **Experience with emergency re-sternotomy** |                 |                |             | <0.05   |
| No experience                       | 0 (0)           | 5 (33)         | 5 (17)      |         |
| 1 to 5 times                        | 4 (27)          | 9 (60)         | 13 (43)     |         |
| 6 to 10 times                       | 1 (7)           | 1 (7)          | 2 (7)       |         |
## Discussion

### Principal results

In this prospective study, we have designed and evaluated a VR simulation training platform for post cardiac surgery emergencies requiring CPR. To the best of our knowledge, this is the first time that such a VR simulation platform has been developed explicitly for use in a cardiac arrest scenario after cardiac surgery. Although future refinements of this concept are inevitable, we believe that the CPVR-sim will be a successful method that will help to overcome difficult challenges including the infrequent incidence of re-sternotomy after cardiac surgery, accessibility, and costs of clinical training [25]. We observed that the expert and novice opinions were generally positive regarding the face validity as well as the content validity. There was a very positive attitude towards the usefulness and using VR simulations as a (supplementary) training method in both groups, as well as a high likelihood that participants would recommend VR simulation training to other colleagues.

Furthermore, in the CPVR-sim, the trainee was more actively involved in experiencing the virtual
patient case, as compared with conventional eLearning, listening to a presentation, or reading a protocol. An immersive and realistic VR environment facilitates memorising stepwise procedures more efficiently [25]. Additionally, our results showed that frequent practice and increased exposure in CPVR-sim is valuable since it refreshes the knowledge and gives the clinician more confidence in taking the lead in future situations, which is in line with previous studies [8,9,12,13]. This is especially important in infrequent CPR-cases with emergency re-sternotomy, which occurs only a few times per year.

Another important feature of this VR training is the improved accessibility, since the only requirements are an HMD and a computer and there is no need to arrange a physical session. VR training has higher initial costs (e.g. simulation development and purchase costs of the VR hardware) than conventional training. However, the increased accessibility of VR training results in more trainees being reached, spreading these initial costs over a larger group, compared with the relatively linear cost per trainee for conventional training. Therefore, the average cost per trainee would likely be lower in the long term for VR training than conventional training [26]. Moreover, purchasing and using VR hardware adds a new dimension and armature in training possibilities and other applications (i.e., surgical planning) of a department, which can also lead to cost-efficiency. Finally, VR training facilitates the implementation of the new CPR-protocol, enabling training for experts and novices alike who are not yet acquainted with the new protocol.

**Limitations**

In the current simulation, only individual training was possible. It would be desirable to make the simulation available for multiple users at a time, enabling real-time interaction between team members [11]. By making the simulation available for multiple users at the same time, non-technical skills such as communication and leadership can be trained with the team, which is important in CPR
situations [27]. This would also enable learning from other trainees’ mistakes. Multiplayer settings would additionally enable the trainee to view the CPR-situation from different viewpoints, and the possibility to review their own performance from an alternative perspective [25]. Another shortcoming of CPVR-sim is that the simulation requires at least five different buttons to be pressed, which can be confusing for the trainee. The simulation would become more realistic and interactive when voice controls and haptic feedback such as hand or even body tracking are implemented to perform the actions within the simulation, instead of using the controllers as input in the simulation [28]. However, implementing voice control can be computationally and algorithmically challenging, as similar information can be said using a variety of different phraseology, and further research should be performed on the best interaction-method within the VR environment [25-28].

Finally, a shortcoming in the current simulation was the lack of pressure felt by participants and the absence of a hectic environment characteristic of such an emergency situation. The virtual nurses stood very still, walked calmly, and there was a lack of background noise. This could be improved in future development by adding stress components, such as sounds or extra persons who are panicking [20]. Making the simulation more resembling the real-life situation might improve the success of VR training [25]. However, further research is needed to ensure such stress components do not comprise the educational value of the CPVR-sim.

**Future perspective**

The most crucial next step in improving the simulation and increasing the educational value is to extend CPVR-sim with multiple scenarios. In this way, the trainee actually needs to make decisions based on the protocol, on what needs to be the treatment plan, and retain what the required steps are for a variety of different situations. The current simulation scenario was based on a case of PEA, and as such could be extended to multiple situations described within the protocol (for example, VF
where shocking is essential, or asystole where pacing is required) [2].

These face and content validity results support the use of the simulator as a training tool, but they are subjective measures of validity. Besides improving the simulation, since face validity and content validity are subjective measures, it is imperative to validate the simulation objectively. This can be perceived by determining the construct validity and predictive validity of CPVR-sim [14,15,20]. Construct validity in simulation is defined as the ability to distinguish objectively between different levels of experience [14,15,20]. In future research, this could be determined by testing a large number of users with various levels of experience in CPR and emergency re-sternotomy cases after cardiac surgery. Moreover, predictive validity is an even more powerful evidence method, which can be assessed by comparing the outcomes of the simulation with an established assessment method to assess the skills [15,20]. In further research, predictive validity could be determined by comparing the clinical staff’s skills in a real-life simulation setting and CPVR-sim. These skills could be obtained by a structured skills assessment of both the skills in real life and within the VR simulation determined by blinded experienced CPR trainers.

**Conclusion**

We have developed a proof-of-concept of a VR simulation of a CPR case after cardiac surgery, which is immersive and useful, as stated by the expert and novice participants. Additional research is needed to further develop and validate the simulation platform, including multiple possible clinical scenarios, voice control, multi-user possibilities and assessing the construct validity. However, we made a first step towards a CTS VR training platform, including multiple realistic and repetitive simulation training for the CTS department by proving the face validity and content validity of CPVR-sim.
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Conflict of interest

None declared.

Abbreviations

CPR - Cardiopulmonary resuscitation
CPVR-sim - Cardiopulmonary resuscitation virtual reality-simulator
CTS - Cardiothoracic surgery
IQR - Interquartile range
VF - Ventricular fibrillation
VR - Virtual reality
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Figure Legends

Figure 1: Screenshots of the CPVR-sim simulation training
Screen captures of the cardiopulmonary resuscitation virtual reality simulation (CPVR-sim), showing an overview with five virtual nurses in a patient room (A), the main menu (B), opening the incision with a virtual scalpel (C) and a participant performing the simulation wearing the head-mounted display, with an in-screen screen capture of the CPVR-sim (D).

Figure 2: Representation of the results on face validity-related questionnaires assessed from all (expert and novice) participants.

Figure 3: Representation of the results on content validity-based questionnaires, assessed from the expert participants.
Supplementary Files
Figures
Screenshots of the CPVR-sim simulation training. Screen captures of the cardiopulmonary resuscitation virtual reality simulation (CPVR-sim), showing an overview with five virtual nurses in a patient room (A), the main menu (B), opening the incision with a virtual scalpel (C) and a participant performing the simulation wearing the head-mounted display, with an in-screen screen capture of the CPVR-sim (D).
Representation of the results on face validity-related questionnaires assessed from all (expert and novice) participants.
Representation of the results on content validity-based questionnaires, assessed from the expert participants.
Multimedia Appendixes
Supplementary Video of the CPVR-simulation.
URL: http://asset.jmir.pub/assets/edb8f1e5eb95a068be4416a35173262.mp4

Supplementary File.
URL: http://asset.jmir.pub/assets/f6500f3304df3dbd1676f6ae2578b39b.docx