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Collaborative Simulation Training in Extended Reality with High-Fidelity Patient Simulator for Emergency Contexts

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Abstract. This study aims to design and develop a collaborative simulation in extended reality (XR) environments that integrates a high-fidelity patient simulator to enhance emergency medical training, particularly in the context of Korea Advanced Life Support (KALS) education. In hospital settings, the ability to respond swiftly and effectively to cardiac arrest scenarios is essential, requiring structured team coordination, rapid decision-making, and effective communication. The team leader plays a central role in orchestrating the resuscitation process; however, existing training methods often fail to replicate the high-pressure, real-time decision-making requirements of actual emergency situations. To address these limitations, this study proposes an XR-based simulation that immerses learners in realistic emergency scenarios, allowing them to lead a virtual resuscitation team, issue commands, and implement life-saving interventions. By integrating a high-fidelity patient simulator with real-time interactive virtual team members, the training aims to enhance both technical and leadership skills. Additionally, the study will evaluate the effectiveness of XR-enhanced training in improving decision-making efficiency, team coordination, and preparedness for high-stakes medical emergencies. The broader implications of this research extend to scalability and adaptability, exploring how XR-based simulations can be expanded to other advanced life support training programs and integrated into global medical education frameworks.

Keywords: Extended Reality (XR), Collaborative Medical Simulation, High-Fidelity Patient Simulator, Korea Advanced Life Support (KALS), Emergency Medical Training.

1 Introduction

Rapid and effective medical response is essential for patient survival, particularly in in-hospital cardiac arrest (IHCA) scenarios [1]. The Korea Advanced Life Support (KALS) program provides standardized training protocols to equip healthcare professionals with the necessary skills for managing cardiac arrest in hospital settings [2]. Based on Advanced Life Support (ALS) guidelines, KALS integrates team-based collaborative exercises and high-fidelity patient simulators to improve training effectiveness. However, despite its structured approach, conventional KALS training methods have notable limitations.

One of the primary challenges is the lack of real-time feedback, which limits participants' ability to immediately correct errors and refine their decision-making processes. Additionally, leadership development within resuscitation teams is often insufficiently prioritized, despite its crucial role in ensuring effective coordination and clinical efficiency. Existing training environments also fail to simulate dynamic, high-pressure emergencies, as they do not incorporate adaptive virtual team members capable of responding in real-time to the leader's decisions.

To address these gaps, this study proposes the development of an XR-based collaborative simulation that integrates virtual team members, real-time feedback mechanisms, and immersive emergency scenarios. The study aims to evaluate whether XR-enhanced training environments offer a more effective approach to leadership training, decision-making, and resuscitation team coordination compared to conventional methods.

2 Methods

2.1 Simulation Scenario Design

The XR simulation follows a structured, stepwise learning model designed to align with KALS training objectives and evidence-based instructional strategies (Figure 1) [3]. The simulation is divided into six progressive training phases, each focusing on increasing complexity and decision-making demands to reinforce clinical competency and leadership skills.

The first three phases focus on ventricular fibrillation (VF) and pulseless ventricular tachycardia (pVT), where participants practice defibrillation, medication administration, and airway management in progressively challenging conditions. The fourth and fifth phases emphasize the management of asystole and pulseless electrical activity (PEA), training participants to recognize non-shockable rhythms, administer life-saving interventions, and identify reversible causes such as oxygen deprivation or metabolic disturbances. The final phase integrates all prior learning stages into a comprehensive scenario, requiring participants to lead a resuscitation team, analyze cardiac rhythms, and make high-stakes medical decisions in real time.

By structuring the simulation in a progressive learning format, this design ensures that participants systematically acquire technical proficiency, situational awareness, and team leadership competence before engaging in complex clinical emergencies.

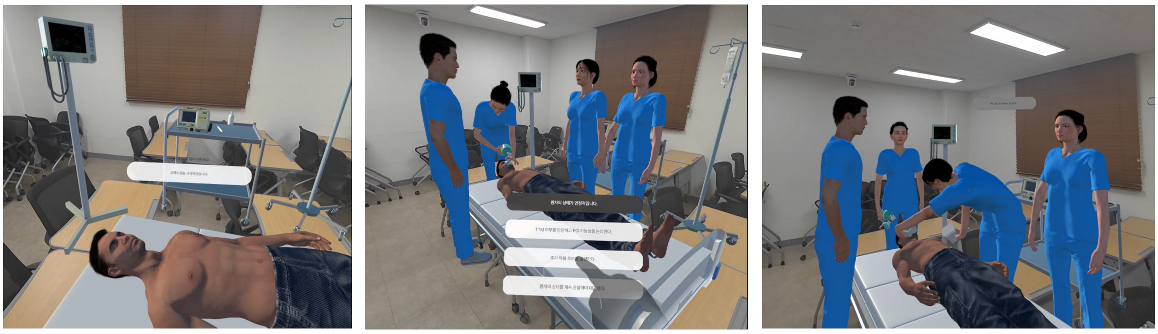
Stage	VF/pVT	VF/pVT	VF/pVT	Asystole/PEA	Asystole/PEA	ROSC
1	☞Defibrillation ☞Epinephrine					☞PCAC
2	☞Defibrillation ☞Epinephrine	☞Defibrillation ☞Advanced airway				☞PCAC
3	☞Defibrillation ☞Epinephrine	☞Defibrillation ☞Advanced airway	☞Defibrillation ☞Amiodarone or Lidocaine			☞PCAC
4				☞Epinephrine		☞PCAC
5				☞Epinephrine	☞Advanced airway ☞Hs&Ts	☞PCAC
6	☞Defibrillation ☞Epineph-rine*	☞Defibrillation ☞Advanced airway	☞Defibrillation ☞Amiodarone or Lidocaine	☞Epinephrine ☞Hs&Ts	☞Epinephrine ☞Hs&Ts	☞PCAC

Fig. 1. Step-by-step learning stages for KALS training.

2.2 Development of XR Simulation

Team-Based Simulation and Training for Leadership Roles. A core component of the XR simulation is the structured team-based training model. The simulation features a six-member team, where five members are virtual characters, and the participant assumes the role of the team leader. Figure 2 illustrates the implementation of collaborative simulation training, depicting the critical stages of emergency response during a cardiac arrest scenario. At the beginning of the scenario, a cardiac arrest event is triggered, requiring the participant to take immediate action (Figure 2a). The participant must assess the situation, analyze the cardiac rhythm displayed on the virtual interface, and initiate the appropriate emergency procedures. As the scenario progresses, the team leader issues commands to the virtual team members, assigning them specific roles and ensuring that emergency protocols are followed correctly (Figure 2b). The interface also provides access to virtual reference materials, which contain detailed descriptions of cardiac rhythm types and corresponding treatment guidelines. Once the resuscitation plan is in place, the virtual team members carry out their assigned interventions based on the participant's instructions, ensuring a dynamic and interactive training experience (Figure 2c).

The virtual interface plays a critical role in supporting decision-making and leadership training. It allows the participant to check procedural checklists and team member assignments in real time. These features can be accessed when needed and minimized to prevent distractions, ensuring that the primary focus remains on simulation-based decision-making and execution. This collaborative and interactive approach mirrors real-world medical teamwork, providing participants with practical experience in leading and coordinating emergency responses.



(a) (b) (c)

Fig. 2. Implementation of collaborative simulation training in the XR environment: (a) Initiation of a cardiac arrest scenario, (b) Providing proper instructions to the resuscitation team, (c) Intervention by virtual team members.

Performance Evaluation and Feedback System. To assess participant performance, the simulation incorporates an evaluation system that combines instructor observation with automated data analysis. The instructor monitors the participant's actions throughout the simulation and records whether they complete the required procedures using a predefined checklist. The system then processes this data to generate an accuracy score, which reflects the participant's adherence to standardized protocols. This score provides immediate feedback, allowing participants to review their performance and identify areas for improvement. The combination of quantitative performance metrics and qualitative instructor insights ensures a comprehensive evaluation of both procedural accuracy and decision-making effectiveness.

Implementation and XR System Features. The XR simulation is developed using Unity, a widely used platform for creating immersive virtual environments. The final implementation will run on the Meta Quest 3s device (Meta Platforms, Inc., Menlo Park, CA, USA), which is equipped with high-resolution displays, spatial audio, and advanced hand-tracking capabilities. These features enhance realism and user interaction, making the device well-suited for medical training applications [6]. The simulation also leverages augmented reality (AR) overlays, which provide contextual visual cues such as cardiac rhythm indicators, procedural guidance, and real-time representations of virtual team members performing assigned roles. For instance, if a virtual team member is assigned to administer medication or perform defibrillation, the corresponding animation will be displayed, reinforcing the procedural steps. A key design consideration is usability, ensuring that the AR interface remains non-intrusive while providing necessary support. Participants can access supplementary information, such as team role assignments or procedural instructions, as needed. The ability to minimize and expand these resources ensures that the focus remains on hands-on interaction with the simulator rather than excessive reliance on on-screen references. Through this integration of XR and AR technologies, the simulation enhances both technical training and cognitive decision-making, creating a highly interactive and effective learning environment.

2.3 Expert Validation

The expert validation phase will involve a comprehensive review process to ensure the educational and clinical relevance of the simulation. A panel of medical and instructional design experts will first participate in a structured simulation walkthrough, during which they will evaluate the content of the scenarios, user interactions, and technical accuracy. Following the walkthrough, the experts will complete a structured questionnaire designed to assess the clarity, realism, and alignment of the simulation with KALS training objectives.

To quantitatively measure agreement among the experts and identify aspects requiring revision, the responses will be analyzed using the Content Validity Ratio (CVR) [7]. Additionally, focus group interviews (FGIs) will be conducted to gather qualitative insights on the strengths and weaknesses of the simulation design. These discussions will focus on enhancing clinical realism and educational effectiveness while identifying potential areas for improvement [8]. Feedback from both the questionnaires and FGIs will shape the refinements required for the simulation, such as adjusting scenarios, improving user interface elements, or modifying procedural instructions.

Following these revisions, a second round of expert reviews will be conducted to ensure that the modifications effectively address the feedback and meet the desired educational and clinical standards. This iterative validation process ensures that the final simulation product is both effective and practical for its intended use in KALS training.

3 Anticipated Effectiveness and Research Implications

3.1 Investigating the Impact on KALS Team Leader Training

One of the well-documented challenges in traditional medical training is the difficulty of replicating the dynamic and high-pressure conditions of real-world emergency situations [9]. Research suggests that simulation-based training improves decision-making, role allocation, and team coordination by allowing learners to engage in authentic, scenario-driven exercises [10]. However, traditional simulations often lack adaptive virtual team members, which limits their ability to replicate complex emergency response interactions.

The proposed XR simulation integrates dynamic virtual team members that respond to real-time leadership commands, providing a controlled yet immersive environment for practicing leadership skills. To evaluate its impact, this study will analyze participants' decision accuracy, response time, and leadership performance before and after training. Additionally, the system's real-time feedback feature will be examined to determine whether it supports self-reflection and skill refinement. By comparing performance data from the XR simulation with traditional KALS training methods, this study seeks to establish a data-driven foundation for assessing its effectiveness in improving team leadership during cardiac arrest scenarios.

3.2 Advancing Innovation in Medical Training

This research contributes to the growing body of evidence supporting the integration of XR technology in medical training. Prior studies have demonstrated that XR-based training enhances knowledge retention, engagement, and procedural skill acquisition by offering a combination of physical task practice and immersive virtual environments [4]. Traditional medical training methods, while effective, often struggle to provide the level of interactivity required for high-stakes emergency response training. The proposed XR simulation bridges this gap by combining the tactile realism of high-fidelity patient simulators with the interactive capabilities of augmented reality (AR).

To assess its educational impact, this study will examine how AR-enhanced learning materials, real-time decision-making tasks, and interactive team coordination influence learning outcomes and user engagement. Additionally, the potential for customizing the simulation to match different training needs will be explored. By systematically evaluating learner experiences and performance improvements, this study will provide empirical insights into the role of XR technology in medical education innovation.

3.3 Exploring Scalability and Broader Educational Applications

A key research focus is the scalability of the XR simulation model beyond KALS training. The modular design allows for potential adaptation to other advanced life support protocols, such as Advanced Life Support (ALS) and Pediatric Advanced Life Support (PALS). Studies indicate that simulation-based training is particularly effective for high-risk, low-frequency medical scenarios, making it an ideal candidate for expansion into mass casualty response and disaster preparedness training [5]. By collecting data on usability, learning engagement, and training effectiveness, this study will determine whether the XR simulation can serve as a cost-effective and scalable solution for global medical education.

4 Discussion

This study explores the design and implementation of an XR-based collaborative simulation tailored for KALS training in emergency medical contexts. By focusing on leadership development and real-time team coordination, the proposed simulation aims to address critical gaps in decision-making skills required during in-hospital cardiac arrest scenarios. Previous research has highlighted the importance of immersive learning environments in improving situational awareness and procedural accuracy in emergency response training [6].

Through expert validation—including structured walkthroughs, content validity analysis, and iterative refinements—this study aims to ensure that the simulation aligns with clinical guidelines and instructional design principles. The assessment of usability, learning engagement, and training effectiveness will provide evidence-based insights into the effectiveness of XR-driven training approaches. If the simulation proves to be a viable training tool, it could serve as a model for future applications of XR technology in medical education.

Beyond KALS training, the flexible design of the XR simulation presents an opportunity for broader applications in advanced life support training, mass casualty incident response, and emergency preparedness programs. By integrating adaptive virtual team members and AR overlays, the proposed model may contribute to the modernization of clinical training methodologies. Future studies will be needed to explore longitudinal learning outcomes, user retention, and the comparative effectiveness of XR-based simulations versus traditional methods.

5 Conclusion

This study outlines the development and implementation of a collaborative XR simulation for KALS training, designed to improve leadership, decision-making, and team coordination skills in high-stakes emergency situations. By integrating augmented reality overlays and high-fidelity patient simulators, the proposed model aims to create an interactive, immersive learning experience that aligns with clinical training standards.

An iterative validation process, informed by expert feedback and empirical analysis, will ensure that the simulation meets educational and clinical requirements. The study will investigate the impact of real-time feedback, dynamic team interactions, and scenario adaptability in enhancing medical training outcomes. Additionally, the potential for scalability suggests that this XR-based training model could be applied beyond KALS training to other life support programs and emergency medical protocols.

As the system is refined and implemented in real-world training settings, future research will be required to evaluate its long-term effectiveness, user adoption, and integration into existing medical education frameworks. Ultimately, this study seeks to contribute to the advancement of evidence-based XR applications in medical education, with the goal of improving patient outcomes through enhanced clinical training methodologies.

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