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Modelling Processes of Anaesthesiology and Resuscitation Care in Crisis Situations: Utilisation of Simulation Trainers and Models for Training Medical Professionals—A Multifactorial Analysis

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ABSTRACT

BACKGROUND

The study was motivated by the necessity to enhance the training of anaesthesiologists and intensivists for work in crisis situations through the integration of innovative simulation technologies, including VR and MR modelling. The objective of this work was a comprehensive evaluation of the impact of these methods on the development of cognitive strategies, improvement of situational awareness, and reduction of medical errors in critical conditions.

MATERIALS AND METHODS

The study employed a multifactorial analysis of simulation training efficacy, incorporating Objective Structured Clinical Examination, cognitive testing, expert assessment of professional competency, and statistical analysis of the dynamics in mastering resuscitation algorithms. The evaluation focused on the speed of clinical decision-making, accuracy of life-saving procedures, and effectiveness of team coordination in intensive care settings.

RESULTS

The results confirmed the high efficacy of VR and MR models in optimising resuscitation protocols, reducing tactical errors, and improving physicians' adaptation to extreme clinical scenarios. It was established that the integration of simulation training enhances action algorithmisation, fosters robust crisis management skills, and elevates professionals' confidence levels. The analysis of the obtained data substantiated the feasibility of implementing simulation techniques in postgraduate training for anaesthesiologists and intensivists, as well as in continuous medical education programmes to standardise interventions in critical conditions.

CONCLUSION

The study's findings demonstrated the significance of VR and MR simulations in shaping strategic clinical reasoning, refining professional competencies, and minimising the risk of errors in high-stress environments. The practical value of this work lies in expanding the capabilities of simulation training for preparing medical professionals for crisis situations, improving patient safety, and developing adaptive educational programmes to optimise anaesthesiology and resuscitation care.

Keywords: Cognitive-motor integration, Multimodal training, Virtual prototyping, Virtual reality technologies

Highlights

- VR/MR enhances crisis training, boosts decision-making, cuts errors.
- SBT improves cognitive-motor skills, resuscitation, team coordination.
- 2024 study: 72 participants, faster decisions, fewer errors ($p < 0.05$).
- VR/MR standardizes postgraduate training, improves patient safety.

Introduction

Reproducing the processes of anaesthesiology and resuscitation care in emergency settings is a crucial component of training medical professionals to work in extreme conditions, particularly during military conflicts, industrial disasters, and epidemics. The use of simulation technologies enables the replication of complex clinical scenarios, the refinement of critical skills, and the reduction of errors in emergency care delivery. The integration of such methodologies into professional training systems contributes to the enhancement of personnel preparedness and the improvement of medical care quality in crisis situations.

The adoption of advanced simulation methods has become a key direction in the development of emergency medicine. Global challenges arising from pandemics, armed conflicts, and industrial accidents have necessitated the application of high-fidelity manipulators, virtual reality (VR), and mixed reality (MR) to practice action algorithms in critical situations without endangering patients. Leading nations actively implement this technology to standardise medical interventions and refine emergency care mechanisms.

Simulation training is improving, but its long-term impacts on physicians' professional adaptation, team collaboration, and decision-making in non-standard settings are unknown. The impact of modern simulation modelling in anaesthesiology and resuscitation on medical staff preparedness can be assessed, and innovative methods should be integrated into educational systems to improve emergency response effectiveness. Several major studies have examined the use of simulation technology to train medical professionals in extreme anaesthesiology and resuscitation.

I.T. Ydyrysov et al.[1] examined tactical and technical solutions for managing critical situations during surgical procedures using Industry 4.0 technologies,[2] with an emphasis on digital simulation systems for optimising clinical decisions and improving patient safety. However, this study lacks an analysis of the long-term impact of these technologies on medical

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professionals' adaptation, warranting further investigation. A similar outcome was observed in the work of G.K. Omukeeva et al.,[3] which evaluated the efficacy of simulation training for emergency medical personnel, demonstrating significant improvement in knowledge and skills ($p < 0.001$). Nevertheless, the study did not explore the long-term effects of these methods on professionals' readiness for crisis situations or their ability to make clinical decisions in resuscitation practice, necessitating additional research.

One of the primary challenges in delivering anaesthesiology and resuscitation care in military conflict settings is limited access to high-tech training, particularly simulation technologies, due to resource shortages, unstable infrastructure, and critical time constraints. W.A. Awuah et al.[4] analysed the challenges of providing medical care to patients with abdominal trauma in combat zones, focusing on low- and middle-income countries (LMICs). F. Ismailova et al.[5] examined the challenges and prospects of improving emergency medical care (EMC) systems in resource-limited settings. The authors identified insufficient personnel training, inadequate technical equipment, and the absence of effective operational response mechanisms as key factors complicating the delivery of anaesthesiology and resuscitation care in critical situations.

J.H. Pek et al.[6] assessed the efficacy of simulation training in disaster and mass-casualty incident response. It was found that such training improves coordination and personnel preparedness, yet its real-world effectiveness remains understudied due to methodological variability and the rarity of such events. A.S. Baetzner et al.[7] analysed traditional and technological training methods for first responders in disaster scenarios, concluding that VR and MR technologies demonstrate comparable or superior efficacy. However, the study did not evaluate their role in training anaesthetists and intensivists or in modelling critical conditions in emergency medicine.

J. Abualenain et al.[8] analysed the efficacy of full-scale simulation exercises in enhancing hospital disaster preparedness. The authors assessed the impact of such training on medical facility personnel, identifying strengths and weaknesses in current response protocols. It was established that full-scale simulation improves hospital emergency plans and enhances coordination in crisis conditions. A. Monesi et al.[9] investigated the efficacy of in-situ simulation training for intensive care unit (ICU) nurses during the COVID-19 pandemic. The authors described the implementation of a cost-effective training approach combining brief lectures and hands-on simulation sessions directly in hospital settings. This method improved staff adaptation to equipment use, enhanced teamwork, and refined technical and non-technical skills, though it did not assess their efficacy in practising resuscitation algorithms or clinical decision-making in emergencies.

S. Damiani et al.[10] analysed patient safety and clinical risk management in anaesthesiology and intensive care, emphasising the need for improved medical education and leadership to reduce preventable harm. However, the research did not address the role of simulation technologies in training anaesthesiologists and intensivists or their efficacy in modelling crisis scenarios to enhance patient safety.

The analysis of scientific literature confirmed the significance of simulation technologies in preparing anaesthesiologists and intensivists for crisis situations. Gaps were identified in studies of their long-term impact on professional adaptation, the efficacy of VR and MR modelling in critical conditions, and their integration into emergency medicine curricula. The role of simulations in decision-making during mass emergencies remains unresearched, necessitating standardised training approaches and optimised resuscitation care protocols.

To evaluate the efficacy of simulation technologies in preparing anaesthesiologists and intensivists for work in crisis situations, the following research tasks were formulated:

1. Assess the impact of VR and MR trainers on mastering resuscitation care algorithms.
2. Evaluate the role of simulation methods in developing clinical reasoning and professional adaptation to extreme conditions.
3. Analyse the potential for integrating simulation technologies into emergency medicine training programmes.

Materials and Methods

The study was empirical in nature and aimed to assess the efficacy of simulation trainers and models in preparing anaesthesiologists and intensivists for work in crisis situations. The research analysed contemporary methods for modelling critical conditions, the role of VR and MR technologies in shaping professional adaptations, and the potential for integrating simulation training into emergency medicine curricula. Particular attention was given to evaluating the impact of simulation technologies on clinical decision-making quality, physicians' situational awareness, and their readiness to perform under high-stress conditions.

The study was conducted from January to December 2024 at the National Hospital of the Ministry of Health of the Kyrgyz Republic in Bishkek. Inclusion criteria for participants comprised a medical degree in "Anaesthesiology and Intensive Care", at least one year of practical experience, and voluntary consent to participate in training activities. A total of 72 participants were enrolled in the study. All participants initially underwent training using traditional methods; however, during the experiment, they incorporated VR and MR technologies into their training regimen. Exclusion criteria included the presence of neuropsychiatric disorders and participation in similar studies within the preceding 12 months.

The collection of empirical data was based on a multicomponent analysis of outcomes from simulation training sessions involving anaesthesiologists and intensivists of varying expertise levels – from junior specialists to physicians with extensive experience in critical care. The evaluation methodology employed the Objective Structured Clinical Examination (OSCE),[11] ensuring an objective dynamic assessment of resuscitation algorithm proficiency, technical mastery, and clinical decision-making speed. Evaluations were conducted using digital simulators, interactive VR and MR trainers, as well as high-fidelity manikins capable of replicating emergency conditions while accounting for individual patient pathophysiological parameters. The study utilised VR trainers from the "Oxford Medical Simulation" model, along with MR platforms based on Microsoft HoloLens 2 with dedicated training software for real-time clinical scenario modelling.

The studied parameters encompassed cognitive processes under stress, motor-sensory integration, and the efficacy of interdisciplinary team collaboration. The level of situational awareness among physicians during critical condition simulations – including multiorgan failure, acute respiratory distress, anaphylactic shock, and cardiac arrest – was examined. The Crisis Resource Management (CRM)[12] methodology assessed teams' adaptability under time and resource constraints. Psychophysiological testing included cortisol level measurements, heart rate, and heart rate variability to evaluate stress resilience. The assessment focused not only on procedural quality but also on the ability to anticipate complications and adjust treatment strategies promptly.

A comprehensive approach employing multiple complementary methods was applied to assess the efficacy of simulation training. The primary method was an experimental design implemented via OSCE, enabling the evaluation of physicians' professional competence before and after training. Standard clinical scenarios – such as cardiac arrest, anaphylactic shock, and multiorgan failure – were simulated. Changes in decision-making speed, the accuracy of resuscitation measures, and team coordination were analysed. Additional cognitive testing methods evaluated theoretical knowledge retention and critical decision-making algorithms.

Subjective training efficacy assessments were conducted using standardised questionnaires and expert evaluations. Analysed metrics included physicians' confidence in their skills, readiness to apply knowledge in clinical practice, and psychological resilience under stress. A comparative analysis method discerned performance variations before and after the experiment, assessing their influence on professional adaptability.

A multicomponent analytical approach incorporating quantitative and qualitative analyses was applied for data interpretation. Quantitative analysis relied on statistical processing of OSCE data to determine changes in procedural accuracy and speed pre- and post-training. Significance was assessed using variance analysis, including mean values, standard deviations, confidence intervals, and Student's t-test ($p < 0.05$).

The primary endpoint of this study is the improvement in OSCE scores, reflecting clinical competence in resuscitation and decision-making. Secondary and exploratory endpoints include cortisol levels, assessed as a biomarker of stress response, and questionnaire scores, which offer information about participant perceptions of training effectiveness and psychological resilience. The primary endpoint will be analysed separately from these secondary measures to avoid statistical issues related to multiplicity.

Qualitative analysis involved expert assessments of simulation recordings to evaluate situational awareness, stress resilience, and team interaction efficacy. Thematic analysis structured questionnaire responses, identifying key trends in physicians' perceptions of simulation training efficacy and its impact on professional development. Training efficacy was assessed using Kirkpatrick's four-level model, encompassing reaction (participant satisfaction), learning (knowledge and skill acquisition), behaviour (post-training clinical practice changes), and results (impact on care quality and error reduction).

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration, its later amendments or comparable ethical standards. A study was approved by the National Ethics Commission of the I.K. Akhunbaev Kyrgyz State Medical Academy on December 21, 2023, No. 1106-A.

Results

Training in Anaesthesiology and Intensive Care

Simulation training is a cornerstone of critical care education, particularly for anaesthesiologists and intensivists. Its integration into curricula aims to enhance service safety, optimise clinical decision-making algorithms, and improve interdisciplinary communication under stressful conditions. Innovative simulation technologies create very realistic training settings that mimic complicated medical conditions and emergency situations, which helps professionals be better prepared.

Table 1 presents a systematic analysis of simulation training objectives in anaesthesiology and intensive care, integrating methodological concepts, technological innovations, and clinical validation. The outlined data reflect a multifactorial approach to critical condition modelling, including cognitive behavioural adaptation mechanisms, precision motor skill development, and team coordination optimisation. This structural analysis enables the calibration of VR and MR simulator efficacy in critical care training, standardised educational algorithms, and integration potential assessments.

Anaesthesiology and intensive care are high-risk medical fields requiring decision-making under critical uncertainty.[14,15] Traditional training methods – lectures and clinical placements – often fail to adequately prepare specialists for dynamic patient deterioration or extreme scenarios. Simulation training provides a standardised, controlled environment for practising intensive care and resuscitation protocols without compromising patient safety.[16,17] This method fosters integrated cognitive-behavioural skill acquisition and

Table 1 | Theoretical foundations of simulation training in anaesthesiology and intensive care

Aspect	Description	Clinical Cases
Methodological principles	Simulation training is grounded in adaptive learning, Team-Based Learning, and Crisis Resource Management, enhancing individual and team performance in critical scenarios	Cardiopulmonary resuscitation under time and resource constraints
Technological approaches	Utilisation of low- and high-tech simulation platforms, including VR, MR, interactive manikins, and computerised programs simulating patient physiological responses	Tracheal intubation in patients with complex anatomical variations
Clinical scenarios	Modelling complex conditions such as massive haemorrhage, anaphylactic shock, multiorgan failure, cardiac arrest, and acute respiratory distress	Septic shock and multiorgan failure management in critical patients
Psychophysiological training	Enhancing decision-making under stress, resilience development, and reaction speed. Analysis of cognitive strategies in crisis scenarios	Team response to intraoperative cardiac arrest
Standardisation and efficacy metrics	Defining key performance indicators (decision time, procedural accuracy, team coordination). Developing standardised training programs and action protocols	Comparative analysis of physician preparedness post-simulation vs. traditional training
Curriculum integration	Developing unified postgraduate programs for anaesthesiologists-intensivists. Incorporating simulation technologies into continuous professional development	Staff adaptation to new emergency protocols following simulation training
Challenges and limitations	High equipment costs, instructor training requirements, and insufficient long-term data on VR/MR impact on professional adaptation	Efficacy analysis of simulation programs in regions with varying resource availability

Source: Compiled by the authors based on J. Abualenain et al.,[8] A.I. Mossenson.[13]

improves real-world clinical decision-making. Adaptive training enables physicians to develop robust action algorithms, minimise errors in high-stress environments, and enhance interdisciplinary teamwork.

Simulation training develops critical thinking, interdisciplinary coordination, and rapid strategic decision-making under stress by adapting genuine clinical circumstances. Experiential Learning Theory[18] states that anaesthesiologist-intensivists retain professional knowledge best through active practical application. Specialists must make reliable decisions in high-intensity conditions to respond to unexpected cardiac malfunction, acute respiratory failure, or multiorgan failure.[19,20] Simulation training replicates unusual clinical cases to develop competency without compromising patient care.

Modern simulation technologies include low-tech (anatomical manikins, intubation trainers, vascular access modules) and high-tech (computer models, VR, MR). Virtual reality lets clinicians rehearse resuscitation techniques in a safe and adaptive environment.[21,22] MR technologies connect virtual models with tangible items, making training more realistic and developing motor and cognitive skills needed to handle extreme clinical problems. Innovative simulation systems may create complicated scenarios with physiological characteristics, medical equipment details, and external stressors to prepare for unanticipated events.

VR and MR simulators are innovative technologies that enable the modelling of complex clinical scenarios with high realism, including massive haemorrhage, anaphylactic reactions, and multi-organ failure.[23,24] By integrating physiological parameters into virtual models, these simulation platforms replicate dynamic patient-state changes in response to medical interventions. This practice facilitates not only the rehearsal of emergency care protocols but also the development of algorithmic approaches to managing critical cases. Furthermore, interactive simulations provide immediate feedback on the clinician's actions, fostering reflective thinking and real-time error self-correction.

The application of VR technology in simulation training allows the practice of highly specialised procedures, such as videolaryngoscopy, cricothyroidotomy, tracheotomy, extracorporeal membrane oxygenation (ECMO), and complex airway management in critical conditions.[25,26] MR simulations, which combine physical objects with digital components, facilitate the rehearsal of procedures requiring high motor-skill precision and rapid adaptation to variable conditions. The use of these technologies optimises the learning process, reducing the required duration of clinical practice while enhancing professionals' readiness to work in high-stress environments.

The integration of VR and MR technologies into the training of anaesthesiologist-intensivists enhances cognitive skills and improves decision-making efficacy under uncertainty.[27,28] Empirical studies indicate that specialists who undergo regular simulation-based training (SBT) demonstrate superior resuscitation outcomes compared to those trained via traditional methods. Simulation environments provide a safe setting for evaluating errors, thereby reducing the risk of their recurrence in real clinical practice.

Such training in anaesthesiology and critical care courses standardises medical education and ensures professional competency independent of training site. This is especially important for clinicians in resource-limited environments like conflict zones or pandemics. VR and MR simulators help doctors develop emergency response abilities, reducing medical errors in crucial situations.[29,30] Thus, the adoption of simulation technologies not only elevates professional competence but also improves the overall quality of anaesthesiology and resuscitation care.

Despite significant advantages, the implementation of simulation technologies faces several limitations. The high cost of VR and MR simulators, the need for regular software updates, and instructor training restrict their widespread adoption. Additionally, the long-term impact of these methods on the professional adaptation of anaesthesiologist-intensivists and their efficacy in real clinical settings remains insufficiently studied.

Simulation training is a promising direction in critical care education, enabling realistic replication of clinical scenarios, fostering decision-making skills, and improving team dynamics.[31,32] VR and MR technologies allow the adaptation of training programmes to variable clinical situations, enhancing professional competence. Their use also aims to minimise clinical risks and improve the standardisation of anaesthesiological care.

Empirical Evaluation of the Effectiveness of Simulation Training Systems for Anaesthesiologists and Intensive Care Specialists

Simulation technologies are a key tool in the training of anaesthesiologists and intensive care specialists, aimed at refining professional skills without risk to patients. Empirical studies confirm that the integration of training systems enhances the mastery of emergency care algorithms and improves decision-making in critical situations. Among modern training methods, the most promising are high-fidelity manikins, digital simulators based on machine learning, and VR and MR platforms, which provide a realistic environment for practicing clinical scenarios.

Physicians' cognitive, motor, and communication abilities are used to evaluate simulation training systems. According to research, VR and MR systems cannot properly duplicate sophisticated anaesthesiological operations such airway management, intubation, anaesthesia administration, and haemodynamic instability patient treatment. However, adaptable algorithms in VR trainers provide individualised learning and scenario adaption to practitioners' demands. Simulation technologies are useful for measuring healthcare workers' skills in real-world settings. Studies show that anaesthesiologists and critical care specialists who receive regular simulation training make diagnostic and treatment decisions faster and more accurately than their colleagues. Real-time feedback improves self-analysis and clinical competency in simulation training.

The adaptation of anaesthesiologists and intensive care specialists to extreme conditions is another critical aspect of evaluating simulation training systems. VR and MR models allow physicians to operate in environments simulating real-life critical scenarios–from mass emergencies to crises in ICUs. This enhances resilience to high psychological stress and refines prioritisation skills for non-standard medical decision-making.

Table 2 provides the essential characteristics for assessing simulation training systems' anaesthesiologist and intensive care specialist preparation. The data show how VR and MR simulations improve professional competences like decision-making speed, technical precision, and cognitive integration in resuscitation scenarios. Improved experts' adaptive capacity in difficult settings, algorithmic clinical behaviour, and standardised action protocols reduce medical errors.

Table 2 systematises the primary limitations of simulation training implementation, including the high costs of technical infrastructure, the need for regular software updates, and instructor training. The importance of objective evaluation criteria – such as technical proficiency, psychological readiness, and cognitive load – is emphasised.

Research on simulation training effectiveness also focuses on comparing different training methods. Analysis of practical testing demonstrates that integrating VR and MR technologies into curricula improves material retention by 50–60% compared to traditional lectures or static manikins.[36] High scenario realism enables physicians to master complex procedures before first contact with real patients, minimising risks in clinical practice.

Despite substantial advantages, the integration of simulation training systems into anaesthesiology and intensive care education requires further empirical research, particularly on long-term impacts on professional adaptation. The optimal methods for evaluating VR and MR training in real clinical settings remain unresolved, necessitating standardised approaches and universally accepted assessment criteria.

Thus, empirical evaluation confirms the significant role of simulation training systems in enhancing the professional preparation of anaesthesiologists and intensive care specialists. The implementation of VR and MR technologies improves resuscitation algorithms, clinical reasoning, and adaptation to critical conditions. Future research should focus on long-term effects and optimising integration in medical education.

Table 2 | Empirical evaluation of simulation training effectiveness

Evaluation Parameter	Assessment Methodology	Expected Outcomes
Theoretical knowledge retention	Pre- and post-simulation course testing	Significant improvement post-course
Technical skill proficiency	Analysis of practical performance on manikins	Optimised motor skills and reduced error frequency
Clinical decision-making speed	Monitoring reaction time in simulated scenarios	Reduced decision-making time in critical conditions
Teamwork efficiency	Evaluation of interdisciplinary team dynamics	Improved coordination among team members
Response to critical situations	Quantitative analysis of variable patient parameters	Higher response accuracy to dynamic conditions
Stress resilience	Cortisol level measurement and psychological surveys	Increased adaptability to stressors
Skill transfer to clinical practice	Observation of correlation between simulated and real cases	Effective application of acquired skills in real clinical settings
Error reduction during training	Comparative analysis of error trends across repeated sessions	Decreased frequency of critical errors
Objective clinical indicators (virtual patients)	Assessment of simulated patient vitals	Improved adherence to treatment protocols
Subjective participant evaluation	Post-training questionnaires and interviews	High satisfaction and confidence in acquired skills

Source: Compiled by the authors based on A. Tauscher et al.,[33] Y. Jung,[34] S. Minna et al.[35]

Optimising Emergency Medicine Training Through Simulation Technologies

The incorporation of simulation training into the education of anaesthesiologists and intensive care specialists is essential for advancing the professional competence of practitioners working in critical conditions. In emergency medicine – particularly anaesthesiology and resuscitation – the use of VR and MR technologies creates a highly adaptive learning environment that mirrors real clinical scenarios. Visualising complex pathophysiological processes in VR facilitates a more profound understanding of critical states, enabling physicians to anticipate potential complications and make real-time therapeutic decisions.

Realistic training scenarios allow practitioners to refine protocols for emergencies, including cardiopulmonary resuscitation (CPR), airway management, anaphylactic shock, and critical hypotension. High-tech simulators enhance strategic clinical reasoning and rapid adaptation to dynamic conditions. Hospitals with regular VR/MR training report faster decision-making and heightened situational awareness during emergencies.

Figure 1 presents an analysis of simulation training effectiveness for anaesthetists and intensive care specialists using the Kirkpatrick model, which includes four evaluation levels: reaction, learning, behavioural changes, and results. The data demonstrate positive impacts on participant satisfaction, professional confidence, and practical skills. However, long-term behavioural changes and clinical outcome improvements remain understudied.

SBT requires large investments in high-fidelity simulators, multipurpose manikins, and complicated multimodal training environments, as shown in Figure 1. Critical educational gaps include the need to improve feedback systems, integrate evidence-based learning models, and develop clinical skill retention measures. Special attention is paid to the standardisation of methodological approaches, assuring the integration of simulation technologies into traditional curricula, and preventing skill erosion and motor degeneration once training is done. The analysis emphasises the need for empirical research in SBT to improve its long-term efficacy, reduce economic expenses, and develop creative techniques to maintain intensive care professionals' professional competence.

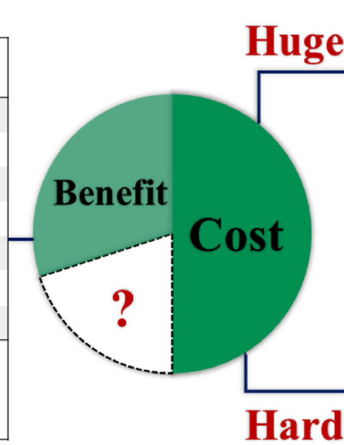
It is important to add that simulation technologies play a pivotal role in fostering cohesive teamwork in intensive care and emergency medicine. Beyond improving technical skills, simulation training facilitates team interaction in multidisciplinary groups, which is a critical factor in resuscitation departments. The application of Team-Based Learning (TBL) and CRM methodologies in simulation training enhances coordination among anaesthesiologists, surgeons, nurses, and other emergency care providers. This is particularly crucial in time-sensitive scenarios that require synchronised actions, such as emergency cardiac intubation or pulmonary resuscitation.

The integration of simulation technologies into postgraduate training for anaesthesiologists and intensivists standardises the educational process and ensures a uniform level of professional competence among graduates of specialised programmes. Furthermore, VR and MR models enable remote learning, which is particularly relevant in contexts with limited access to traditional educational platforms, such as during pandemics or armed conflicts. The use of simulation training in continuous medical education (CME) programmes ensures regular skill refinement and maintains clinicians' readiness to work under resource constraints and high clinical uncertainty.

Developing universal SBT effectiveness assessment methods is a priority. Multifactorial analysis, which includes quantitative metrics (response time, treatment

Kirkpatrick framework	Evaluation items	Meta-analysis result	GRADE quality
Reaction	Satisfaction	Favored SBT	Low
	Confidence	Favored SBT	Low
Learning	Skills	Favored SBT	Moderate
	Knowledge	Favored SBT	Moderate
Behavior	Short-term	Favored SBT	Low
	Long-term	?	-
Results	?	?	-

Reaction: how learners perceive the educational intervention
Learning: learning of skills and knowledge
Behavior: learners' behavioral changes in professional setting
Results: the effect of learners' actions



Investment	Gaps
Feedback	Evidence-based model, sound recording system
Simulation fidelity	High-fidelity and multi-model mannequins
Instructor training	Simulation teaching skills, mastery learning models, training for various devices

Implementation	Gaps
Deliberate practice	Sites, equipment, time for practice
Curriculum integration	Mix with existing learning modalities
Skill maintenance	Mechanism of skill decay and maintenance, follow-up evaluation

Fig 1 | Cost-benefit analysis of simulation-based training
Source: Compiled by the authors based on Y. Su and Y. Zeng.[37]

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strategy selection accuracy) and subjective indications (cognitive load levels, psychological adaptation), assesses doctors' critical-care readiness. Systematic VR and MR training improves clinical decision-making and implementation in real intensive care scenarios, according to studies.

Optimising the training process through simulation technologies directly reduces medical error rates and improves outcomes in critical care management. The interactive learning approach enhances clinicians' assimilation of action algorithms, particularly in high-risk scenarios such as severe polytrauma, septic shock, or acute heart failure.

The implementation of simulation methods in anaesthesiology and intensive care training requires a systemic approach, including the development of standardised curricula, the integration of digital technologies into continuous learning, and the adoption of new models for assessing training efficacy. Special attention must be given to research on the long-term impact of simulation training on clinicians' professional adaptation and their ability to perform effectively in extreme conditions.

Thus, the integration of simulation technologies into anaesthesia and intensive care training programs enhances professional competence, standardises training approaches, and improves the quality of resuscitation care. The use of VR and MR technologies enables the effective modelling of crisis scenarios, increasing patient safety and reducing medical errors. Further research should focus on refining the integration of simulation technologies into medical education, expanding methodological frameworks for efficacy assessment, and developing optimal training protocols aligned with modern emergency medicine standards.

Discussion

The obtained results confirm the significance of SBT in developing critical competencies among anaesthesiologists and intensivists. Improved clinical decision-making speed and procedural accuracy correlated with enhanced situational awareness among clinicians, reflected in fewer errors during emergency resuscitation measures. These findings align with the study by S. Barteit et al.,[38] which analysed the efficacy of MR and VR in medical education. The use of head-mounted displays (HMDs) was found to improve cognitive skills, procedural accuracy, and situational awareness, enhancing decision-making efficacy in clinical scenarios.

The implementation of telemedicine technologies in ICUs is regarded as a strategic tool for improving healthcare quality and optimising patient outcomes. C.D. Spies et al.[39] conducted a comprehensive analysis of a multicomponent telemedicine programme within a regional German ICU network, focussing on adherence to standardised quality indicators (QIs). Researchers concluded that expert-led telemedicine rounds and remote consultations standardised critical care management, improved protocol compliance, and enhanced patient stratification. Telemedicine integration improved situational awareness among medical teams, increased adherence to evidence-based practices, and reduced deviations from clinical standards.

The study by J.F. Jensen et al.[40] confirmed that CRM-based simulation training enhances non-technical skills among ICU staff. Training improved teamwork, situational awareness, and clinical decision-making efficacy in critical conditions. Semi-structured interviews with physicians and nurses revealed that CRM training optimised role distribution in multidisciplinary teams, reducing communication barriers and improving coordination during emergencies. Notably, post-training staff demonstrated better priorities in critical situations, lowering the likelihood of tactical errors.

In the study by S. Couarraze et al.,[41] the short-term impact of simulation training on stress, anxiety, and burnout levels among anaesthesiology and intensive care specialists was analysed. Authors found that post-training, perceived stress levels (PSL), state anxiety (STAI-state), and trait anxiety (STAI-trait) significantly decreased, indicating a positive psychological impact. A measurable reduction in burnout levels (assessed via the Maslach Burnout Inventory[42]) confirmed the effectiveness of simulation training in mitigating emotional exhaustion.

D.A. Meguerdichian[43] affirmed the value of manikin-based simulators in medical training, emphasising their role in skill acquisition without patient risk. Modern manikins equipped with embedded sensors, realistic physiological functions, and automated platforms significantly enhance clinical scenario simulation. Prior studies have drawn similar conclusions, demonstrating that simulator realism directly influences knowledge retention and training efficacy.

The work of anaesthetist-intensivists in high-stress environments, under intense workload and limited resources, necessitates effective crisis management and cohesive team collaboration. The study by D. Irving et al.[44] analysed adaptive strategies employed by surgical teams in response to staff shortages, operating room deficits, and patient complexity. The primary adaptation mechanisms included resource optimisation, patient flow management, and enhanced interdisciplinary coordination. The findings are crucial for modelling anaesthetic and intensive care, as they underscore the significance of a multidisciplinary approach and efficient resource allocation in crisis situations. The use of simulation trainers and models enables the refinement of response algorithms, improves situational awareness among staff, and minimises clinical errors.

An analysis of the mechanisms for effective Transfer of Learning (ToL) from SBT to clinical practice confirmed the importance of instructional design (ID) as a key factor. The study by R. Masoomi et al.[45] demonstrated that the characteristics of training design play a decisive role in enhancing the effectiveness of ToL within SBT. It was established that scenario structure, simulation realism, interactivity, and feedback availability significantly improve skill acquisition and subsequent clinical application. A literature review and semi-structured interviews with instructors and learners allowed for the identification of key SBT features that facilitate effective ToL. Specifically, it was confirmed that simulating real clinical scenarios with progressively increasing task complexity enhances cognitive adaptation, while feedback supports error correction and confidence-building. These findings align with the concept that adaptive curriculum design increases the relevance of simulation-based experience and improves the integration of acquired skills in real clinical settings.

An analysis of adaptive strategies in SBT during the COVID-19 pandemic, conducted by N.A. Nadir et al.,[46] demonstrated that physical distancing restrictions led to the adoption of alternative simulation formats, including virtual platforms, remote scenarios, and hybrid sessions. These innovations ensured the continuity of emergency medicine training, though they simultaneously complicated the realism of clinical scenario replication and team interaction. The results closely correlate with the conclusions of R. Masoomi et al.[45] regarding the importance of ID in SBT. The success of transferring simulation-acquired skills to clinical practice largely depends on scenario structuring, interactivity, and high-quality feedback. Both studies highlight the necessity of adapting educational methods to crisis conditions, reinforcing the critical role of simulation technologies in ensuring medical professionals' competency.

This study has several limitations. Firstly, the single-centre design limits the generalisability of the findings, necessitating multi-centre studies for broader applicability. The short follow-up period also limits the ability to assess the long-term impact of VR/MR training on performance and patient outcomes. Additionally, the potential for the Hawthorne effect, where participants alter their behaviour due to awareness of being observed, may lead to an overestimation of the training benefits. Furthermore, the study did not include patient outcome data, such as morbidity or mortality, which are essential for understanding the real-world impact of the intervention. Finally, the high cost of VR/MR hardware presents significant financial barriers for many healthcare institutions, particularly in low-resource settings, which may limit the widespread adoption of these technologies.

Conclusions

The results showed that SBT is effective in developing crisis-management skills among anaesthesiologists and critical care professionals. We found that VR and MR technologies improve algorithmic diagnostic and treatment procedures, situational awareness, and post-clinical decision-making in high-dynamic critical care conditions. Cognitive assessment of simulation training efficacy showed considerable gains in physicians' strategic planning and tactical adaptability amid crucial uncertainty. Interactive modelling improves psychomotor skills, reduces latency in responding to clinically relevant patient status changes, and eliminates tactical errors in emergency care procedures.

Simulation training positively impacts cognitive-motor integration, leading to improved decision-making speed and procedural accuracy in critical conditions ($p < 0.05$). VR simulation with integrated biophysiological monitoring improves physicians' adaptive mechanisms to extreme conditions, while MR technologies improve spatiotemporal coordination and kinetic reflexivity during resuscitation. A comparative analysis of traditional and SBT methods showed that VR and MR models in postgraduate anaesthesiology and intensive care specialist education reduce error rates and standardise critical medical intervention algorithms, which improves ICU patient safety.

The validated results support the widespread use of simulation technology in anaesthesiologist and acute care specialist training to improve important clinical decision-making. VR and MR modelling should be standardised in postgraduate education, with an emphasis on adaptive scenarios imitating changeable pathophysiological states and multi-agent simulations to increase team cooperation in high-stress settings. Cognitive monitoring and psychophysiological analysis of physicians will personalise simulated training.

Promising directions for future research include the development of AI-driven simulation platforms that enable automated training efficacy analysis and real-time modelling of non-standard clinical scenarios. Another critical aspect is the implementation of neurophysiological monitoring to assess cognitive load in physicians during critical conditions, enhancing adaptive mechanisms and stress resilience. The use of biometric indicators of psychoemotional state in simulation training opens new possibilities for developing advanced methods of assessing professional readiness and long-term retention of acquired skills in high-stress environments.

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