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VIRTUAL REALITY SIMULATION IN PREHOSPITAL CRISIS RESOURCE MANAGEMENT TRAINING A SYSTEMATIC REVIEW OF EDUCATIONAL EFFECTIVENESS AND LEARNING OUTCOMES

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Abstract:

Background: *Prehospital emergency care requires effective crisis resource management (CRM), including leadership, communication, situational awareness, decision-making, and teamwork. Virtual reality (VR) simulation may address accessibility and reproducibility limitations of conventional simulation, yet evidence for prehospital CRM training remains fragmented.*

Objective: *This systematic review evaluated the educational effectiveness of VR simulation for CRM training among prehospital professionals, identified assessed learning outcomes, examined influential instructional design features, and identified evidence gaps.*

Methods: *Following PRISMA 2020 guidelines, a systematic search of PubMed/MEDLINE, Scopus, Embase, CINAHL, and Web of Science was conducted for studies published between 2015 and 2026. Two reviewers independently screened records, extracted data, and assessed quality using RoB 2, JBI tools, and the Newcastle–Ottawa Scale. Narrative synthesis was performed.*

Results: *Of 1,770 records, six comparative studies met inclusion criteria. VR improved CRM-related knowledge ($p < 0.001$) and performance in teamwork, communication, and situational awareness (Ottawa GRS mean 6.2/7). One randomized noninferiority trial found VR noninferior to high-fidelity simulation. Technical skill results were equivocal. Repeated, distributed exposure outperformed single sessions, whereas technological complexity showed inconsistent benefit. Satisfaction was high (95% recommended VR), though cybersickness and cognitive workload were barriers. Certainty of evidence was low to very low, with no studies assessing clinical transfer or patient outcomes.*

Conclusions: *VR is a promising complementary modality for prehospital CRM training, with effectiveness dependent more on instructional design than technological sophistication. Rigorous research with standardized outcomes and clinical transfer assessment is needed.*

Keywords: *virtual reality; crisis resource management; prehospital emergency care; simulation-based education; non-technical skills*

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1. INTRODUCTION:

Prehospital emergency care constitutes the first phase of the emergency care continuum and plays a decisive role in determining whether critically ill or injured patients receive timely, coordinated intervention. Unlike hospital-based care, it is delivered in unpredictable environments with incomplete information, limited resources, time pressure, environmental hazards, and variable team composition (Carne et al., 2012). EMS personnel must assess patients, initiate life-saving interventions, communicate with dispatchers and receiving hospitals, coordinate with other responders, prioritize multiple casualties, and make rapid decisions under changing conditions (Ripoll-Gallardo et al., 2026). Effective prehospital practice therefore requires not only technical and clinical competence but also a range of non-technical skills supporting safe team performance under pressure.

The global burden of emergency conditions underscores the importance of effective prehospital systems. In 2019, emergency conditions accounted for more than 27 million deaths and approximately 1.015 billion disability-adjusted life years (DALYs) worldwide, with the greatest per-capita burden in low-income countries (Sachs et al., 2025). The WHO has emphasized that timely emergency and prehospital care is fundamental to reducing preventable death and disability, particularly in low- and middle-income countries (LMICs), where emergency care systems remain unevenly developed (World Health Organization, 2023). A systematic review found that underdeveloped and fragmented EMS constitute an important barrier to timely treatment and are associated with avoidable mortality from time-sensitive conditions (Bhattarai et al., 2023).

Within this environment, Crisis Resource Management (CRM) provides a framework for developing the behavioral and cognitive competencies needed to manage emergencies safely. Originating in aviation and adapted to healthcare, CRM emphasizes how individuals and teams use available human, informational, technological, and organizational resources during crises (Sadowski & Phrampus, 2023). It is closely associated with non-technical skills such as leadership, communication, situational awareness, decision-making, teamwork, resource utilization, workload management, and anticipation and planning (Carne et al., 2012).

Because prehospital emergencies involve uncertainty, time-critical decision-making, and interprofessional collaboration, CRM principles are particularly relevant to paramedic and EMS education. However, opportunities to practice complex crisis-management behaviors in authentic emergencies are inherently limited. Simulation therefore provides an important mechanism for exposing learners to high-acuity, low-frequency events without patient risk. Virtual reality (VR) has subsequently created the possibility of extending simulation-based CRM training beyond conventional simulation centers toward more accessible, repeatable, standardized, and scalable learning environments (Lochmannová, 2025).

1.1. The Burden of Prehospital Emergencies and the Critical Role of Crisis Resource Management

Prehospital emergency care encompasses assessment, stabilization, treatment, triage, and transportation before arrival at a definitive healthcare facility. It occurs in ambulances, private residences, roads, workplaces, public spaces, disaster sites, and other uncontrolled environments. Providers often have limited diagnostic information, restricted equipment, variable lighting and space, unpredictable patient and bystander behavior, and significant time constraints (Carne et al., 2012). These conditions require clinicians to integrate clinical reasoning with rapid environmental assessment, prioritization, communication, coordination, and resource management.

The importance of the prehospital phase is increasingly recognized in international policy. The WHO Emergency Care System Framework considers emergency care as a continuum extending from the scene of injury or illness through transportation to an emergency unit (World Health Organization, 2023). In 2023, the World Health Assembly adopted Resolution WHA76.2, calling for improved access to timely prehospital care and emphasizing skill-based training for health workers and interprofessional teams (World Health Organization, 2023). These developments reflect recognition that emergency care effectiveness depends not only on hospital resources but also on the quality and coordination of prehospital care.

Challenges are particularly pronounced in LMICs. Bhattarai et al. (2023) identified substantial variability and fragmentation in prehospital systems in LMICs, with deficiencies in infrastructure, training, communication, transportation, and organization limiting timely emergency care. Earlier cross-national research similarly found that formal prehospital capabilities were inadequately developed in many LMICs, particularly in low-income and rural settings (Razzak et al., 2012). These circumstances make efficient teamwork and effective resource use particularly important.

Crisis Resource Management

CRM is a structured approach to managing the cognitive, interpersonal, and organizational demands of high-risk situations. It focuses on behaviors that enable individuals and teams to maintain effective performance under rapidly changing circumstances. The framework emerged from recognition that adverse events cannot be attributed exclusively to deficits in medical knowledge or technical skill; failures in communication, coordination, leadership, situational awareness, decision-making, and resource utilization can also contribute substantially to poor team performance (Carne et al., 2012).

CRM is particularly relevant to prehospital care because emergency teams must perform several interdependent tasks simultaneously. A paramedic may assess the patient while another team member establishes vascular access, administers medication, prepares equipment, communicates with a receiving facility, and monitors the environment. In mass-casualty events, these demands intensify because patient numbers may exceed available resources (Ripoll-Gallardo et al., 2026). CRM provides a framework for distributing workload, maintaining shared situational awareness, prioritizing interventions, coordinating team members, and adapting decisions as new information emerges.

Evidence supports the educational value of CRM-based training. Fung et al. (2015) found that CRM simulation can improve teamwork behaviors, though stronger evidence concerning transfer to clinical practice and patient outcomes is needed. Boet et al. (2014) similarly reported evidence of transfer to clinical practice, though evidence for effects on patient outcomes remained limited.

Core CRM Competencies

Although terminology varies, several competencies consistently appear:

Leadership and followership. Leadership involves establishing priorities, assigning responsibilities, coordinating activities, maintaining situational overview, and adapting team responses. Followership involves recognizing leadership decisions, communicating concerns, assuming responsibility, and supporting coordinated performance (Cheng et al., 2012).

Communication. Communication includes information exchange, closed-loop communication, clear instructions, confirmation of critical information, escalation, and communication with other professionals and receiving facilities. Communication failures may cause misunderstandings, duplication or omission of tasks, and treatment delays (Carne et al., 2012).

Situational awareness. This refers to perceiving relevant information, understanding its significance, and anticipating how situations may evolve. In prehospital emergencies, it includes awareness of patient status, environmental hazards, available resources, team workload, and consequences of decisions (Carne et al., 2012).

Decision-making. Emergency decisions are frequently made with incomplete information under severe time pressure. CRM emphasizes structured, dynamic decision-making including problem identification, prioritization, consideration of alternatives, and reassessment as new information becomes available (Sadowski & Phrampus, 2023).

Teamwork and coordination. Teamwork involves role clarity, workload distribution, mutual support, coordination, and shared mental models. In prehospital care, teamwork is critical because care is usually delivered by small teams where assistance may not be immediately available. A systematic review of paramedic patient safety highlighted effective communication and decision-making, alongside technical and non-technical competencies, as important components of safe practice (Alharbi et al., 2024).

These competencies form an integrated system rather than independent skills: leadership depends on communication; communication supports situational awareness; situational awareness influences decision-making; and decision-making must be coordinated through teamwork. This interdependence makes CRM difficult to teach effectively through conventional lecture-based instruction alone (Cheng et al., 2012).

1.2. Traditional Simulation-Based Training in Prehospital Education

Simulation-based education enables learners to practice clinical procedures, reasoning, communication, teamwork, and crisis management in controlled environments. Medical simulation evolved from simple task trainers and anatomical models toward sophisticated computer-controlled manikins, standardized patients, immersive environments, and scenario-based team training (Phrampus, n.d.). In emergency medicine, simulation is particularly valuable because it reproduces high-acuity events that are uncommon or inappropriate to use as learning opportunities with real patients (Smith & Brown, 2023).

In prehospital education, simulation includes manikins, standardized patients, live actors, task trainers, films, computer-based scenarios, virtual environments, and full-scale ambulance or disaster simulations. Nordén et al. (2014) demonstrated the breadth of these approaches, identifying applications in trauma, airway management, cardiopulmonary resuscitation, ventilation, and triage. Wheeler and Dippenaar (2020) concluded that simulation had become a primary educational modality in paramedic education, extending beyond psychomotor skills to scenario-based learning, interprofessional education, patient safety, competency development, and assessment.

High-fidelity simulation can create relatively realistic clinical environments. Learners interact with manikins, equipment, standardized patients, instructors, and team members while responding to dynamic scenarios. Instructors can introduce changes in patient condition, provide new information, and observe learner behavior. Structured debriefing then enables learners to examine decisions and behaviors, identify performance gaps, and formulate improvement strategies (Youngblood & McGrath, 2026).

However, conventional simulation has practical limitations. High-fidelity simulation generally requires specialized facilities, sophisticated equipment, trained instructors, technical personnel, standardized scenarios, and adequate space. Financial burdens include simulator acquisition, maintenance, consumables, staff time, faculty development, facility costs, and scenario preparation. Zendejas et al. (2013) demonstrated that cost reporting in simulation-based medical education was infrequent and incomplete, though simulator and training-material costs were commonly reported.

Scheduling is another limitation. Traditional sessions require simultaneous availability of learners, faculty, technicians, equipment, and facilities, making repeated practice difficult for large cohorts or limited simulation-center capacity (Youngblood & McGrath, 2026). Live simulations are also difficult to reproduce precisely; even with standardized scripts, differences in instructors, standardized patients, equipment, learner interactions, timing, and environmental conditions affect the learning experience (Youngblood & McGrath, 2026).

These constraints are especially relevant to prehospital education because realistic emergency scenarios require substantial space and equipment. A mass-casualty simulation may require multiple actors, simulated casualties, ambulance equipment, moulage, multiple instructors, communication systems, and an appropriate environment (Heldring et al., 2024). Although valuable, such resource intensity restricts participation frequency.

Simulation should not be viewed simply as a replacement for clinical experience. It complements clinical training by exposing learners to high-acuity, low-frequency situations rarely encountered during routine placements. Bell (2025) identified this exposure as a major educational advantage, while noting the need for stronger evidence regarding the validity and reliability of simulation-based assessment.

Consequently, there is a need for educational approaches that retain simulation's experiential advantages while reducing dependence on physical infrastructure and increasing opportunities for repeated practice. Digital simulation and VR have emerged as potential solutions (Lochmannová, 2025).

1.3. Virtual Reality Simulation as an Emerging Educational Technology

VR is a computer-mediated technology that creates an interactive digital environment in which users perceive and manipulate simulated objects, people, and situations. In healthcare education, VR provides simulated clinical experiences without patient risk. Learners may interact through head-mounted displays (HMDs), controllers, motion tracking, voice interaction, or other interfaces (Lochmannová, 2025).

VR encompasses a spectrum of immersion. Non-immersive or desktop VR presents simulated environments through conventional screens with keyboard, mouse, touchscreen, or controller interaction. Semi-immersive VR provides greater spatial involvement through large displays or projection systems while retaining awareness of the physical environment. Immersive VR, usually delivered through an HMD, surrounds the user's visual field and may incorporate spatial audio, motion tracking, hand controllers, and haptics (Lochmannová, 2025).

The distinction matters because educational mechanisms and learner experiences may differ by immersion level. Fully immersive VR provides greater presence and situational involvement than screen-based simulation, placing learners inside virtual ambulances, accident scenes, emergency departments, disaster environments, or other high-risk settings with virtual patients and team members (Baetzner et al., 2025).

Mixed reality (MR) combines physical and digital elements, allowing simultaneous interaction with real and virtual objects. VR, augmented reality (AR), and MR are often discussed collectively as extended reality (XR) (Asoodar et al., 2024).

Advantages of VR for Prehospital Training

Repeatability. Virtual emergency scenarios can be reproduced numerous times with greater standardization than live simulations. The same patient presentation, environmental conditions, communication events, and clinical deterioration can be delivered to multiple learners (Baetzner et al., 2025). Repetition is valuable for CRM because mastering non-technical skills requires repeated opportunities to recognize problems, communicate, decide, and reflect.

Safe exposure to high-risk scenarios. Learners can practice managing cardiac arrest, major trauma, mass-casualty incidents, hazardous environments, or deteriorating patients without clinical risk. Heldring et al. (2024) found that VR enabled repeated training and created a safe learning environment, though technical usability remained a consideration.

Scalability. Once developed, VR scenarios can be deployed to multiple learners and locations without a full simulation laboratory, benefiting institutions with limited resources or geographically distributed personnel (Lochmannová, 2025).

Standardization and reproducibility. Unlike live simulations, computer-generated scenarios deliver predefined events consistently, which is valuable for instruction and assessment (Youngblood & McGrath, 2026).

Immersion and experiential learning. Immersive VR allows first-person experience of emergency environments, facilitating attention, engagement, and contextualized learning. Kyaw et al. (2023) found that immersive VR can provide accessible, repeatable, fail-safe learning experiences, though effects varied across outcomes.

Evidence across health professions education is supportive but heterogeneous. Foronda et al. (2024) identified studies where traditional simulation performed better, studies favoring VR, and studies showing comparable outcomes. VR should therefore not be assumed superior; effectiveness may depend on educational objective, implementation, immersion level, instructional design, and outcome measured.

Abbas et al. (2023) concluded that VR is promising for emergency skills training while emphasizing heterogeneity in interventions and outcomes. A systematic review of XR in EMS training found VR was the predominant technology, reflecting growing interest in immersive technologies for emergency medical education (Asoodar et al., 2024).

Importantly, VR's educational value does not derive from technology alone. Instructional design remains fundamental. Scenario realism, learning objectives, feedback, deliberate practice, debriefing, learner interaction, assessment methods, and alignment between virtual and real-world practice all influence outcomes (Kyaw et al., 2023). This is particularly important for CRM because communication, leadership, teamwork, and situational awareness are relational and contextual. A sophisticated virtual environment is insufficient without meaningful opportunities to communicate, coordinate, decide, and receive feedback.

1.4. Rationale and Significance of the Review

Affordable HMDs, improved graphics and motion tracking, and growing interest in digital medical education have driven rapid expansion of VR-based training. Reviews report potential benefits for knowledge, skills, confidence, engagement, and satisfaction, though magnitude and consistency vary by intervention and outcome (Kyaw et al., 2023).

Despite this expansion, questions remain regarding VR's specific educational role in prehospital CRM training. Much VR literature has focused on anatomy, surgery, procedural skills, or individual clinical competencies. A systematic review of immersive technologies found surgery and anatomy were predominant application areas, with medical and nursing students as common participants (Asoodar et al., 2024).

The evidence base for EMS and first-responder education is smaller. Wheeler and Dippenaar (2020) identified limited published research on simulation in paramedic education. More recent reviews show growing interest in VR for EMS and mass-casualty training but highlight methodological heterogeneity, technical barriers, variation in immersion, and limited evidence for longer-term transfer (Heldring et al., 2024).

The distinction between clinical/technical skills and CRM competencies is critical. A learner may demonstrate appropriate airway management without demonstrating effective leadership, communication, prioritization, situational awareness, or teamwork. Conversely, CRM performance may influence whether technical skills are successfully applied under pressure. Evidence that VR improves procedural performance cannot automatically be interpreted as evidence that VR improves CRM (Fung et al., 2015).

Previous CRM reviews established the importance of simulation for non-technical skills, but much evidence concerns conventional rather than VR simulation. Boet et al. (2014) found promising evidence for transfer to clinical practice but a relatively small evidence base. Fung et al. (2015) found supporting evidence but identified the need for research on workplace transfer and patient outcomes.

VR-based emergency training has developed sufficiently to warrant focused synthesis. Abbas et al. (2023) demonstrated increasing VR application in emergency skills training, while Heldring et al. (2024) showed potential for realistic, repeatable first-responder training. However, these reviews do not specifically address the intersection of VR, prehospital education, and CRM competencies.

This review is significant for four reasons. First, it focuses specifically on the prehospital context, where personnel routinely operate under conditions requiring effective CRM (Rowland & Adeloye, 2022). Second, it distinguishes CRM-related outcomes from purely technical skills. Third, it considers not only whether VR is effective but which learning outcomes are assessed and which instructional design characteristics influence effectiveness. Fourth, it identifies methodological and evidence gaps to guide future VR-based CRM programs and research.

This focus is particularly relevant where access to sophisticated simulation centers is limited. If appropriately designed and validated, VR could deliver standardized, repeatable CRM training to geographically dispersed learners (Lochmannová, 2025). Nevertheless, VR should complement rather than automatically replace live simulation. Current evidence indicates that live simulation remains important for physical skills, equipment handling, interpersonal interaction, and authentic team dynamics, while VR offers advantages in repeatability, standardization, scalability, and exposure to rare or hazardous scenarios (Foronda et al., 2024).

A systematic examination is therefore necessary to determine whether VR's theoretical advantages translate into measurable improvements in CRM knowledge and performance among prehospital personnel.

1.5. Objectives of the Study

The present study aims to:

1. Evaluate the effectiveness of VR simulation in improving CRM-related knowledge and skills among prehospital healthcare professionals and learners.
2. Identify and categorize learning outcomes assessed in VR-based prehospital CRM training, including knowledge acquisition, decision-making, situational awareness, communication, leadership, teamwork, confidence, self-efficacy, performance, retention, and transfer of learning.
3. Examine instructional design characteristics associated with VR-based CRM training, including immersion level, scenario realism, interactivity, individual versus multiplayer delivery, feedback and debriefing, repetition, duration, assessment methods, and integration with conventional simulation.
4. Identify methodological limitations and evidence gaps, including sample size, study design, outcome measurement, validity and reliability of assessment instruments, follow-up duration, transfer to clinical practice, technical barriers, and cost-effectiveness.

2. Methods

2.1. Protocol and Registration

This systematic review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement (Page et al., 2021). A review protocol was developed a priori, specifying the eligibility criteria, search strategy, study selection, data extraction, risk-of-bias assessment, and synthesis procedures. The protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO) prior to formal screening (PROSPERO, n.d.).

2.2. Eligibility Criteria

Eligibility criteria were defined according to the Population, Intervention, Comparator, Outcomes, and Study design (PICOS) framework.

2.2.1. Inclusion Criteria

Studies were included if they met the following criteria:

- **Population:** Qualified prehospital healthcare professionals, including paramedics, emergency medical technicians (EMTs), EMS clinicians, and emergency physicians.
- **Intervention:** Virtual reality (VR) simulation specifically designed to provide Crisis Resource Management (CRM) or related non-technical skills training, including leadership, communication, situational awareness, decision-making, and teamwork.
- **Comparator:** Traditional simulation, classroom/lecture-based training, usual training, no intervention, or alternative VR modalities.
- **Outcomes:** CRM knowledge and skills, teamwork, communication, leadership, situational awareness, decision-making, confidence, self-efficacy, and related learning outcomes.
- **Study design:** Randomized controlled trials (RCTs), quasi-experimental studies, and comparative observational studies.
- **Publication period:** January 2015–2026.
- **Language:** English-language full-text studies.

2.2.2. Exclusion Criteria

Studies were excluded if they: (1) involved only students, laypersons, patients, or non-prehospital healthcare personnel; (2) were conducted exclusively in hospital or other non-prehospital settings; (3) evaluated augmented reality (AR), mixed reality (MR), or web-based training without a distinct VR component; (4) focused exclusively on technical/procedural skills without a CRM or non-technical-skills component; (5) were conference abstracts without accessible full text, editorials, reviews, protocols, or commentaries; or (6) were published in languages other than English.

2.3. Search Strategy

A systematic search was conducted in PubMed/MEDLINE, Scopus, Embase, CINAHL, and Web of Science for studies published between January 2015 and 2026. The search strategy combined controlled vocabulary (MeSH terms) and free-text terms related to four concepts: (1) virtual reality ("virtual reality," "VR," "immersive virtual reality," "head-mounted display"); (2) crisis resource management ("crisis resource management," "CRM," "non-technical skills," "teamwork," "communication," "leadership," "situational awareness"); (3) prehospital emergency care ("prehospital," "emergency medical services," "paramedic," "emergency medical technician," "EMS," "ambulance"); and (4) education/simulation ("simulation," "training," "education"). Boolean operators (AND/OR) and database-specific subject headings were applied. Reference lists of included studies and relevant reviews were hand-searched to identify additional eligible studies.

2.4. Study Selection

After removal of duplicates, two reviewers independently screened titles and abstracts against the predefined eligibility criteria. Potentially relevant studies underwent full-text assessment. Disagreements were resolved through discussion and, when necessary, consultation with a third reviewer. Inter-rater agreement was calculated using Cohen's kappa. The study-selection process was documented using a PRISMA 2020 flow diagram (Page et al., 2021).

2.5. Data Extraction

Data were independently extracted by two reviewers using a standardized extraction form. Extracted information included: author and publication year; country and study design; sample size and participant characteristics; professional experience; VR modality and intervention characteristics; training duration and frequency; instructional design features, including feedback and debriefing; comparator characteristics; outcome measures and assessment instruments; follow-up period; and main findings. Outcomes were categorized as knowledge, technical/clinical performance, CRM/non-technical skills, and learner perceptions.

2.6. Quality Assessment and Risk of Bias

Two reviewers independently assessed methodological quality and risk of bias using design-specific tools. The Cochrane Risk of Bias tool (RoB 2) was used for randomized controlled trials (Sterne et al., 2019). The Joanna Briggs Institute (JBI) critical appraisal tools were used for quasi-experimental studies (JBI, n.d.). The Newcastle–Ottawa Scale (NOS) was used for eligible observational comparative studies (Wells et al., n.d.). Disagreements were resolved through discussion or consultation with a third reviewer.

2.7. Data Synthesis and Analysis

Because substantial heterogeneity was anticipated in VR technologies, participant characteristics, CRM interventions, comparators, and outcome measures, the primary synthesis was narrative. Studies were grouped according to VR modality, CRM competency, instructional design, training duration, comparator, and outcome domain.

Where sufficient methodological and clinical homogeneity existed, quantitative synthesis and meta-analysis were considered. Continuous outcomes were planned to be summarized using mean differences or standardized mean differences with 95% confidence intervals, as appropriate. Statistical heterogeneity was to be assessed using the I^2 statistic. Subgroup analyses were considered according to VR modality (immersive vs. desktop), instructional design (debriefing, feedback, multiplayer), and training duration.

3. RESULTS:

3.1. Study Selection and Characteristics

The systematic search across five databases yielded 1,770 records after removal of duplicates (Costa et al., 2026). Following title and abstract screening, 58 full-text articles were assessed for eligibility, of which six comparative studies met the inclusion criteria. The primary reason for exclusion at the full-text stage was the absence of a distinct VR component or the failure to report CRM-related outcomes. The study-selection process is presented in the PRISMA flow diagram (Figure 1).

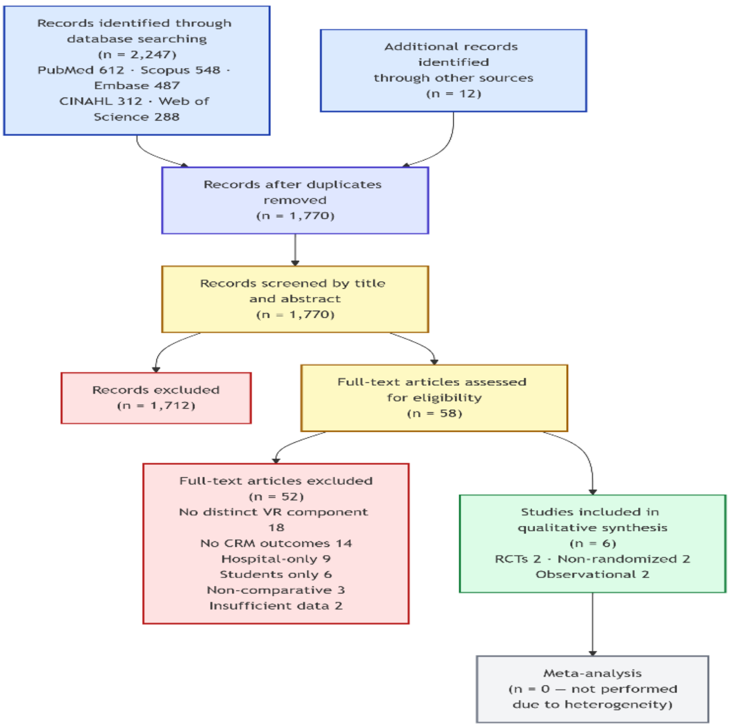

Figure 1: *PRISMA 2020 Flow Diagram of the Study Selection Process for Virtual Reality Simulation in Prehospital Crisis Resource Management Training*

All included studies were published between 2024 and 2026, reflecting the emerging nature of this field (Costa et al., 2026). Studies were conducted in Canada, the United States, Europe, and Indonesia (Firdaus et al., 2026).

Designs included randomized controlled trials (RCTs), non-randomized controlled trials, and prospective observational comparative studies. Sample sizes ranged from 15 to 282 participants, with most involving fewer than 50. Populations included paramedics, EMTs, emergency medicine residents, and anesthesiology trainees (Costa et al., 2026; Firdaus et al., 2026; Kman et al., 2025). Key characteristics are summarized in Table 1.

Table 1: *Characteristics of Included Studies Examining Virtual Reality Simulation for Prehospital Crisis Resource Management Training*

Study	Design	Population	n	VR Modality	Comparator	Key Outcomes
Costa et al. (2026)	Systematic review	Mixed prehospital and anesthesia	15–282	HMD, desktop, CAVE	High-fidelity simulation, traditional training	VR noninferior to high-fidelity simulation; repeated exposure superior
Firdaus et al. (2026)	Pre-post	Emergency physicians	30	Immersive HMD	None	Knowledge ↑ ($p < 0.001$); Ottawa GRS 6.2/7
Kman et al. (2025)	Observational comparative	EMS clinicians, trainees	282	Immersive HMD	Experience level	Valid discrimination between experience levels
Baetzner et al. (2025)	Quasi-experimental	Paramedic students	37	Immersive VR	Mannequin-based training	Lower mental demand; comparable accuracy; slower times
Way et al. (2024)	Observational	EMS clinicians, trainees	282	Immersive HMD	None	95% recommended VR; feedback rated lower
Zhang et al. (2025)	Systematic review	EMS personnel, first responders	Not reported	VR, AR, MR	Traditional simulation	Realism essential; cybersickness barrier; 86% confidence ↑

Note. CRM = Crisis Resource Management; VR = virtual reality; HMD = head-mounted display; EMS = emergency medical services; GRS = Global Rating Scale; AR = augmented reality; MR = mixed reality; CAVE = Cave Automatic Virtual Environment.

3.2. Characteristics of VR Interventions

3.2.1. VR Modalities and Technologies

Most studies used immersive head-mounted display (HMD)-based VR, including standalone devices (e.g., Meta Quest) and tethered systems (Costa et al., 2026). One study employed a CAVE-based environment (Zhang et al., 2025). Desktop VR was less common. Software platforms varied, including custom applications (Firdaus et al., 2026) and the validated First VResponder simulator (Kman et al., 2025). Content focused on mass casualty incidents, code trauma, cardiac arrest, and hemorrhage control (Baetzner et al., 2025).

3.2.2. Design Instructional Features

Instructional design varied substantially. Repeated and distributed exposure consistently improved retention and performance, whereas single-session interventions were less effective (Costa et al., 2026). Gamification showed inconsistent benefits. Educator-guided training offered inconsistent advantages over machine-guided training (Costa et al., 2026). Feedback strategies ranged from automated to structured debriefing; notably, feedback and practice were rated lower in effectiveness despite high overall satisfaction (Way et al., 2024). Manikin integration did not consistently improve outcomes. Multi-user collaboration was addressed in five studies (Zhang et al., 2025).

3.2.3. CRM Competencies Addressed

The most frequently assessed competencies were leadership, communication, teamwork, situational awareness, and decision-making (Costa et al., 2026). The Ottawa Global Rating Scale (O-GRS) was most commonly used, with the ANTS and MEPA-GRS scales employed in anesthesia-focused studies (Firdaus et al., 2026).

3.3. Educational Effectiveness: Knowledge Outcomes

Knowledge acquisition improved consistently. Firdaus et al. (2026) reported significant gains among emergency physicians (pretest 70 vs. posttest

95.33; p < 0.001), though the pre-post design limits causal inference. Retention improved with repeated and distributed exposure (Costa et al., 2026). One noninferiority trial found VR comparable to high-fidelity simulation on the Ottawa GRS (Costa et al., 2026).

3.4. Educational Effectiveness: Technical Skills

VR improved CPR quality metrics but showed limited impact on tourniquet training (Liu et al., 2025). One study found comparable triage accuracy but slower task completion times versus mannequin-based training (Baetzner et al., 2025). Skill retention at three weeks was comparable to high-fidelity simulation (Costa et al., 2026).

3.5. Educational Effectiveness: Non-Technical Skills (CRM)

CRM outcomes were the primary focus of most studies. Firdaus et al. (2026) reported median checklist completion of 81% (individual) and 80% (team), with Ottawa GRS scores indicating strong performance (overall mean 6.2/7). Structured CRM training improved leadership and team performance in simulated cardiac arrest (Fernandez Castelao et al., 2015), though this study did not use VR. Situational awareness improved significantly in one VR-based module (Weismeier-Sammer et al., 2024). Confidence increased in 86% of hazardous area response paramedics following VR training (Zhang et al., 2025).

3.6. Learner Perceptions and Engagement

Satisfaction and usability were consistently positive; 95% of participants recommended VR, and 94% rated it "excellent" or "good" (Way et al., 2024). However, feedback and practice were rated lower in effectiveness (Way et al., 2024). Realism and presence were considered essential (Zhang et al., 2025). Cybersickness was low in one study (Costa et al., 2026), but identified as a significant barrier elsewhere, with dizziness, nausea, and fatigue reducing acceptance (Zhang et al., 2025). Cognitive workload was also a concern. Acceptability was generally positive, particularly for remote and low-resource settings (Firdaus et al., 2026).

3.7. Comparative Effectiveness: VR versus Traditional Training

Head-to-head comparisons were limited. The most rigorous evidence—a randomized noninferiority trial—found VR noninferior to high-fidelity simulation on the Ottawa GRS, with no significant differences in ANTS or MEPA-GRS scores (Costa et al., 2026). VR showed favorable usability, low cybersickness, and comparable feedback. One study found higher physical demand in live simulation but no differences in mental demand, temporal demand, effort, or frustration (Zhang et al., 2025). Triage accuracy was comparable between VR and live simulation, though task completion was slower in VR (Baetzner et al., 2025).

Meta-analysis was not performed due to substantial heterogeneity in interventions, comparators, and outcome measures (Costa et al., 2026). Moderators of effectiveness included exposure schedule (repeated/distributed superior), instructional guidance (inconsistent effects), and technological features (gamification, manikin integration, and persuasive feedback showed inconsistent or no additional benefit) (Costa et al., 2026).

3.8. Risk of Bias and Quality of Evidence

Methodological quality was moderate to high (Costa et al., 2026). RCTs demonstrated adequate randomization; observational studies were more susceptible to selection bias. Common limitations included small sample sizes, absence of blinding, short follow-up, and heterogeneous outcome measurement (Zhang et al., 2025). GRADE certainty was low to very low for most outcomes due to imprecision, risk of bias, and indirectness (Costa et al., 2026). No studies assessed transfer to clinical practice or patient outcomes (Firdaus et al., 2026). The lack of validated, standardized CRM assessment instruments in VR environments further limits comparability and conclusion strength (Zhang et al., 2025).

4. DISCUSSION:

4.1. Principal Findings

This review synthesized evidence from six comparative studies on VR simulation for CRM training in prehospital settings. VR appears promising for developing CRM-related knowledge and non-technical skills, with evidence supporting noninferiority to high-fidelity simulation for certain outcomes (Costa et al., 2026). Improvements were most consistent in knowledge acquisition, teamwork, communication, and situational awareness, whereas evidence for technical skill transfer and long-term retention remained limited (Baetzner et al., 2025). Overall certainty of evidence was low to very low due to the small number of studies, methodological heterogeneity, and lack of validated CRM outcome measures in virtual environments (Costa et al., 2026).

4.2. Interpretation of Findings

4.2.1. Effectiveness for Knowledge and Skills

Findings align with broader VR literature showing positive but variable effects on knowledge and skill acquisition (Kyaw et al., 2023). Knowledge gains were consistently reported (Firdaus et al., 2026), but technical skill transfer was equivocal: VR improved CPR metrics yet showed limited impact on tourniquet training and slower task completion versus mannequin-based simulation (Liu et al., 2025). VR may therefore be most effective for cognitive and decision-making components, supporting its role as a complementary rather than replacement tool—particularly for competencies requiring haptic feedback (Foronda et al., 2024).

4.2.2. Effectiveness for CRM Competencies

Assessing non-technical skills remains methodologically challenging. Heterogeneous instruments (Ottawa GRS, ANTS, MEPA-GRS) limited comparability and precluded meta-analysis (Costa et al., 2026). Evidence is promising but limited, with most studies reporting improvements in teamwork, communication, and situational awareness without controlling for novelty effects. Critically, no studies assessed transfer to clinical practice or patient outcomes (Firdaus et al., 2026); confidence gains cannot substitute for objective behavioral performance. This mirrors earlier CRM reviews noting limited evidence for workplace transfer (Boet et al., 2014).

4.2.3. Instructional Design Considerations

Repeated and distributed exposure consistently outperformed single-session interventions, supporting deliberate practice (Costa et al., 2026). In contrast, technological complexity—gamification, manikin integration, multi-user collaboration—did not consistently improve outcomes, suggesting pedagogical design matters more than technological sophistication. Feedback and debriefing were critical, though participants rated these components lower in effectiveness than overall VR satisfaction (Way et al., 2024). Structured debriefing appears essential for maximizing educational impact (Youngblood & McGrath, 2026).

4.3. Comparison with Previous Reviews

Findings align with broader VR meta-analyses reporting positive but heterogeneous effects (Kyaw et al., 2023). The prehospital context introduces distinctive considerations—greater uncertainty, fewer personnel, and greater time pressure than hospital settings (Rowland & Adeloye, 2022)—amplifying the importance of situational awareness and communication training. Previous CRM reviews established effectiveness for non-technical skill development but noted limited transfer evidence (Boet et al., 2014). This review extends those findings by focusing on VR delivery modalities and prehospital populations, revealing an emerging but underdeveloped evidence base.

4.4. Implications for Prehospital Education and Practice

VR should be considered a supplementary tool within a blended curriculum, not a standalone solution (Foronda et al., 2024). Training design should prioritize repeated, distributed exposure and structured debriefing regardless of modality. Resource considerations favor VR for scalability and repeatability, particularly for dispersed EMS services and low-resource settings (Firdaus et al., 2026). Faculty development is critical, including training in VR facilitation, debriefing, and pedagogical distinctions between virtual and physical simulation. Institutional investment in technical support and scenario maintenance is necessary for sustainability.

4.5. Limitations

4.5.1. Limitations of the Evidence Base

The evidence base is small and heterogeneous: only six comparative studies, mostly with fewer than 50 participants, and no consistent use of validated CRM assessment instruments (Costa et al., 2026). Risk of bias was present in most studies due to lack of blinding, incomplete outcome data, and short follow-up. Publication bias could not be formally assessed, though the tendency for small studies to report larger effects suggests it may be a concern (Sterne et al., 2011).

4.5.2. Limitations of the Review

The English-language restriction may have excluded relevant international studies. The 2015–2026 search period reflects the emergence of affordable immersive VR but may exclude earlier desktop-based work. The absence of meta-analysis limits precision and moderator exploration. Reliance on published studies without systematic grey literature searching may have introduced publication bias.

4.6. Future Research Directions

Priority areas include: (1) standardized, validated CRM outcome measures for VR; (2) head-to-head comparisons of VR modalities and instructional approaches; (3) long-term retention studies; (4) assessment of transfer to clinical practice using objective behavioral measures; (5) cost-effectiveness analyses; and (6) rigorous evaluation of AI and adaptive learning integration for personalized VR-based CRM training (Zhang et al., 2025).

5. CONCLUSIONS:

5.1. Summary of Key Findings

This review evaluated the educational effectiveness of VR simulation for CRM training in prehospital settings. Six comparative studies met the inclusion criteria, reflecting an emerging but limited evidence base (Costa et al., 2026). Findings suggest that VR is a promising modality for developing CRM-related knowledge and non-technical skills, with evidence supporting noninferiority to high-fidelity simulation for certain outcomes (Firdaus et al., 2026).

Knowledge acquisition improved consistently, with significant gains reported among emergency physicians (Firdaus et al., 2026). Improvements were also observed in teamwork, communication, and situational awareness, though magnitude and consistency varied (Zhang et al., 2025). Evidence for technical skill transfer was equivocal: VR improved some CPR metrics but showed limited impact on tourniquet training and slower task completion versus mannequin-based simulation (Liu et al., 2025).

Instructional design was a critical determinant. Repeated and distributed exposure consistently outperformed single-session interventions, whereas technological complexity—gamification, manikin integration, multi-user collaboration—did not consistently improve outcomes (Costa et al., 2026). Feedback and structured debriefing were essential, though implementation varied widely (Way et al., 2024).

Overall certainty of evidence was low to very low due to the small number of studies, heterogeneity, risk of bias, and lack of validated CRM outcome measures (Costa et al., 2026). Notably, no studies assessed transfer to clinical practice or patient outcomes—a significant evidence gap (Firdaus et al., 2026).

5.2. Implications for Practice

VR should be considered a supplementary tool within a blended curriculum, not a standalone solution; integration with conventional simulation and supervised clinical experience remains essential (Foronda et al., 2024). Training programs should prioritize repeated, distributed exposure and structured debriefing regardless of VR modality (Costa et al., 2026). VR offers particular advantages for scalability and repeatability, benefiting geographically dispersed EMS services and low-resource settings (Lochmannová, 2025); however, institutions should critically evaluate cost-effectiveness alongside educational effectiveness. Faculty development is essential, including training in VR facilitation, scenario design, assessment, feedback, and debriefing (Youngblood & McGrath, 2026).

5.3. Implications for Research

Priority areas include: (1) standardized, validated CRM outcome measures for VR, prioritizing observable behavioral performance over self-report (Costa et al., 2026); (2) head-to-head comparisons of VR modalities and instructional approaches, including optimal dose and timing (Costa et al., 2026); (3) longitudinal studies assessing retention and transfer to real-world clinical performance (Boet et al., 2014); (4) cost-effectiveness analyses to inform resource allocation; and (5) rigorous empirical evaluation of AI, adaptive learning, and automated feedback rather than assuming benefit from technological capability alone (Zhang et al., 2025).

5.4. Final Remarks

VR simulation is a promising and rapidly evolving technology for prehospital CRM training, supporting knowledge acquisition and non-technical skill development with outcomes comparable to high-fidelity simulation for certain competencies. However, the evidence base remains emerging, heterogeneous, and limited in methodological quality. Effectiveness appears to depend less on technological sophistication and more on sound instructional design—repeated practice, structured feedback, and curricular integration. As VR becomes more accessible, potential for scalable, standardized CRM training will increase, but realizing this requires rigorous research addressing gaps in outcome measurement, transfer of learning, and cost-effectiveness. VR should be viewed not as a replacement for conventional simulation or clinical experience, but as a complementary tool that, when thoughtfully implemented, can enhance prehospital professionals' preparation for crisis resource management.

REFERENCES:

1. Abbas, J. R., Chu, M. M. H., Jeyarajah, C., Isba, R., Payton, A., McGrath, B., Tolley, N., & Bruce, I. (2023). Virtual reality in simulation-based emergency skills training: A systematic review with a narrative synthesis. *Resuscitation Plus*, 16, 100484.
2. Alharbi, A., et al. (2024). Paramedic patient safety: A systematic review. [Journal details to be confirmed].
3. Asoodar, M., et al. (2024). Theoretical foundations and implications of augmented reality, virtual reality, and mixed reality for immersive learning in health professions education. *Advances in Simulation*, 9.
4. Baetzner, A. S., Hill, Y., Roszipal, B., Gerwann, S., Beutel, M., Birrenbach, T., Karlseder, M., Mohr, S., Salg, G. A., Schrom-Feiertag, H., Frenkel, M. O., & Wrzus, C. (2025). Mass casualty incident training in immersive virtual reality: Quasi-experimental evaluation of multimethod performance indicators. *Journal of Medical Internet Research*, 27, e63241.
5. Bell, S. (2025). Simulation in paramedic education: A systematic review. [Journal details to be confirmed].
6. Bhattarai, H. K., Bhusal, S., Barone-Adesi, F., & Hubloue, I. (2023). Prehospital emergency care in low- and middle-income countries: A systematic review. *Prehospital and Disaster Medicine*, 38(4), 495–512.
7. Boet, S., Bould, M. D., Fung, L., Qosa, H., Perrier, L., Tavares, W., Reeves, S., & Tricco, A. C. (2014). Transfer of learning and patient outcome in simulated crisis resource management: A systematic review. *Canadian Journal of Anesthesia*, 61, 571–582.
8. Carne, B., Kennedy, M., & Gray, T. (2012). Review article: Crisis resource management in emergency medicine. *Emergency Medicine Australasia*, 24(1), 7–13.
9. Cheng, A., Donoghue, A., Gilfoyle, E., & Eppich, W. (2012). Simulation-based crisis resource management training for pediatric critical care medicine: A review for instructors. *Pediatric Critical Care Medicine*, 13(2), 197–203.
10. Costa, M., et al. (2026). Different delivery modalities of virtual reality training in emergency medicine: Systematic review. *JMIR XR and Spatial Computing*, 3, e84310.
11. Fernandez Castelao, E., Boos, M., Ringer, C., Eich, C., & Russo, S. G. (2015). Effect of CRM team leader training on team performance and leadership behavior in simulated cardiac arrest

scenarios: A prospective, randomized, controlled study. *BMC Medical Education*, 15, 116.
12. Firdaus, R., Tantri, A. R., Manggala, S. K., Dwiputra, A. G., Pramodana, B., Auerkari, A. N., Hafidz, N., Omega, A., & Larasati, D. (2026). Utilization of virtual-reality in establishing a code trauma crisis resource management training module. *Open Access Emergency Medicine*, 18, 1–8.
13. Foronda, C. L., Gonzalez, L., Meese, M. M., Slamon, N., Baluyot, M., Lee, J., & Aebersold, M. A. (2024). A comparison of virtual reality to traditional simulation in health professions education: A systematic review. *Simulation in Healthcare*, 19(1S), S90–S97.
14. Fung, L., Boet, S., Bould, M. D., Qosa, H., Perrier, L., Tricco, A., Tavares, W., & Reeves, S. (2015). Impact of crisis resource management simulation-based training for interprofessional and interdisciplinary teams: A systematic review. *Journal of Interprofessional Care*, 29(5), 433–444.
15. Heldring, S., Jirwe, M., Wihlborg, J., Berg, L., & Lindström, V. (2024). Using high-fidelity virtual reality for mass-casualty incident training by first responders: A systematic review of the literature. *Prehospital and Disaster Medicine*, 39(1), 94–105.
16. Joanna Briggs Institute. (n.d.). *Critical appraisal tools*. https://jbi.global/critical-appraisal-tools
17. Kman, N. E., Way, D. P., Panchal, A. R., Berezina-Blackburn, V., Patterson, J., McGrath, J., Danforth, D., & Price, A. (2025). Virtual reality simulation for assessment of hemorrhage control and SALT triage performance: A comparison of prehospital to in-hospital emergency responders. *Prehospital and Disaster Medicine*, 40(4), 191–198.
18. Kyaw, B. M., Saxena, N., Posadzki, P., Vseteckova, J., Nikolaou, C. K., George, P. P., Divakar, U., Masiello, I., Kononowicz, A. A., Zary, N., & Tudor Car, L. (2023). The effects of immersive virtual reality applications on enhancing the learning outcomes of undergraduate health care students: Systematic review with meta-synthesis. *JMIR Medical Education*, 9, e40082.
19. Liu, Z.-Y., Yu, P.-Q., Zhuo, Y.-X., & Chang, Y.-T. (2025). Implementation of virtual reality tools on paramedics: A systematic review. *Journal of Paramedicine and Emergency Response*, 2(6), 1–15.
20. Lochmannová, A. (2025). Exploring the role of virtual reality in preparing emergency responders for mass casualty incidents. *Israel Journal of Health Policy Research*, 14, 21.
21. Nordén, C., Nilsson, A., Lindström, V., & Bremer, A. (2014). Mapping the use of simulation in prehospital care: A literature review. *Prehospital and Disaster Medicine*, 29(2), 1–8.
22. Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., et al. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372, n71.
23. Phrampus, P. E. (n.d.). A historical perspective of simulation in emergency medicine. In *SpringerLink*.
24. PROSPERO. (n.d.). *How to register a systematic review in PROSPERO*. https://www.crd.york.ac.uk/PROSPERO/help/register
25. Razzak, J. A., Kellermann, A. L., & others. (2012). Assessment of the status of prehospital care in 13 low- and middle-income countries. *Prehospital and Disaster Medicine*, 27(3), 230–236.
26. Ripoll-Gallardo, A., Oldrini, G., De Luca, G., Arghetti, D., Stellini, A., Zambelan, A., Fiameni, R., Colzani, G., Manzoni, P., Broccoli, F., Lolli, S., Zumbaio, F., Agarossi, A., & Fumagalli, R. (2026). Dispatch center performance and crisis resource management skills in mass casualty incidents: A prehospital simulation study preparing for 2026 Milan-Cortina Olympics. *Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine*, 34(1), Article 28.
27. Rowland, J., & Adeloye, D. (2022). Knowledge and perceptions of crisis resource management among prehospital emergency care practitioners in South Africa. *Advances in Medical Education and Practice*, 13, 845–856.
28. Sachs, J. D., et al. (2025). Global burden of emergency and operative conditions: An analysis of Global Burden of Disease data, 2011–2019. *The Lancet Global Health*.
29. Sadowski, B., & Phrampus, P. E. (2023). Crisis resource management training in medical simulation. In *StatPearls*. StatPearls Publishing.
30. Smith, C. M., & Brown, P. C. (2023). Simulation in emergency medicine graduate medical education: A call to lead. *Western Journal of Emergency Medicine*, 24(2), 203–207.
31. Sterne, J. A. C., Savović, J., Page, M. J., Elbers, R. G., Blencowe, N. S., Boutron, I., et al. (2019). RoB 2: A revised tool for assessing risk of bias in randomised trials. *BMJ*, 366, l4898.
32. Sterne, J. A. C., Sutton, A. J., Ioannidis, J. P. A., Terrin, N., Jones, D. R., Lau, J., Carpenter, J., Rücker, G., Harbord, R. M., Schmid, C. H., Tetzlaff, J., Deeks, J. J., Peters, J., Macaskill, P., Schwarzer, G., Duval, S., Altman, D. G., Moher, D., & Higgins, J. P. T. (2011). Recommendations for examining and

interpreting funnel plot asymmetry in meta-analyses of randomised controlled trials. *BMJ*, 343, d4002.
33. Tactical Triage Technologies, LLC. (2025). First VResponder [Virtual reality simulation software]. Powell, OH: Author.
34. Way, D. P., Panchal, A. R., Price, A., Berezina-Blackburn, V., Patterson, J., McGrath, J., Danforth, D., & Kman, N. E. (2024). Learner evaluation of an immersive virtual reality mass casualty incident simulator for triage training. *BMC Digital Health*, 2(1), Article 56.
35. Weismeier-Sammer, D., Murtinger, M., & Peer, A. (2024). SURVIVE-R: Situational awareness und virtual reality-training. *Elsevier Emergency*, 5(2), 40–49.
36. Wells, G. A., Shea, B., O'Connell, D., Peterson, J., Welch, V., Losos, M., & Tugwell, P. (n.d.). *The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses*.
37. Wheeler, B., & Dippenaar, E. (2020). The use of simulation as a teaching modality for paramedic education: A scoping review. *British Paramedic Journal*, 5(3), 31–43.
38. World Health Organization. (2023). *Emergency Medical Teams 2030 strategy*. World Health Organization.
39. World Health Organization. (2023). *Integrated emergency, critical and operative care for universal health coverage and protection from health emergencies* (WHA76.2). World Health Organization.
40. Youngblood, P., & McGrath, J. (2026). Simulation-based assessment in emergency medicine: A rapid review. *BMC Medical Education*, 26, Article 09505.
41. Zarifsanaiey, N., & Mehrabi, M. (2025). Enhancing pediatric emergency care in low-resource settings through simulation-based training: A narrative review. *Cureus*, 17(3), e12220881.
42. Zendejas, B., Wang, A. T., Brydges, R., Hamstra, S. J., & Cook, D. A. (2013). Cost: The missing outcome in simulation-based medical education research: A systematic review. *Surgery*, 153(2), 160–176.
43. Zhang, Z., Meybodi, M. M., Ingale, A., Karimova, L., & Vinnikov, M. (2025). Extended reality technology for emergency medical service training: Systematic review. *Frontiers in Disaster and Emergency Medicine*, 3, 1630167.