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Clinical Simulation and Virtual Reality for Training in Pediatric Endocrine Emergencies: A Narrative Review Focusing on Iran and Comparison with Global Trends

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Abstract

Background*:* Pediatric endocrine emergencies require rapid, guideline-based management, complication monitoring, and effective teamwork. Limited exposure to high-risk clinical cases and patient-safety concerns highlight the value of clinical simulation and virtual reality (VR). This review synthesized evidence on these approaches for training healthcare learners in pediatric endocrine emergency management and identified implications for adaptation and development in Iran.

Materials and Methods*:* A structured narrative review was conducted using descriptive, analytical, and comparative approaches. Persian- and English-language sources were searched from database inception through February 28, 2026, across international and Iranian databases. Two reviewers independently screened, selected, and reviewed eligible sources; disagreements were resolved by consensus. Data on emergency type, educational modality, learner group, setting, instructional design, debriefing, outcomes, and implementation factors were extracted and narratively synthesized using Kirkpatrick's framework.

Results: Evidence primarily addressed pediatric diabetic ketoacidosis (DKA); studies of adrenal crisis, severe hypoglycemia, congenital adrenal hyperplasia–related hyperkalemia, thyroid storm, and hyperosmolar hyperglycemic state were limited. Principal modalities included high-fidelity manikin-based simulation, interprofessional education, in situ simulation, immersive VR, and screen-based virtual patients. These approaches generally improved knowledge, problem-solving, confidence, simulated performance, and team coordination. Multifaceted interventions combining simulation, structured feedback, and guideline-based checklists improved adherence to DKA-management processes in some studies. In situ simulation identified latent safety threats and workflow failures. Evidence for transfer to clinical practice, learning retention, cost-effectiveness, and patient-related outcomes remained limited. Published Iranian evidence on intervention design, implementation, and evaluation was sparse.

Conclusion: Simulation and VR are complementary. Iran should develop phased, locally adapted, Persian-language training for DKA, severe hypoglycemia, and adrenal crisis, incorporating debriefing, interprofessional learning, faculty development, and objective learner and system-level assessment.

Key Words: Clinical Simulation, Diabetic Ketoacidosis, Iran, Virtual Reality, Pediatric Endocrine Emergencies.

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1- INTRODUCTION

Pediatric endocrine emergencies—including diabetic ketoacidosis (DKA), severe hypoglycemia, and adrenal crisis—are time-critical, potentially life-threatening conditions frequently encountered in pediatric emergency and intensive care settings. Their safe management requires rapid recognition, structured assessment, timely therapeutic decisions, accurate fluid and medication management, correction of electrolyte abnormalities, and close monitoring for complications. In children with type 1 diabetes, DKA is among the most important metabolic emergencies; errors in fluid replacement, potassium management, insulin administration, or neurological monitoring may contribute to serious complications, including cerebral injury (1, 2).

Effective management depends on more than theoretical knowledge. Clinicians must interpret clinical and laboratory data, prioritize actions, calculate and administer treatments safely, adhere to evidence-based guidelines, and coordinate care within multidisciplinary teams. However, opportunities for learners to manage real pediatric endocrine emergencies under supervision are limited and unpredictable, particularly for severe or complex presentations. Conventional teaching methods, such as lectures and bedside instruction, may therefore be insufficient for developing timely decision-making and crisis-management skills while maintaining patient safety.

Simulation-based education (SBE) enables repeated practice of clinical scenarios in a safe, controlled environment without exposing patients to avoidable risk. It can support training in initial assessment, interpretation of laboratory results, treatment selection, error management, and non-technical competencies, including crisis communication, team leadership, task allocation, and resource management. Interprofessional simulation training for pediatric DKA has been associated with improved knowledge and preparedness among physicians and nurses; nevertheless, the retention of learning and its transfer to real clinical practice require further investigation (3).

Virtual reality (VR) is an emerging simulation modality that provides immersive, interactive, and standardized three-dimensional learning environments. It may be particularly useful for practicing rare, high-risk, and time-sensitive scenarios, especially where access to high-fidelity manikins or dedicated simulation facilities is limited. A systematic review and meta-analysis found that VR-based education improved healthcare professionals' cognitive skills compared with conventional teaching (standardized mean difference, 1.12; 95% confidence interval, 0.81–1.43). However, evidence regarding behavioral change in practice, cost-effectiveness, and patient-related outcomes remains limited (4).

Although simulation and VR are increasingly used in medical education worldwide, pediatric emergency simulation research has predominantly focused on resuscitation, trauma, shock, and airway management. Evidence on standardized simulation or VR scenarios specifically addressing pediatric endocrine emergencies remains comparatively limited. Existing DKA studies have primarily examined knowledge, self-confidence, perceived realism, simulated performance, and adherence to treatment guidelines. For example, in situ simulation combined with structured feedback in community emergency departments has been associated with improved adherence to pediatric DKA-management processes. High-fidelity DKA scenarios have also been judged realistic and professionally relevant by pediatric and emergency medicine residents (5).

In Iran, pediatric DKA remains a clinically important concern. A study conducted in southern Iran found that 57.1% of children newly diagnosed with type 1 diabetes mellitus presented with DKA. Younger age, rural residence, delayed diagnosis, and lower maternal educational level were associated with DKA at presentation (6). These findings emphasize the importance of strengthening early recognition and safe management of pediatric endocrine emergencies. Interest in simulation-based health professions education is also growing; a recent scoping review identified 95 quasi-experimental studies published over a decade (7). Nevertheless, published evidence on the design, implementation, and evaluation of clinical simulation or VR specifically for training in pediatric endocrine emergency management remains sparse. Differences in access to simulation centers, equipment, software, Persian-language content, trained faculty, and financial resources may affect the feasibility of widespread implementation. Critically synthesizing global evidence and examining its adaptability to Iranian educational needs and capacities may support the development of locally relevant scenarios, interprofessional training, and the gradual integration of simulation-based technologies into pediatric and emergency medicine education (7, 8).

1-1. Study Aim

This structured narrative review aimed to critically synthesize evidence on the use of clinical simulation and virtual reality technologies for training healthcare learners in the recognition, decision-making, and management of pediatric endocrine emergencies. It examined educational interventions, learner groups, implementation settings, reported outcomes, and implementation requirements and identified implications for adapting and developing contextually appropriate educational programs in Iran in relation to global trends.

The review addressed three interrelated domains:

- **Educational applications and interventions:** To describe and analyze the use of clinical simulation and VR in training for the recognition, decision-making, and management of pediatric endocrine emergencies, considering emergency type, educational modality, learner group, setting, and instructional design.
- **Outcomes and implementation requirements:** To critically examine reported educational and operational outcomes, including knowledge, clinical reasoning, decision-making, technical and non-technical skills, teamwork, confidence, guideline adherence, and clinical readiness, alongside the role of debriefing, organizational facilitators, implementation barriers, and infrastructure requirements.
- **Comparative interpretation and implications for Iran:** To interpret international evidence in light of Iran’s educational needs, capacities, and constraints and to identify practical priorities for the design, local adaptation, phased implementation, and evaluation of simulation and VR interventions in pediatric and emergency-care training.

2- MATERIALS AND METHODS

2-1. Study Design

This study was a structured narrative review using descriptive, analytical, and comparative approaches. It aimed to critically synthesize evidence on the use of clinical simulation and extended reality technologies for training healthcare learners in the recognition, clinical decision-making, and management of pediatric endocrine emergencies. Technologies of interest included virtual reality (VR), augmented reality (AR), mixed reality (MR), virtual patients, and other digital simulation approaches. The review also considered the practical implications of this evidence for the local adaptation and development of educational programs in Iran in relation to international trends.

A structured narrative review is appropriate for topics with heterogeneous evidence in terms of technology type, learner population, educational setting, scenario complexity, intervention design, and assessed outcomes. This approach aims to provide a systematic and critical interpretation of available evidence, applications, knowledge gaps, and practical implications rather than a quantitative estimate of effect size or an exhaustive mapping of all published literature (9–12).

2-2. Review Scope and Questions

The review addressed three main domains:

1. Educational applications and interventions: To describe and analyze the use of clinical simulation and extended reality technologies for training in the recognition, decision-making, and management of pediatric endocrine emergencies, considering emergency type, educational modality, learner group, setting, and instructional-design components.

2. Outcomes and implementation requirements: To critically examine educational and implementation outcomes, including knowledge, problem-solving, clinical decision-making, technical and non-technical skills, teamwork, confidence, adherence to clinical guidelines, and clinical readiness. The review also examined the contributions of debriefing, implementation facilitators, organizational barriers, and infrastructure requirements.

3. Implications for Iran: To interpret international evidence in light of the needs, capacities, and constraints of medical education in Iran and to identify practical priorities for the design, local adaptation, phased implementation, and evaluation of simulation- and VR-based interventions in pediatric and emergency-care education.

The endocrine emergencies of interest included diabetic ketoacidosis (DKA), hyperosmolar hyperglycemic state (HHS), adrenal crisis and acute adrenal insufficiency, severe hypoglycemia, thyroid storm, and other acute pediatric metabolic-endocrine conditions.

2-3. Information Sources and Search Strategy

Persian- and English-language sources were searched from database inception through February 28, 2026. International databases included PubMed/MEDLINE, Scopus, Web of Science Core Collection, Embase, ERIC, CINAHL, the Cochrane Library, and Google Scholar. To identify Persian-language evidence, Iran-specific information, and implementation- or policy-related sources, SID, Magiran, IranDoc, ISC, Civilica, and the Iranian Registry of Clinical Trials (IRCT) were also searched.

The search strategy combined controlled vocabulary, including Medical Subject Headings (MeSH) in PubMed, with free-text terms. The principal concepts included:

- Clinical simulation, simulation-based education, manikins, high-fidelity simulation, in situ simulation, standardized patients, and virtual patients
- Virtual reality, augmented reality, mixed reality, and extended reality
- Children, pediatrics, neonates, infants, and adolescents

- Diabetic ketoacidosis, hyperosmolar hyperglycemic state, adrenal crisis, adrenal insufficiency, severe hypoglycemia, thyroid storm, and endocrine emergencies
- Medical and nursing education, clinical decision-making, teamwork, debriefing, and adherence to treatment guidelines.

To supplement database searches, reference lists of key studies, relevant reviews, and authoritative clinical guidelines were manually screened. Forward citation searching of key publications was also undertaken using Google Scholar. Clear reporting of information sources, search dates, search terms, and selection rationale was considered essential to the rigor of this narrative review (9–12).

Example PubMed Search Strategy:

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(
  "Simulation Training"[Mesh]
  OR "simulation-based education"[Title/Abstract]
  OR "clinical simulation"[Title/Abstract]
  OR "high-fidelity simulation"[Title/Abstract]
  OR "in situ simulation"[Title/Abstract]
  OR "Virtual Reality"[Mesh]
  OR "virtual reality"[Title/Abstract]
  OR "augmented reality"[Title/Abstract]
  OR "mixed reality"[Title/Abstract]
  OR "extended reality"[Title/Abstract]
  OR "virtual patient"[Title/Abstract]
  OR manikin[Title/Abstract]
  OR mannequin[Title/Abstract]
)
AND
(
  "Pediatrics"[Mesh]
  OR "Child"[Mesh]
  OR "Adolescent"[Mesh]
  OR "Infant"[Mesh]
  OR pediatric*[Title/Abstract]
  OR paediatric*[Title/Abstract]
  OR child*[Title/Abstract]
  OR adolescen*[Title/Abstract]
  OR infant*[Title/Abstract]
  OR neonat*[Title/Abstract]
)
AND
(
  "Diabetic Ketoacidosis"[Mesh]
  OR "diabetic ketoacidosis"[Title/Abstract]
  OR DKA[Title/Abstract]
  OR "hyperosmolar hyperglycemic state"[Title/Abstract]
  OR "adrenal crisis"[Title/Abstract]
  OR "adrenal insufficiency"[Title/Abstract]
  OR hypoglycemi*[Title/Abstract]
  OR "thyroid storm"[Title/Abstract]
  OR "endocrine emergenc*"[Title/Abstract]
  OR "endocrine crisis"[Title/Abstract]
)
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For other international and Persian databases, the search strategy was adapted while retaining the core concepts and accounting for each database's indexing structure, search syntax, abbreviations, and search functions.

2-4. Source Selection and Prioritization

The search process, initial title and abstract screening, and selection of relevant sources were conducted independently by two reviewers. Sources were initially assessed for relevance to the review objectives, pediatric populations or learners involved in pediatric care, endocrine emergency type, and use of simulation or extended reality technologies. Full texts of potentially relevant sources were then examined for intervention characteristics, learner group, implementation setting, educational outcomes, implementation barriers, and practical implications.

Disagreements regarding relevance, inclusion, or interpretation were resolved through discussion and consensus. Priority was given to peer-reviewed primary studies, educational intervention studies, trials, quality-improvement initiatives, feasibility studies, scenario-development or validation reports, relevant systematic reviews, and authoritative clinical guidelines.

Sources focused solely on the clinical treatment of endocrine emergencies without an educational component were excluded from the main synthesis. Studies using VR exclusively for treatment, rehabilitation, pain management, or entertainment were also excluded. Persian-language sources, official documents, and credible grey literature were considered when they provided specific information on feasibility, barriers, infrastructure, implementation, or localization in Iran.

2-5. Data Extraction and Evidence Synthesis

Data from selected sources were recorded in a predesigned extraction matrix. The matrix included author, publication year, country, study or source type, learner group, implementation setting, target emergency, simulation modality or extended reality technology, instructional-design components, the roles of prebriefing and debriefing, assessment methods, reported outcomes, and implementation barriers or facilitators.

Findings were analyzed using a narrative thematic synthesis. Sources were first organized according to endocrine emergency type, educational modality, learner group, implementation setting, and intervention design. Evidence was then interpreted across four themes:

1. Patterns of evidence and educational interventions in pediatric endocrine emergencies
2. Educational and performance outcomes, including knowledge, clinical decision-making, technical and non-technical skills, teamwork, confidence, and guideline adherence
3. Roles of scenario design, debriefing, interprofessional education, and in situ simulation in intervention effectiveness
4. Research gaps, implementation barriers, and practical implications for Iran.

Kirkpatrick's framework was used as an analytical lens to classify findings across learner reaction, learning, behavioral change, and organizational- or patient-related outcomes. Because of considerable heterogeneity in technology type, learner population, setting, intervention design, and outcome measures, meta-analysis was not undertaken.

2-6. Trustworthiness and Ethical Considerations

To enhance the trustworthiness of the synthesis, the review considered study design, clarity of intervention reporting, appropriateness of learner groups and settings, outcome-measurement methods, the presence of comparison groups, follow-up duration, and consistency between reported data and the authors' conclusions. Reporting was aligned with the SANRA criteria, including the importance of the topic, clarity of aims, description of literature sources and search strategy, quality of referencing, scientific reasoning, and presentation of relevant data (10).

As this study was a secondary review of previously published literature and did not involve direct intervention with human participants or access to confidential patient records, separate biomedical ethics approval was not required. Nevertheless, principles of scientific integrity, bias reduction, accurate reporting, and adherence to the Committee on Publication Ethics (COPE) principles and codes of conduct were observed throughout the study (13).

3- RESULTS

The selected evidence was organized through a narrative thematic synthesis across three analytical domains: (1) educational applications and interventions in pediatric endocrine emergencies; (2) educational outcomes and potential mechanisms of effect; and (3) implementation requirements and practical implications for Iran in the context of global trends. The literature predominantly focused on training for pediatric diabetic ketoacidosis (DKA) management. Reported interventions included high-fidelity manikin-based simulation, in situ simulation, interprofessional education, immersive virtual reality (VR), and screen-based virtual patients. Studies addressing adrenal crisis, congenital adrenal hyperplasia (CAH)-related hyperkalemia, and severe hypoglycemia were more limited and were mainly scenario-based or focused on system readiness. Evidence on simulation- or VR-based training for pediatric thyroid storm and hyperosmolar hyperglycemic state (HHS) was limited (3, 5, 7, 14–21).

3-1. Educational Applications

3-1-1. DKA as the Predominant Focus

DKA represented the most extensively studied pediatric endocrine emergency. Educational scenarios commonly addressed early recognition, initial assessment, interpretation of blood gas and electrolyte results, fluid management, timing of insulin initiation, potassium replacement, and recognition of neurological deterioration suggestive of cerebral injury or cerebral edema (1,7). Thus, DKA simulation extends beyond teaching isolated technical skills; it provides an opportunity to integrate knowledge, clinical reasoning, therapeutic calculations, prioritization, guideline adherence, and teamwork.

Interprofessional simulation is particularly relevant to DKA because safe management requires coordinated work among physicians, nurses, and, in complex cases, clinical pharmacists and intensive care teams. Larson-Williams et al. reported that a multistage interprofessional simulation program for pediatric residents and nursing staff improved DKA-management knowledge. The partial decline in retention at follow-up also highlighted the need for periodic practice and integration of simulation into continuing professional development (3).

High-fidelity manikin-based scenarios can reproduce dynamic changes in patient status and allow learners to practice stepwise decision-making. Monzani et al. demonstrated that a standardized DKA scenario was rated by pediatric and emergency medicine residents as realistic and professionally relevant. Learners practiced diagnosis, fluid therapy, insulin administration, electrolyte correction, and complication monitoring in a controlled setting (7). This standardized scenario also enabled practice in neurological assessment, reassessment of treatment, and team coordination in response to potential complications, including cerebral edema (7).

3-1-2. In Situ Simulation and System Readiness

In situ simulation has value beyond individual learner training because it can assess team and system readiness in the actual emergency-care environment. In an observational in situ simulation study conducted in general emergency departments, the mean overall adherence score of interprofessional teams to pediatric DKA-management guideline components was 55.6%. Inappropriate use of intravenous fluid boluses, insulin, and bicarbonate was reported among some teams (21). These findings suggest that in situ simulation can reveal discrepancies between theoretical knowledge, guideline implementation, and real-world readiness.

Conversely, multifaceted programs incorporating simulation, performance feedback, and educational resources may move beyond identifying gaps and contribute to improving care processes. One intervention in general emergency departments increased adherence to a DKA-management checklist from 77.8% to 88.9%, with significant improvements in hourly glucose monitoring and the selection of appropriate fluid rates (20). Therefore, the practical value of in situ simulation may be greatest when implemented as a cycle of scenario delivery, data-informed feedback, process improvement, and repeated practice (20, 21).

3-1-3. Virtual Reality and Virtual Patients

Immersive VR enables repeated practice of clinical decision-making in a standardized environment and may reduce dependence on manikins, dedicated physical space, and synchronous instructor availability. In a pilot study, Mallik et al. reported that VR scenarios increased learners' confidence in managing diabetic emergencies, including DKA (14). However, confidence was largely self-reported and cannot, by itself, establish transfer of learning to clinical performance.

A randomized controlled trial by Baek and Lee found that experiential learning–based VR simulation improved nursing students' problem-solving ability and self-confidence in DKA management compared with electronic case-based learning (15). This finding supports VR as a tool for cognitive learning and decision-making practice; however, direct extrapolation to pediatric emergency teams or actual clinical environments requires caution.

Screen-based virtual patients may offer a potentially lower-cost and more scalable alternative for individual practice. Mahou et al. described the development of a virtual patient for teaching nursing management of DKA. The platform allowed learners to practice patient assessment, treatment selection, and decision-making in DKA scenarios; however, the report focused primarily on intervention development and usability and did not provide sufficient comparative evidence of educational superiority or clinical benefit (19).

Table-1: Synthesis of Selected Studies and Educational Interventions in Pediatric Endocrine Emergencies.

Emergency/topic	Learners and setting	Educational intervention	Primary educational objective	Reported outcome	Analytical interpretation	References
Pediatric DKA	Pediatric residents and nurses; simulation center	Multistage interprofessional simulation	DKA-management knowledge, team coordination, and recognition of complications	Improved post-intervention knowledge	Appropriate for joint physician–nurse training; retention requires repeated practice	(3)
Pediatric DKA	Interprofessional teams; general emergency departments	Observational in situ simulation	System readiness and guideline adherence	Identified important gaps in DKA-guideline implementation	Main value is identifying workflow failures and latent safety threats	(21)
Pediatric DKA	General emergency-department staff	Simulation, feedback, and quality-improvement intervention	Care-process improvement and checklist adherence	Checklist adherence increased from 77.8% to 88.9%	Simulation combined with feedback and organizational support may improve process performance	(20)
Pediatric DKA	Pediatric and emergency medicine residents; simulation center	Standardized high-fidelity manikin scenario	Diagnosis, stepwise decision-making, and treatment management	High perceived realism and educational relevance	Useful for standardizing learning experiences and practicing decision-making	(7)
Pediatric DKA, including neurological monitoring for cerebral edema	Pediatric and emergency medicine residents; simulation center	High-fidelity manikin simulation	Early recognition, fluid management, insulin initiation, electrolyte correction, and neurological monitoring	Realistic and relevant to professional practice; enables stepwise decision-making in a controlled setting	Cerebral edema was one of several monitored complications, rather than the exclusive focus of the scenario	(7, 16)
DKA and other diabetic emergencies	Healthcare professionals; VR environment	Immersive VR	Decision-making and perceived preparedness	Increased acceptance and confidence	Promising for individual, repeatable practice; clinical transfer	(14)

Emergency/topic	Learners and setting	Educational intervention	Primary educational objective	Reported outcome	Analytical interpretation	References
					requires evaluation	
DKA	Nursing students; educational VR environment	Experiential learning–based VR	Problem-solving and self-efficacy	Improved problem-solving and confidence compared with electronic case-based learning	Effects depend on instructional design and feedback, not technology alone	(15)
Adrenal crisis/CAH	Emergency-care learners; simulation center	Manikin-based scenario	Recognition of shock, hyperkalemia management, and steroid administration	Practice in diagnostic and treatment algorithms	Understudied but appropriate for scenario-based training because of high time sensitivity	(17)
Hypoglycemia with seizures	Emergency teams; multiple centers	Systems-focused simulation	System readiness and process safety	Identified errors in dextrose delivery, medication processes, and team coordination	Primarily useful for evaluating system safety and uncovering latent threats	(18)
Nursing management of DKA	Students and nurses; digital setting	Screen-based virtual patient	Decision-making and nursing care	Platform development and usability	Potentially lower-cost option for individual practice and remote learning	(19)

Note*:* CAH: Congenital adrenal hyperplasia; DKA: Diabetic ketoacidosis; VR: Virtual reality. Table data were extracted from the cited sources (3, 7, 14–21).

3-2. Educational Outcomes and Mechanisms

3-2-1. From Learner Reaction to Process Performance

The narrative synthesis indicated a hierarchical pattern in the outcomes reported across studies. Most studies assessed outcomes close to the intervention, including satisfaction, perceived realism, engagement, confidence, knowledge, problem-solving, and performance in simulation settings. Outcomes closer to clinical practice—such as guideline adherence, team communication, workplace performance, and system readiness—were assessed less often. Final patient-related outcomes, including reduced cerebral edema, shorter hospitalization, fewer treatment errors, or lower mortality, were rarely reported.

This pattern suggests that simulation and VR are currently used primarily to enhance educational preparedness and learner competence. Although confidence is important for learner readiness, it should be interpreted alongside objective measures of performance. Indicators such as correct completion of critical actions, time to intervention, adherence to guidelines, and quality of team communication have greater relevance to clinical performance.

Multifaceted DKA programs suggest that combining simulation scenarios with checklists, data-driven feedback, and process improvement can move educational impact beyond knowledge and satisfaction toward behavioral and care-process performance (20, 21). A systematic review by Thim et al. associated simulation-based team training in pediatric emergencies with improved execution of time-critical interventions and greater adherence to treatment guidelines; however, heterogeneity and risk of bias limited conclusions regarding patient outcomes (22).

3-2-2. The Role of VR in Educational Outcomes

The principal advantages of VR are standardized educational experiences, repeatability, independent practice, and interactive decision-making environments. However, VR is not necessarily superior to high-fidelity manikin simulation across all outcomes. Kim et al. found that both VR and high-fidelity simulation could influence anxiety, confidence, learner engagement, and perceived learning, but no consistent advantage of VR was demonstrated across outcomes (23). Therefore, decisions regarding VR adoption should be based on learning objectives, cost, access, the need for team-based practice, and learner characteristics rather than technological novelty alone.

Table-2: Educational and Implementation Outcomes Interpreted Through Kirkpatrick's Framework.

Kirkpatrick level	Reported outcomes	Examples of evidence	Analytical interpretation	References
Level 1: Reaction	Satisfaction, acceptability, perceived realism, presence, and engagement	DKA and VR scenarios were generally viewed as acceptable and useful	Acceptability is necessary for sustained use but does not alone establish educational or clinical effectiveness	(7, 14, 15, 23)
Level 2a: Attitudes	Confidence, self-efficacy, and perceived readiness	Increased confidence following interprofessional simulation and VR	Mostly self-reported outcomes; should be interpreted alongside objective performance measures	(3, 14, 15)
Level 2b: Knowledge and skills	Knowledge, problem-solving, decision-making, critical actions, and scenario performance	Improved DKA knowledge, decision-making, and problem-solving	Evidence supports short-term learning, but measures and follow-up periods are heterogeneous	(3, 7, 15, 19)
Level 3: Behavior	Teamwork, communication, guideline adherence, and workplace performance	Simulation with feedback improved DKA care processes	Integrating simulation with feedback and process improvement may increase transfer to	(20, 21)

Kirkpatrick level	Reported outcomes	Examples of evidence	Analytical interpretation	References
			performance	
Level 4: Results	Safety threats, care quality, complications, and patient outcomes	Identification of process failures in hypoglycemia and DKA management	Useful for identifying system risk; direct effects on patient outcomes remain uncertain	(18, 21, 22)

Note*:* In the available literature, Level 4 outcomes were more often related to safety threats or process indicators than to demonstrated reductions in mortality or patient complications (18, 21, 22). DKA: Diabetic ketoacidosis; VR: Virtual reality.

3-3. Educational Design and Implementation Requirements

3-3-1. Technology Alone Is Insufficient

The synthesis indicated that intervention effectiveness depends more on instructional design than on technological sophistication. First, scenarios should be aligned with evidence-based guidelines and critical actions. In DKA, these include assessment of hydration and neurological status, appropriate fluid therapy, timing of insulin initiation, potassium correction, glucose monitoring, and recognition of warning signs of cerebral injury (1).

Second, scenario design should be matched to learners' level of experience. For novice learners, scenarios may focus on recognizing DKA and sequencing essential actions. At more advanced levels, dynamic potassium changes, reduced consciousness, possible cerebral edema, communication errors, or equipment-access barriers can be incorporated. Such progressive complexity helps maintain attention to key decisions and avoids excessive cognitive load in less experienced learners (7, 15, 19).

Third, structured debriefing and data-informed feedback are necessary to transform scenario participation into transferable learning. In DKA scenarios, debriefing should address the rationale for therapeutic decisions, team communication, role allocation, guideline implementation, and organizational barriers. Interprofessional training involving physicians and nurses may strengthen team coordination, mutual role understanding, and crisis-resource management (3, 5, 22).

3-3-2. Implementation Barriers and Facilitators

Key barriers to implementing simulation and VR include equipment costs, limited simulation space, clinical workload, challenges in scheduling interprofessional education, shortages of faculty skilled in scenario design and debriefing, and, for VR, the need for technical support and the potential for cybersickness. Nevertheless, virtual patients and screen-based simulation may provide practical complementary approaches for individual decision-making practice and use in resource-constrained settings.

Table-3: Key Design Elements, Implementation Barriers, and Practical Implications.

Domain	Element or factor	Contribution to effectiveness	Implementation challenge	Practical implication	References
Scenario content	Alignment with guidelines and critical actions	Makes scenarios standardized tools for performance assessment	Unclear objectives or unrealistic scenarios	Design DKA, adrenal crisis, and hypoglycemia scenarios using performance checklists	(1, 5, 7, 16, 20, 21)
Learning design	Progressive complexity and dynamic patient changes	Strengthens clinical reasoning and prioritization	Excessive cognitive load for inexperienced learners	Match scenario complexity to the learner's educational stage	(7, 15, 19)
Debriefing	Structured, data-informed feedback	Converts experience into learning and error correction	Limited time and insufficient skilled facilitators	Train faculty and use a consistent feedback framework	(3, 5, 15, 20)
Interprofessional education	Inclusion of physicians, nurses, and relevant team members	Strengthens communication, task allocation, and crisis-resource management	Scheduling and role-related differences	Conduct joint DKA scenarios in simulation centers and emergency departments	(3, 5, 22)
Technology	Choice of manikin, VR, or virtual patient according to learning objectives	Improves alignment between educational tool and targeted skills	Cost, maintenance, access, and cybersickness	Use phased and blended technology implementation	(4, 14, 15, 19, 23)
Evaluation	Objective checklists, OSCEs, and process indicators	Enables progression from satisfaction to assessment of performance and behavior	Overreliance on self-report and short follow-up	Use pre/post testing, delayed follow-up, and workplace-performance assessment	(5, 7, 20–22)

Note*:* OSCE: Objective Structured Clinical Examination; VR: Virtual reality; DKA: Diabetic ketoacidosis. Multifaceted interventions incorporating scenarios, feedback, and educational resources may have greater potential to improve adherence to DKA-management processes (20).

3-4. Implications for Iran

In the Persian- and English-language sources reviewed, published studies specifically addressing clinical simulation or VR for training in pediatric endocrine emergencies in Iran were limited. This finding does not necessarily indicate an absence of local activity; rather, it may reflect limitations in the documentation, publication, or indexing of existing initiatives. Nevertheless, the review by Sohrabi et al. suggests that simulation-based education is expanding within Iranian health professions education, indicating foundational capacity for more targeted interventions (8).

International trends suggest that DKA training has evolved from isolated manikin-based scenarios toward integrated programs that combine in situ simulation, performance feedback, interprofessional training, guideline-based checklists, and digital technologies. In Iran, the initial priority should not be the procurement or widespread deployment of VR alone. Instead, emphasis should be placed on developing standardized, Persian-language, guideline-based educational packages for DKA, severe hypoglycemia, and adrenal crisis.

Such packages may include measurable behavioral objectives, staged scenarios, critical-action checklists, pre-learning materials, facilitator guides, structured debriefing frameworks, and performance-assessment tools. Initially, appropriately selected manikin-based simulation, screen-based virtual patients, or tabletop simulation may be used to teach individual decision-making and algorithm mastery. In subsequent stages, interprofessional education and in situ simulation can strengthen physician–nurse coordination, assess system readiness, and identify workflow failures. Following needs assessment and feasibility evaluation, VR may be introduced in selected centers as a complementary tool for individual practice, remote learning, and repeated practice of low-frequency scenarios.

Table-4: International Trends, Published Evidence in Iran, and Proposed Priorities.

Domain	International trends	Published evidence in Iran	Proposed priority for Iran	References
Clinical topics	Predominant focus on DKA; more limited evidence for adrenal crisis and hypoglycemia	Published studies specific to pediatric endocrine emergencies are limited	Develop three priority scenarios: DKA, severe hypoglycemia, and adrenal crisis	(3, 5–8, 16–18)
Intervention model	Integration of scenarios, feedback, in situ simulation, and interprofessional education	General expansion of simulation is documented, but endocrine-specific data are limited	Develop multicomponent packages rather than stand-alone workshops	(5, 8, 20, 21)
Technology	Blended use of high-fidelity manikins, VR, and virtual patients	Limited evidence on VR specifically for pediatric endocrine emergencies	Begin with manikins or lower-cost virtual patients; pilot VR based on needs assessment	(4, 8, 14, 15, 19)
Learner groups	Residents, nurses, emergency staff, and caregivers	General simulation capacity exists in health professions education	Prioritize physician–nurse teams, followed by selected caregiver education	(3, 8, 19)
Outcome assessment	Increasing focus on guideline adherence, system safety, and process indicators	Longitudinal and endocrine-specific data are limited	Use OSCEs, DKA checklists, teamwork assessment, and learning follow-up	(5–8, 20–22)
Infrastructure	Gradual expansion of	Resource variability	Share scenarios, develop	(4, 8, 19)

Domain	International trends	Published evidence in Iran	Proposed priority for Iran	References
	design teams and technological capacity	across educational centers is likely	faculty capacity, and conduct multicenter pilots	

Note*:* Statements regarding Iran are based on the published sources reviewed and should be interpreted as an analysis of needs and opportunities for locally adapted program development. DKA: Diabetic ketoacidosis; VR: Virtual reality.

3-5. Summary of Findings

The narrative thematic synthesis indicates that clinical simulation and VR have complementary roles in training for pediatric endocrine emergency management. High-fidelity manikin simulation is particularly suitable for practicing dynamic clinical changes and complications; in situ simulation can identify performance and organizational gaps; interprofessional education can strengthen teamwork; and VR or virtual patients can support standardized, repeatable individual decision-making practice.

DKA was the central focus of educational interventions because of its clinical complexity, time sensitivity, and potential for standardized critical-action training. Although findings were encouraging for knowledge, confidence, problem-solving, teamwork, and adherence to care processes, evidence for adrenal crisis, severe hypoglycemia, thyroid storm, and HHS was more limited. Evidence regarding learning retention, transfer to actual clinical performance, cost-effectiveness, and patient-related outcomes also remains insufficient. For Iran, the gradual development of locally adapted, guideline-based scenarios; faculty development in simulation design and debriefing; implementation of interprofessional education; and targeted adoption of digital technologies represent practical opportunities for advancing this field.

4- DISCUSSION

This structured narrative review critically synthesized evidence on the use of clinical simulation and virtual reality (VR) technologies for training in the recognition, decision-making, and management of pediatric endocrine emergencies; examined educational outcomes and implementation requirements; and interpreted their implications for Iran in relation to international trends. The narrative thematic synthesis showed that the literature predominantly focused on pediatric diabetic ketoacidosis (DKA). Reported educational approaches included high-fidelity manikin-based simulation, in situ simulation, interprofessional education, immersive VR, and screen-based virtual patients. These interventions were generally associated with improvements in knowledge, problem-solving, confidence, simulated performance, and, in some studies, adherence to guideline-based care processes. In contrast, evidence regarding patient outcomes, sustained transfer of learning to clinical practice, cost-effectiveness, and non-DKA emergencies—including adrenal crisis, severe hypoglycemia, thyroid storm, and hyperosmolar hyperglycemic state (HHS)—was more limited. Published condition-specific evidence on simulation or VR for pediatric endocrine emergency education in Iran was also sparse.

4-1. DKA Simulation: From Individual Knowledge to Team Performance

The predominance of DKA in the literature is consistent with the clinical complexity of this condition. Safe DKA management involves a sequence of time-sensitive decisions: recognizing the condition, performing an initial assessment, interpreting blood gas and electrolyte results, selecting appropriate fluid therapy, determining the timing of insulin initiation, correcting potassium abnormalities, monitoring glucose, and repeatedly assessing neurological status. Therefore, theoretical knowledge alone is insufficient; learners must integrate changing clinical and laboratory information within a coherent management framework (1, 7, 16).

Simulation enables learners to rehearse this sequence of decisions in a safe environment where predictable errors can be experienced, analyzed, and corrected. Its main value in DKA education is not merely improving knowledge but integrating clinical reasoning, treatment calculations, prioritization, guideline adherence, and team communication. Larson-Williams et al. found that multistage interprofessional simulation improved DKA-management knowledge among pediatric residents and nursing staff. The partial decline in learning observed at follow-up further emphasized the need for periodic practice and structured refresher training (3).

Findings from in situ simulation and quality-improvement initiatives suggest that DKA errors do not arise solely from individual knowledge deficits. Inadequate physician–nurse communication, unclear role allocation, delays in medication preparation, ambiguous orders, limited access to equipment or protocols, and weaknesses in patient-transfer pathways may all compromise guideline implementation (5, 20, 21). Training in DKA management should therefore move beyond an individual-focused model and involve pediatric residents, emergency physicians, nurses, and, where feasible, clinical pharmacists. Such interprofessional approaches may support the development of shared mental models, closed-loop communication, crisis-resource management, and explicit task allocation.

A systematic review by Thim et al. reported that simulation-based team training in pediatric emergencies may improve the delivery of time-critical actions and adherence to clinical guidelines. However, heterogeneity across interventions, risk of bias, and limited assessment of patient outcomes constrain definitive conclusions regarding effects on clinical outcomes in children (22). Simulation should therefore be considered one component of a broader competency-development and patient-safety program rather than a stand-alone substitute for real clinical experience.

4-2. Virtual Reality as a Complementary Modality

VR offers important potential for standardizing learning experiences, enabling independent and repeatable practice, and providing flexible access to educational content. These features may be particularly valuable for low-frequency, high-risk, and time-sensitive scenarios, such as DKA and adrenal crisis. In a systematic review and meta-analysis, Kyaw et al. found that VR-based education was associated with improved cognitive skills among healthcare professionals compared with conventional teaching; however, evidence for changes in clinical behavior, cost-effectiveness, and patient outcomes remained limited (4).

Studies focusing more specifically on DKA have also suggested that VR may improve learners' confidence, problem-solving, and educational outcomes (14, 15). Nevertheless, these findings were largely obtained in educational settings, often assessed short-term outcomes, and in some cases relied on self-reported measures. VR should therefore not be viewed as a complete replacement for high-fidelity manikin-based simulation or interprofessional training. Manikin-based simulation is generally better suited to practicing technical skills, observing physiological changes, responding to complications, and coordinating team-based care. VR and virtual patients, by contrast, may be particularly useful for individual practice, algorithm review, interpretation of clinical data, and repetition of decision pathways.

A blended model is therefore defensible. Learners may first use VR or virtual patients to practice DKA algorithms, interpret blood gas and electrolyte findings, and rehearse individual decisions. They can then progress to manikin-based or in situ simulation to practice communication, task allocation, leadership, and responses to evolving clinical deterioration. Such an approach places technology in the service of learning objectives rather than treating technology itself as the objective of the educational program.

A review by Lie et al. identified barriers to implementing VR in health professions education, including the absence of appropriate standards, inadequate infrastructure, challenges in content development and updating, cost, requirements for technical support, and limited organizational support (24). Accordingly, VR implementation in Iran should be based on educational needs assessment, context-appropriate technology selection, development of Persian-language content, faculty and user training, and feasibility and cost evaluation.

4-3. Cognitive Load and Scenario Design

The management of pediatric endocrine emergencies, particularly DKA, requires simultaneous processing of multiple data streams: clinical signs, dehydration severity, blood gas results, glucose values, electrolyte disturbances, neurological status, and response to treatment. From a cognitive-load perspective, poorly designed educational activities may introduce unnecessary demands and reduce learners' capacity for clinical reasoning. In contrast, staged scenario design, information tailored to learner level, critical-action checklists, and opportunities for repetition may facilitate information organization and maintain focus on key decisions (25).

This framework should be used as a foundation for instructional design rather than interpreted as evidence of effectiveness measured in every study included in this review. For example, a DKA scenario for novice learners may initially focus on recognizing the condition and sequencing essential actions. For more advanced learners, dynamic potassium changes, declining consciousness, suspected cerebral edema, communication breakdowns, or unavailability of essential medications can be incorporated. This progressive approach aligns scenario complexity with learner competence and intended educational outcomes.

4-4. Debriefing and Educational Quality

The findings of this review indicate that technology alone does not determine educational effectiveness. The quality of instructional design—and particularly structured debriefing—is central to meaningful learning. Debriefing transforms participation in a clinical scenario from a practical event into an opportunity for reflection, decision analysis, error identification, revision of mental models, and transfer of learning to similar situations. Best-practice standards in healthcare simulation emphasize that planned debriefing should be incorporated into all simulation-based educational activities.

The Promoting Excellence and Reflective Learning in Simulation (PEARLS) framework is one example of a structured debriefing approach that combines learner self-assessment, facilitated discussion, and directive feedback or teaching (26). Such frameworks may be especially useful for less experienced educators because they guide discussion away from simple performance judgments and toward exploration of decision-making processes, recognition of strengths, and identification of improvement strategies.

In DKA scenarios, debriefing should address three interconnected levels. At the clinical level, it should explore the rationale for fluid management, insulin timing, potassium monitoring, and neurological assessment. At the team level, it should address role allocation, closed-loop communication, leadership, and coordination. At the system level, it should consider access to medications, infusion pumps, essential laboratory testing, written protocols, and transfer pathways. This multilevel approach can help learners distinguish among individual errors, team-level failures, and organizational barriers.

4-5. In Situ Simulation and System Safety

An important implication of the present findings is that in situ simulation shifts the focus from assessing learners alone to evaluating the readiness of the broader care system. Conducted within the actual clinical environment, in situ simulation can identify latent safety threats before they affect real patients. These threats may include difficulty accessing medications, unavailable equipment, unclear responsibilities, poor team communication, delays in laboratory testing, and failures in referral or transfer processes.

A review by Grace and O'Malley found that in situ simulation in emergency medicine is valuable for identifying latent safety threats, with equipment- and communication-related problems among the most frequently reported findings (27). In DKA care, this approach may reveal potential errors in fluid choice or rate, insulin initiation, bicarbonate use, glucose monitoring, or coordination of patient transfer. Multifaceted programs combining simulation, performance feedback, and process improvement have also shown potential to improve adherence to guideline-based actions (5, 20, 21).

However, in situ simulation requires careful planning to avoid disrupting the care of actual patients. A safety review of in situ simulation in emergency settings found that, although the method is useful for identifying latent threats, reporting on its effects on real patients present in the same environment remains limited (28). Program design should therefore include coordination with shift leaders, selection of appropriate times, predefined scenario-stop procedures for clinical emergencies, and debriefing only after actual patient-care priorities have been addressed.

4-6. Implications for Iran

The need for contextually appropriate educational strategies is reinforced by the clinical burden of pediatric DKA in Iran. In a study from southern Iran, 57.1% of children with newly diagnosed type 1 diabetes mellitus presented with DKA. Younger age, rural residence, delayed diagnosis, and lower maternal educational level were associated with DKA at presentation (29). These findings highlight the importance of strengthening the capacity of healthcare teams to recognize and manage pediatric DKA promptly and safely, particularly in settings where delayed presentation and unequal access to specialized care may occur.

The findings of this review underscore the importance of contextual adaptation rather than simple transfer of technology. In Iran, the initial priority should be the development of standardized, Persian-language, guideline-based educational packages for DKA, severe hypoglycemia, and adrenal crisis. These packages should include measurable behavioral objectives, staged scenarios, pre-learning materials, critical-action checklists, facilitator guides, structured debriefing plans, and objective assessment tools.

During the first implementation phase, appropriately selected manikin-based simulation, tabletop simulation, or screen-based virtual patients may be used to teach individual decision-making and algorithm mastery. In the second phase, interprofessional and in situ simulation can be introduced to strengthen physician–nurse coordination, assess team readiness, and identify workflow failures. In the third phase, VR may be evaluated in selected centers as a complementary tool for repeated practice, distance education, and cognitive preparation.

A review by Kouijzer et al. on VR implementation in healthcare settings found that successful adoption requires barrier identification, a coherent multilevel strategy, stakeholder engagement, attention to users' needs, and organizational support (27). Thus, localization of VR in Iran should involve more than translating scenario language. It should reflect the actual availability of medications, fluids, emergency laboratory testing, transfer facilities, team composition, and local clinical protocols.

Implementation planning should also consider the workload, psychological well-being, and organizational support needs of healthcare personnel. A study conducted among Iranian healthcare workers during the COVID-19 pandemic identified substantial levels of anxiety, depression, and health anxiety and showed that workplace-related factors were associated with these outcomes (30). Although this evidence does not specifically evaluate simulation-based education or VR, it supports the practical importance of introducing educational innovations with adequate staffing, protected training time, accessible faculty support, and managerial commitment rather than as an additional uncompensated burden for clinical staff.

Involving pediatric endocrinologists, emergency physicians, nurses, medical educators, clinical pharmacists, and information-technology specialists in scenario design and validation may improve content validity, feasibility, and local acceptability. This approach is consistent with the findings of Sohrabi et al., who reported growing use of simulation in Iranian health professions education and emphasized the need to strengthen intervention design and outcome evaluation (8).

4-7. Research Gaps

First, standardized scenarios for pediatric adrenal crisis, severe hypoglycemia, HHS, thyroid storm, and CAH-related hyperkalemia should be developed and validated. The dominance of DKA in the literature should not result in educational neglect of less frequent but high-risk emergencies.

Second, future research should move beyond self-reported outcomes and assess objective indicators, including OSCE performance, time to critical actions, accuracy of fluid and medication administration, checklist adherence, quality of team communication, learning retention, and system readiness.

Third, fair comparisons are needed among VR, high-fidelity manikins, virtual patients, and blended educational models. These comparisons should examine not only educational outcomes but also cost, feasibility, learner needs, and the suitability of each modality for individual versus team-based skills.

Fourth, future studies should investigate the transfer of learning from simulation to clinical practice and patient-related outcomes. A review by Zendejas et al. found that simulation-based education, compared with no intervention or non-simulation instruction, was associated with small-to-moderate benefits in patient outcomes; however, studies assessing direct patient outcomes were substantially fewer than those assessing educational outcomes (31). This evidence gap is particularly important in pediatric endocrine emergencies, where critical events are relatively infrequent and evaluation of hard clinical outcomes is challenging.

4-8. Limitations

This narrative review has several limitations. Heterogeneity in learner populations, educational technologies, settings, scenario types, and assessment instruments limited direct comparison of findings and precluded quantitative estimation of effect sizes. In addition, the retrieved literature was predominantly focused on DKA, with substantially fewer data available for other pediatric endocrine emergencies, particularly thyroid storm and HHS.

A considerable proportion of included studies relied on short-term and self-reported outcomes, such as satisfaction, confidence, and perceived learning. Evidence regarding long-term skill retention, transfer to real clinical practice, cost-effectiveness, and patient outcomes was more limited. Furthermore, published and retrievable Iranian evidence specifically addressing simulation or VR for pediatric endocrine emergency education was sparse. Therefore, the recommendations proposed for Iran should be interpreted as contextually adapted implications of international evidence rather than as conclusions drawn from a large body of Iran-specific studies.

5- CONCLUSION

This structured narrative review indicates that clinical simulation and VR are complementary approaches for training in pediatric endocrine emergency management. High-fidelity manikin-based and interprofessional simulation are particularly suited to practicing clinical decision-making during dynamic conditions, responding to complications, team communication, and crisis-resource management. In situ simulation can support learner training while also identifying performance gaps and latent safety threats in the real clinical environment. VR and virtual patients offer substantial potential for standardized, repeatable, individual practice in clinical decision-making.

Current evidence most strongly supports these interventions in pediatric DKA education. However, the predominance of DKA should not prevent the development of educational scenarios for adrenal crisis, severe hypoglycemia, CAH-related hyperkalemia, HHS, and thyroid storm. Future research should extend beyond satisfaction and confidence measures to assess objective performance, accuracy of treatment decisions, guideline adherence, teamwork, learning retention, system readiness, and child-related outcomes.

For Iran, developing locally adapted, Persian-language, guideline-based educational packages for DKA, severe hypoglycemia, and adrenal crisis represents a practical starting point. Such packages should include staged scenarios, critical-action checklists, structured debriefing, interprofessional education, and objective assessment tools. A phased implementation strategy—beginning with appropriate manikin-based simulation or lower-cost virtual patients, followed by expansion of in situ training and evaluation of VR in selected centers—may provide a realistic path toward safe, sustainable, and evidence-informed pediatric endocrine emergency education.

6- AUTHORS' CONTRIBUTIONS

Study conception or design: HK, SP; Data analyzing and draft manuscript preparation: HK, and SP; Critical revision of the paper: HK; Supervision of the research: HK and SP; Final approval of the version to be published: HK, and SP.

7- CONFLICT OF INTEREST: None.

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