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DIGITAL TOOLS AND VIRTUAL PATIENT SIMULATIONS IN PEDIATRIC HYPERTENSION TRAINING: A COMPREHENSIVE REVIEW OF EDUCATIONAL STRATEGIES AND OUTCOMES

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Abstract

Background. Pediatric hypertension is sufficiently common to require routine training, but it is often missed because blood pressure measurement in children is technically demanding and is not consistently emphasized in clinical education. Digital learning tools, virtual patients, telesimulation, virtual reality, and artificial intelligence-based simulators may help learners practise decision-making in a safe setting.

Objective. This review aimed to summarize recent evidence on digital tools and virtual patient simulations relevant to pediatric hypertension training, with attention to educational strategies, **outcomes, and practical application.**

Materials and methods. A narrative review was performed using an attached database of 18 papers published mainly after the COVID-19 pandemic. Exact title duplicates were checked before analysis; 18 unique sources were retained. The papers were grouped into four themes: pediatric hypertension education, digital learning tools, virtual patients for clinical reasoning, and pediatric simulation or telesimulation.

Results. The evidence shows clear educational gaps in pediatric blood pressure measurement and hypertension management. Short educational sessions improved knowledge, attitude, and practice scores from low or moderate levels to higher post-training levels. Virtual patient tools and digital simulations improved clinical reasoning, data gathering, case management and learner confidence in many studies. Pediatric telesimulation and virtual reality programs were feasible after COVID-19 and were associated with high learner satisfaction, better knowledge or practical skills, and improved team-based learning.

Conclusion. There is limited direct research on virtual patient simulation specifically for pediatric hypertension. However, related evidence supports a structured training model that combines digital modules, virtual cases, feedback, debriefing, and objective assessment. Future studies should test pediatric hypertension-specific virtual patient scenarios and measure diagnostic accuracy, correct blood pressure classification, management decisions, and long-term retention.

Keywords: pediatric hypertension; blood pressure measurement; digital learning; virtual patient; telesimulation; virtual reality; medical education; clinical reasoning.

Introduction

Pediatric hypertension is no longer considered a rare problem. It is linked with obesity, kidney disease, endocrine disorders, cardiovascular risk and hypertension in adulthood. It is also frequently silent, which means that correct blood pressure measurement and interpretation are essential parts of pediatric training. Current evidence shows that pediatric hypertension affects approximately 3%-5% of children in the United States, yet many affected children are not diagnosed or do not receive recommended follow-up care [1].

Training in pediatric hypertension has several specific challenges. Learners must select the correct cuff size, measure blood pressure correctly, interpret values by age, sex and height, identify stage 1 and stage 2 hypertension, recognize secondary causes, and decide when follow-up, ambulatory monitoring, laboratory tests, referral or urgent care is needed. These steps are more complex than adult blood pressure interpretation. Educational gaps remain even among medical students and pediatric physicians. In one recent study, many students and physicians reported limited experience with pediatric blood pressure measurement, and baseline knowledge and practice scores were inadequate before an educational session [2].

The COVID-19 pandemic accelerated the use of digital learning in medical education. Clinical placements were interrupted, face-to-face simulation was restricted, and educators needed safe ways to provide patient care experience. This created strong interest in digital cases, interactive simulators, telesimulation and virtual reality. These tools allow learners to repeat cases, make decisions without risk to real patients and receive feedback. For pediatric hypertension, such tools can be especially valuable because many training programs do not provide enough repeated exposure to children with elevated blood pressure.

Virtual patients are computer-based clinical cases that allow learners to collect history, interpret findings, request investigations and choose management. They can be text-based, screen-based, conversational, voice-driven or immersive. Systematic reviews show that virtual patient tools can support clinical reasoning, especially when they are integrated into the curriculum and linked with clear learning goals [3-5]. This makes them relevant for training in pediatric hypertension, where reasoning depends on accurate measurement, risk recognition and stepwise decisions.

The aim of this review was to analyze evidence from recent literature on digital tools and virtual patient simulations that can inform pediatric hypertension training. The review focuses on educational strategies, outcomes, strengths, limitations and practical recommendations for building pediatric hypertension-specific training modules.

Materials and Methods

This article is a narrative review based on a database of 18 full-text publications provided for analysis. The database included articles on pediatric hypertension education, digital learning tool development, virtual patients, artificial intelligence-based virtual patient simulation, telesimulation, virtual reality, pediatric emergency simulation, pediatric cardiology simulation and machine learning for pediatric hypertension prediction.

Before writing the review, the database was screened for exact title duplicates. No exact duplicates were identified after title normalization, and all 18 papers were retained. The evidence was then organized into four analytical groups: (1) pediatric hypertension training needs and system-level barriers; (2) digital tools and prediction models for hypertension-related education; (3) virtual patient tools for clinical reasoning and consultation skills; and (4) pediatric telesimulation and virtual reality as models for teaching high-risk or low-frequency pediatric situations.

The review extracted information on study design, target learners, intervention type, educational outcomes, and relevance to pediatric hypertension training. The analysis was not intended as a formal meta-analysis because the included studies differed widely in design, target population, and outcome measures. Instead, the goal was to synthesize practical lessons for the development of pediatric hypertension training programs.

Results

1. Educational need in pediatric hypertension

Two papers directly addressed pediatric hypertension as an educational or clinical systems problem. HyperChildNET described a European multidisciplinary network created to improve research, prevention, diagnosis and knowledge exchange in pediatric blood pressure measurement and management. The network was developed because high blood pressure in youth is still under-recognized despite its life-course importance. This supports the need for structured training and shared educational tools [6].

Zaidi et al. examined parent needs and health system barriers in pediatric hypertension detection. The study reported that pediatric hypertension affects 3%-5% of children in the United States, but only about one quarter are diagnosed and many do not receive recommended follow-up care. Parents and clinicians described limited understanding of pediatric blood pressure, uncertainty about elevated readings and barriers to continued care. These findings show that training should include communication with families, follow-up planning and explanation of risk [1].

Sedik et al. provided the most direct evidence on educational gaps. The study included medical students and pediatric physicians and assessed attitude, knowledge and practice related to pediatric blood pressure measurement and hypertension. At baseline, average scores were low to moderate, but after an educational awareness session, attitude, knowledge and practice scores improved substantially. This indicates that even short, focused teaching can improve pediatric hypertension competence and should be built into medical curricula [2].

2. Digital tools and data-driven learning

Puncher et al. described the development of digital learning tools in medical education after the COVID-19 pandemic. One of the tools was an interactive case-based game related to hypertension. The work is important because it shows how educators, clinicians and technical teams can build practical digital tools through iterative development. For pediatric hypertension, the same model can be adapted to cases on correct blood pressure measurement, classification and referral decisions [7].

Simoes et al. studied machine learning and transfer learning for prediction of hypertension in a pediatric population. Although this paper is focused on prediction rather than teaching, it is relevant because it shows how digital risk models may support decision-making. In education, such models can be used as teaching aids to help learners understand risk factors, compare model outputs with clinical judgment and discuss the limits of automated prediction [8].

Digital tools should not be treated as simple slide replacements. The reviewed literature suggests that strong digital education requires active decisions, immediate feedback and repeated practice. A pediatric hypertension module should therefore ask learners to choose cuff size, repeat abnormal readings, interpret percentile-based values, identify possible secondary hypertension and plan follow-up rather than passively read information.

3. Virtual patients and clinical reasoning

Virtual patient simulation has strong relevance for pediatric hypertension because the diagnosis is often made through sequential reasoning. Learners must combine history, examination, blood pressure technique, percentile interpretation, and risk factors. In a study on virtual patients for clinical reasoning, learners worked through diagnostic and management decisions and received automated feedback. The authors concluded that virtual patient simulation can support reasoning when it is connected to the clinical task being taught [9].

Plackett et al. systematically reviewed virtual patient educational tools for clinical reasoning. Nineteen experimental studies were included. Eleven studies reported a positive effect, four reported no significant effect and four reported mixed results. Improvements were more consistent for data gathering, diagnostic ideas and patient management than for broad problem-solving. This is highly relevant to pediatric hypertension because correct diagnosis depends on case-specific data gathering and management steps [3].

Garcia-Torres et al. reviewed conversational virtual patients and found that they may improve history taking, clinical reasoning and learner satisfaction, especially when interactions feel realistic. Faferek et al. added that virtual patients are more useful when they are well integrated into curricula rather than used as isolated add-ons. Together, these papers suggest that pediatric hypertension virtual cases should be part of a planned course with pre-briefing, feedback, debriefing, and assessment [4,5].

Tyrrell et al. compared a web-based artificial intelligence-driven virtual patient simulator with actor-based simulation for consultation skills. This type of simulator is relevant for pediatric hypertension because learners must explain elevated blood pressure to parents, discuss lifestyle changes and address anxiety about medications or referral. Artificial intelligence-based systems can provide repeated practice, but they still require careful content control and validated assessment [10].

4. Pediatric telesimulation and virtual reality

Yang et al. described a telesimulation elective created during the COVID-19 pandemic to provide medical students with pediatric patient care experience. Sixteen sessions were conducted with 48 students, and 90% of students reported increased comfort with pediatrics and improved knowledge or skills. This supports telesimulation as a feasible way to teach pediatric scenarios when direct clinical access is limited [11].

Leung et al. implemented a North American pediatric emergency medicine simulation curriculum using the Virtual Resus Room, a low-resource distance telesimulation platform. The study showed that a virtual simulation environment can standardize access to pediatric emergency cases across training sites. McCarthy et al. then compared this virtual approach with in situ simulation, providing evidence for evaluating virtual methods against traditional simulation rather than assuming equivalence [12,13].

Nomura et al. studied emotional outcomes in pediatric emergency telesimulation. Emotional response is important because simulation can cause stress, and learner confidence is part of the educational effect. For pediatric hypertension training, this matters in scenarios such as hypertensive urgency, suspected secondary hypertension or family counseling after repeated elevated readings [14].

Ulumbekova and Kildiyarova evaluated an interactive pediatric simulator during distance learning. The simulator included virtual patient dialogue, physical examination, laboratory and instrumental tests, and treatment decisions. Students who used the simulator showed better objective structured clinical examination performance than controls. This design is directly adaptable to pediatric hypertension cases [15].

Virtual reality was also represented in several pediatric studies. Ring et al. [16] used virtual reality simulation in interprofessional pediatric cardiology education and found that participants considered the environment useful for pediatric education. Keicher et al. reported knowledge gains and positive learning experiences after a pediatric emergency virtual reality scenario. Kim et al. [18] developed a virtual reality nursing simulation for pediatric pneumonia care and used pre-post testing, usability assessment, and qualitative feedback. These studies show how virtual reality can support pediatric case practice, even when the clinical topic differs from hypertension [17].

5. Educational outcomes and assessment approaches

The included studies used several outcome measures: knowledge tests, self-reported confidence, attitude and practice scores, clinical reasoning measures, objective structured clinical examination scores, learner satisfaction, usability, emotional response and team performance. For pediatric hypertension, these outcomes should be translated into specific indicators: correct cuff selection, correct repeated measurement, correct use of pediatric blood pressure tables, recognition of stage 2 hypertension, identification of red flags for secondary causes, appropriate counseling and follow-up planning.

One important finding across the literature is that satisfaction alone is not enough. Many learners enjoy virtual and digital tools, but educational value should be measured by knowledge, reasoning, behavior, and long-term retention. The systematic reviews of virtual patients emphasize the need for validated assessment tools and case-specific measures [3,4]. Pediatric hypertension training should therefore use both subjective and objective outcomes.

Table 1. Main educational functions of digital tools for pediatric hypertension training

Training function	Possible digital format	Outcome to measure	Key evidence base
Blood pressure measurement	Interactive module or virtual case	Correct cuff choice and repeated measurement	Sedik et al. [2]
Diagnosis and staging	Virtual patient with branching decisions	Correct classification and referral choice	Plackett et al. [3]; Garcia-Torres et al. [4]
Risk recognition	Data-driven case or prediction model	Identification of obesity, kidney disease and red flags	Simoes et al. [8]
Emergency management	Telesimulation or virtual room	Time-sensitive decisions and team communication	Leung et al. [12]; McCarthy et al. [13]
Family counseling	Conversational virtual patient	Clear explanation and shared follow-up plan	Tyrrell et al. [10]; Zaidi et al. [1]

Discussion

The reviewed literature shows that pediatric hypertension training can benefit from digital and simulation-based methods, but the evidence is still indirect. Only a small part of the database addressed pediatric hypertension itself. Most evidence came from broader studies on virtual patients, digital learning, pediatric simulation and pediatric emergency education. This is not a weakness of the review; rather, it identifies a clear research gap.

A practical training model for pediatric hypertension should be built around the learner's clinical task. First, a short digital module can teach blood pressure measurement, cuff size, positioning, repeated readings and percentile interpretation. Second, a virtual patient can present a child with an elevated reading and require the learner to collect history, check risk factors, interpret values and decide on follow-up. Third, telesimulation can be used for urgent cases, such as severe hypertension with headache, seizures, kidney disease or suspected endocrine causes. Fourth, a communication scenario can train learners to explain the diagnosis and follow-up plan to parents.

The strongest educational value of virtual patients is the opportunity to make decisions repeatedly. This is useful for pediatric hypertension because learners often know the definition but fail at the practical steps. A well-designed virtual case can force the learner to repeat measurement, look for secondary causes, use appropriate tables and choose a management plan. Feedback should be immediate and specific. Debriefing should explain why a decision was right or wrong.

Virtual reality and telesimulation are most useful when the scenario requires teamwork, urgency or environmental realism. Pediatric hypertension is often outpatient, but severe hypertension can present in emergency or hospital settings. A virtual room can train team communication, monitoring, medication choices and escalation. However, virtual reality should not be used only for novelty. It should be selected when immersion adds value beyond a screen-based case.

The studies also show important limits. Some interventions had small samples, short follow-up and mainly self-reported outcomes. Some virtual patient reviews found mixed effects, and several studies noted the need for validated assessment. For pediatric hypertension, future research should measure practical outcomes: correct blood pressure classification, recognition of stage 2 hypertension, correct management steps, referral decisions and retention after several months.

Another important issue is equity. Digital tools can widen access if they are low-cost, mobile-friendly and easy to update. They can also create barriers if learners have limited internet access or if platforms require expensive equipment. For many settings, a simple virtual patient module with branching decisions and feedback may be more realistic than high-cost virtual reality. Therefore, the best approach is not a single technology but a matched strategy: simple tools for knowledge and reasoning, and higher-fidelity simulation for complex team-based situations.

Conclusion

Digital tools and virtual patient simulations provide a promising direction for pediatric hypertension training. The direct evidence specific to pediatric hypertension is still limited, but the related literature shows strong potential for improving knowledge, clinical reasoning, practical skills, confidence and access to standardized pediatric cases.

A comprehensive training program should combine short digital lessons, pediatric hypertension virtual patients, feedback, debriefing, and objective assessment. The core content should include correct blood pressure measurement, interpretation by pediatric standards, risk factors, secondary causes, management decisions, and family counseling. Future studies should test pediatric hypertension-specific virtual cases using validated outcomes and longer follow-up.

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