

Artificial Intelligence in Clinical Medical Training: Current Applications and Future Directions

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Abstract: Artificial intelligence (AI) technologies are profoundly transforming contemporary clinical medical education, catalyzing a paradigm shift from traditional experience-based instruction to precise, personalized and immersive learning. This paper systematically examines key application scenarios and representative practices of AI in clinical training, highlights major challenges, and outlines future development directions. The analysis underscores three principal domains in which AI advances clinical education: virtual patient and clinical environment simulations, personalized adaptive learning pathways, and the modeling of clinical reasoning and decision-making. Evidence demonstrates that AI-driven tools can significantly enhance the efficiency and quality of medical training. Nevertheless, critical barriers including algorithmic transparency, data privacy protection and ethical governance-continue to hinder large-scale adoption. In the foreseeable future, the deep integration of AI into clinical medical training depends on standardized curricula, innovative simulation technologies, and robust ethical frameworks, which together will foster clinical competencies aligned with the evolving demands of intelligent healthcare.

Keywords: Artificial Intelligence; Clinical Medical Training; Virtual Patients; Personalized Learning; Medical Education Ethics

1. Introduction

The core objective of clinical medical training is to cultivate competent physicians with solid theoretical foundations, advanced practical skills, and strong decision-making abilities[1]. Traditional apprenticeship models, together with training methods based on standardized patients and simulation centers, have played an indispensable role in the development of medical

education. However, these approaches face significant limitations: qualified mentors are scarce and overburdened, training costs remain high, the performance of patients is difficult to standardize and quantify, and complex or rare clinical scenarios are often challenging to replicate. More importantly, traditional methods struggle to provide timely, objective and personalized feedback, leading to slow learning progress among trainees and limiting the scalability of individualized instruction[2].

In recent years, the rapid advancement of AI, natural language processing, computer vision, and virtual reality (VR) has introduced a new paradigm for addressing these challenges[3]. AI is increasingly integrated into diverse dimensions of clinical medical training, encompassing the development of realistic virtual patients, real-time data-driven guidance in surgical simulators, personalized and adaptive learning pathways, and the simulation of complex, multi-role clinical decision-making environments[4]. These applications no longer treat AI as a mere auxiliary tool but rather position it as a super coach capable of understanding context, reasoning, and providing intelligent, continuous learning support.

Research has shown that AI-driven training systems can analyze learners' performance data, knowledge mastery and decision-making processes to generate dynamic competency maps. Based on these maps, the systems can deliver customized learning content and exercises, enabling a fundamental shift from uniform, one-size-fits-all instruction to genuinely individualized learning. In virtual patient encounters, AI can simulate patients with diverse social backgrounds and personality traits, dynamically responding to learners' queries to assess both communication and clinical reasoning skills[5]. In surgical simulations, AI can monitor key metrics such as instrument trajectories and tissue damage in real time, providing quantitative feedback with precision exceeding that of human evaluators[6].

Despite its promising prospects, the deep integration of AI into clinical medical training still faces several challenges, including technological reliability, data privacy and security protection, algorithmic transparency and fairness, and the effective implementation of optimal human-machine collaboration in educational models. This paper aims to systematically review current AI applications in clinical medical training, analyze the challenges involved, and explore future development directions, offering both academic insights and practical guidance for innovation in medical education. We begin by outlining the fundamental theories and technological foundations supporting AI applications in medical education. Subsequently, we perform an in-depth analysis of representative domestic and international cases, focusing on core scenarios including clinical reasoning and decision-making simulation, surgical and procedural skills training, and personalized adaptive learning. Finally, we critically examine existing challenges and limitations, offer perspectives on future directions, and aim to provide academic insights as well as practical guidance to advance the intelligent transformation of medical education.

2. Key Applications of AI in Clinical Training

2.1 Virtual Patients and Clinical Environment Simulation

In clinical medical training, AI applications in virtual patients and clinical simulation environments primarily enable the creation of highly realistic interactive scenarios, offering medical students and healthcare professionals safe, repeatable training platforms that enhance clinical decision-making and procedural skills[7].

In the domain of virtual patients, traditional case-based medical learning has largely relied on static text descriptions, whereas AI-driven virtual patients introduce dynamic interactivity, making the learning process more closely resemble real clinical encounters. The Baichuan Intelligence team, in developing the medical large model Baichuan-M2[8], created an innovative virtual clinical world. These virtual patients not only possess symptoms and medical histories derived from real clinical records but also incorporate social attributes such as MBTI personality types and cultural backgrounds. This

enables dynamic, natural conversations with AI physicians, with responses shaped by personality traits (e.g., introversion or extroversion) and contextual concerns (e.g., sensitivity to medical costs), thereby rigorously testing and enhancing medical students communication skills. Similarly, the Agent Hospital system[9] developed by the Institute for AI Industry Research (AIR) at Tsinghua University represents a recent frontier in this field. Powered by multi-modal large models, it simulates the entire clinical workflow from triage and registration, through diagnostic testing, diagnosis and treatment recommendations, to follow-up visits. Notably, in the MedQA benchmark test based on the United States Medical Licensing Examination, it achieved a diagnostic accuracy of 96% for both virtual and real-symptom patients, comparable to the clinical expertise accumulated by human physicians over many years.

AI has facilitated multi-scenario simulations in clinical simulation environments, ranging from surgical procedures to emergency decision-making. A research team at McGill University employed the NeuroVR virtual reality neurosurgical simulator[10], enabling medical students to perform tumor resections in an immersive environment. The system uses AI to monitor trainees' operations in real time and generate error data. Combined with human instructors' guidance i.e., AI-enhanced personalized instruction significantly reduces operational errors while improving instrument handling precision and tissue preservation. Similarly, STEP-VR[11] is an AI-driven virtual reality emergency training system that allows medical students to simulate the management of acute coronary syndrome in an immersive environment. Through interactive virtual patients and real-time feedback, it enhances learners' clinical decision-making skills and knowledge acquisition.

Notably, in surgical disciplines that rely heavily on manual dexterity, integrating AI with VR and haptic feedback technologies has created highly immersive training environments. In collaboration with industry partners, Ruijin Hospital, affiliated with Shanghai Jiao Tong University School of Medicine, developed the Vision-Audio-Touch Interactive Feedback Metaverse Intelligent Virtual Surgery System[12], China's first clinical procedure simulation training system. This platform enables physicians to operate on virtual patients

via a surgical robot console. Employing haptic feedback technology, the system precisely reproduces the tactile sensations of surgery, providing an experience comparable to operating on real patients. Additionally, it offers over ten surgical training modules, along with personalized course customization and assessment functions, effectively helping young physicians rapidly identify and correct operational errors while gaining practical experience.

The core advantage of AI-simulated patients and environments is their ability to realistically and safely reproduce high-risk, low-probability clinical scenarios. As Academician Ya-Qin Zhang has emphasized, early use of these tools in training can help students acquire knowledge more quickly and effectively, while mitigating concerns about potential harm to real patients.

2.2 Personalized Adaptive Learning

In clinical medical training, AI-based personalized and adaptive learning relies on analyzing each learner's study data, knowledge mastery, and operational habits. Based on this analysis, customized learning pathways and content can be generated, enabling a shift from uniform, one-size-fits-all instruction to truly individualized education.

In practical applications, AI systems can construct dynamic knowledge and competency maps, forming the basis for delivering precisely tailored learning resources to individual trainees. For example, the First Clinical College of Huazhong University of Science and Technology developed the UNION-AID intelligent course[13] in infectious diseases, in which the system delineates four core competencies and twelve sub-competencies, covering eighty-six knowledge points and seventy-seven key questions. The AI engine embedded in the course generates clinical cases and assists in lesson preparation based on this structured knowledge, while also functioning as an intelligent learning companion. Across diverse simulated clinical scenarios, it guides students in autonomous exploration and provides personalized learning support based on their interactions and performance.

In skills training, personalized adaptive learning has also demonstrated remarkable effectiveness. The First Affiliated Zhongshan Hospital of Dalian University implemented the nation's first AI-XR large-space medical teaching

application[14], capable of capturing and analyzing trainees' surgical operations and emergency drills in virtual environments in real time. The system automatically generates detailed personalized training reports, identifying each learner's strengths and areas for improvement, thereby overcoming the inefficiencies of traditional one-size-fits-all training models. Additionally, the Third Clinical College of Jilin University (Bethune Medical College) introduced the AI Agent and Knowledge Base[15] for Clinical Medical Education, designed to generate individualized learning pathways via an AI platform. By continuously analyzing students' operational data, it provides instructors with precise teaching feedback, supporting the development of medical professionals in a more personalized and targeted manner.

Taken together, these practices demonstrate that AI-driven personalized and adaptive learning through accurate assessment of learners' progress, tailored learning pathways and real-time feedback effectively fosters students' self-directed learning. It enables learners to progress at a pace suited to their individual needs, providing critical support for cultivating the next generation of medical professionals.

2.3 Simulation Training in Clinical Reasoning and Decision-making

AI-based training in clinical reasoning and decision-making implemented via virtual patients, clinical decision support systems, alongside intelligent diagnostic assistants is playing an increasingly critical role in enhancing these competencies.

Harvard Medical School's Dr. CaBot system[16] generates detailed differential diagnoses and explains the underlying reasoning like an expert physician, performing at a level comparable to human experts in case discussions in the *New England Journal of Medicine*[17]. The value of systems such as Dr. CaBot lies in simulating expert-level clinical reasoning processes. They enumerate potential diagnoses and articulate reasoning pathways in detail, including how different possibilities are weighed, key information is identified and misleading clues are excluded. This is crucial for training medical students and junior physicians to develop systematic diagnostic thinking frameworks. Moreover, the emergence of such systems indicates that AI can handle diagnostically

challenging cases with misleading cues, providing a powerful tool for advanced medical education.

In China, the Zhongda Hospital affiliated with Southeast University has developed a virtual patient system based on large language models (LLMs) to support community-level physicians[18]. It simulates the entire clinical consultation process, allowing trainees to perform history-taking, physical examinations, and treatment planning through interaction with the virtual patient. Studies show that students using this system achieved significantly higher scores in theoretical assessments of clinical reasoning and in systematic, evidence-based thinking, compared with those trained under traditional problem-based learning, demonstrating AI's potential to enhance clinical reasoning skills.

Furthermore, the Rensselaer Polytechnic Institute, together with other institutions, developed a multi-role AI agent-based clinical reasoning training system[19]. Beyond AI-driven virtual patients, the system incorporates virtual instructors and examiners. Drawing on a repository of rare and complex cases, it offers both learning and assessment modes to comprehensively train medical students and young physicians in clinical diagnostic and therapeutic competencies, reducing reliance on standardized patients and limited faculty resources in traditional medical education.

Clinical Time Machine Abstractive Health[20] is an AI simulator built on real historical medical records, providing physicians with a risk-free diagnostic sandbox for training diagnostic skills. Its core concept is to create a safe practice environment that enables physicians to engage in diagnostic and therapeutic decision-making, with direct observation of potential consequences, all without real-world risk. This sandbox experience is particularly valuable for transforming theoretical knowledge into clinical intuition and practical expertise.

Additionally, research at Yale University on AI-based Clinical Decision Support Systems (AI-CDSS)[21] has focused on optimizing collaboration between AI and physicians. Their findings indicate that physicians' trust in and effective use of AI depend not only on its accuracy but also on its presentation-as a tool or team member-and on the transparency of its decision-making processes. These insights provide direct guidance for the seamless and

efficient integration of AI into real-world clinical workflows.

The core advantage of AI-based clinical reasoning and decision-making simulation training is its ability to provide a dynamic, adaptive learning experience. These systems can adjust case difficulty and feedback priorities in real time based on learners' performance, enabling personalized instruction. A hybrid human AI collaboration model is considered the most effective approach: AI delivers objective data and unlimited practice opportunities, while human instructors provide higher-level guidance and inspiration[22]. These AI tools are positioned as educational aids, designed to empower rather than replace traditional teaching. Successful implementation depends on integration with scientifically grounded curriculum design, aiming to cultivate learners' critical thinking and decision-making skills in complex clinical contexts.

3. Challenges and Ethical Considerations

3.1 Technical limitations

Despite AI's tremendous potential in clinical medical training, its technological limitations cannot be overlooked. Foremost among these is the black box problem: studies indicate that 85% of medical educators cannot explain the basis of algorithmic scoring, undermining trust in and acceptance of AI-generated evaluations[23]. Additionally, AI-generated content may contain inaccuracies or misinformation, a limitation closely tied to AI's inability to perform inductive reasoning. In the high-stakes domain of medical education, the dissemination of erroneous information may lead to serious downstream consequences.

Another critical technological challenge concerns data privacy and security. AI systems often require collecting and analyzing large volumes of student and patient data, raising critical questions about safeguarding sensitive information. Experts suggest that in medical education, third-party data storage may be used to protect student information, and that AI systems should collect only the data necessary for their intended tasks, fully complying with relevant privacy regulations.

3.2 Ethics and Educational Equity

The application of AI in clinical medical training has raised a series of ethical concerns.

Overreliance on generative AI tools may hinder the development of learners' creativity and critical thinking. Medical education is not merely the transmission of knowledge and skills, but also the cultivation of clinical reasoning and professional attitudes, excessive technologization may erode essential aspects of humanistic care.

Educational equity is another critical concern. High-quality AI-based medical education tools often require expensive hardware and substantial computational resources, potentially exacerbating disparities in access. Data indicate that VR laboratory penetration in low-income regions is only 12%, whereas high-income countries benefit from significantly better digital infrastructure and interdisciplinary collaboration. This digital divide may further widen the global gap in the quality of medical education[24].

4. Future Directions and Outlook

4.1 Curriculum Design and Training Framework Development

For the deep integration of AI into clinical medical training, constructing standardized and structured curricula and training frameworks is imperative. Effective AI-based medical training should adopt a phased, learner-centered approach that aligns with the evolving needs of medical education. Specifically, an AI medical education framework may follow a three-stage strategy: first, establishing cognitive connections between machine learning and traditional biostatistical methods. Second, analyzing algorithmic decision-making through clinical case studies. Third, cultivating students' ability to critically evaluate AI technologies. This progressive training model effectively enhances the core competencies future physicians need to engage with medical AI, including technical validation, identification of data bias and evidence-based clinical decision-making.

4.2 Advanced Intelligent Simulation and Assessment Technologies

AI-based medical training technologies will continue to evolve and deepen. In the future, virtual patients and simulated clinical environments are expected to advance toward multi-modal interaction and haptic feedback. For example, research is exploring wearable devices with tactile sensors to simulate the sensation of human skin, greatly enhancing the realism of

clinical examination training. Simultaneously, patient-specific modeling using digital twin technology enables the creation of simulated environments closely mirroring real clinical cases.

In terms of assessment, the next generation of AI systems will move beyond evaluating technical competencies alone to encompass multidimensional evaluations of clinical communication, teamwork and even medical professionalism. A diversified assessment framework centered on cross-competencies should be developed, particularly focusing on students' ability to integrate multidisciplinary knowledge to solve real-world clinical problems.

4.3 Ethical Standards and Interdisciplinary Collaboration

Another key direction for AI in clinical medical training is the establishment of robust ethical guidelines and interdisciplinary collaboration mechanisms. As AI applications in medical education deepen, it is essential that these tools are developed, implemented, and used in accordance with ethical standards, without bypassing human judgment. Academic journals and accreditation bodies should require educational programs to disclose AI usage and clearly define its appropriate role in the educational process.

Interdisciplinary collaboration will be a critical driving force for innovation in AI-based medical training. Many universities in China and abroad are leveraging their disciplinary strengths to implement integrated medical engineering training models, aiming to cultivate hybrid medical professionals who understand clinical needs and possess expertise in AI technologies. Such cross-disciplinary, integrative training models are expected to become the mainstream of future medical education.

5. Conclusion

AI is profoundly reshaping the paradigm of clinical medical training, offering unprecedented opportunities to transform medical education. Through virtual patient simulations, personalized learning platforms and intelligent assessment systems, AI can substantially enhance the efficiency and quality of medical training, allowing students to gain broader clinical experience in a safe environment. Nevertheless, challenges such as technological transparency, data privacy, ethical standards and educational

equity must be addressed with caution.

Prospectively, the successful integration of AI into clinical medical education will depend on several key factors: the establishment of structured curricula, continuous innovation in simulation technologies, refinement of ethical frameworks and strengthening of interdisciplinary collaboration. Guided by technological advancement and humanistic values, AI promises to cultivate medical professionals with enhanced clinical competence, greater empathy for patients and a commitment to lifelong learning, ultimately contributing to the advancement of global healthcare.

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