EDITORIAL

Artificial Intelligence (AI) as a Catalyst for Orthopedic Residency Training

Adel Ebrahimpour MD [1,2]; Mohammadreza Dolikhani MD[1,2], Ghazaleh Shakibamaram MD[1,2]

1. Emergency Care Promotion Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran

2. Department of Orthopedic Surgery, Shohada-e Tajrish Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran.

Medical residents are among the most valuable human resources in healthcare, particularly within academic medical centers. Residency training is key to becoming a competent orthopedic surgeon; however, it is both time-consuming and costly. Limited access to professional mentorship and resources hampers efforts to enhance orthopedic treatment and reduce health disparities, especially in developing countries. [1] Meanwhile, artificial intelligence (AI) technologies are rapidly revolutionizing medical education in financially secure regions; however, their implementation in developing nations is constrained by financial, infrastructural, and technological obstacles. [2]

Despite these constraints, practical AI technologies can significantly enhance orthopedic residency training in resource-constrained environments. AI can facilitate the creation of large databases and registries in orthopedic institutions, promoting data-driven research and quality improvement initiatives. These registries facilitate tracking outcomes across broad patient populations and provide comprehensive datasets for developing machine learning models tailored to local patient demographics. [3,4]

Adaptive Learning

Leveraging these digital foundations, AI-driven adaptive learning platforms, integral to an innovative learning environment, deliver personalized educational pathways by analyzing individual resident performance. [5] This approach enhances skill acquisition, even in resource-constrained settings. These platforms can tailor content and assessments to the learner's needs, enhance the efficiency and effectiveness of orthopedic training programs, and assign residents to rotations that align most closely with their training needs.

Virtual Reality

Virtual reality (VR) simulations are validated for their efficacy in surgical training. [6] At the same time, they give residents a unique opportunity to work on rare or complex cases they might not encounter elsewhere. This will help them gain hands-on experience in a safe, replicable environment without expensive equipment.

Moreover, advanced surgical skill evaluation systems that use machine learning algorithms on recorded surgical procedures can provide residents with accurate, timely feedback. This reduces reliance on ongoing in-person supervision and enhances training quality, particularly in institutions with limited access to qualified instructors. [7]

The integration of AI into VR is changing surgical education by providing individualized, dynamic instruction. AI-driven VR systems assess learner movements in real time using machine learning algorithms to provide actionable feedback. These tools evaluate surgical precision, speed, and adaptability to issues such as hemorrhage and anatomical changes, making training more realistic and successful. [8] Research indicates that VR simulations with AI-based feedback improve surgical outcomes. A study found that AI feedback improves student performance more effectively than instructor-led education. [9] Unlike traditional in-person supervision, AI-based feedback provides regular, quantitative performance metrics for more objective judgments. [9]

Corresponding Author: Ghazaleh Shakibamaram, Emergency Care Promotion Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran, Department of Orthopedic Surgery, Shohada-e Tajrish Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran.

Email: ghshakiba2000@gmail.com

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However, AI and VR adoption in surgical training faces obstacles. High development costs, vast datasets for AI training, and unpredictable processes may require ongoing system changes. AI engineers and surgical professionals must work together to improve these systems.

Integration of AI and Practice

Large language models (LLMs), such as GPT-5 and Gemini 2.5, can address training issues for orthopedic residents and improve surgical outcomes, even in resource-constrained environments. LLMs provide accurate decision-support tools during training and review under faculty supervision. Diagnostic and prognostic tools driven by LLMs, when incorporated into residency training, function as effective educational instruments. [8] These tools assist residents in diagnosing fractures by emphasizing subtle indicators on X-rays and CT scans, recommending subsequent actions during simulations, and explaining their reasoning during debriefs.[10,11,12] Additionally, some studies indicate that LLMs can assess postoperative risks, including ICU admission, complications, mortality, and readmission.[13,14]

However, the adoption of AI faces significant challenges. Key barriers include high computing demands and persistent costs that restrict equal access, while unclear regulations create uncertainty about responsibility and safety standards.

Protecting patient data, obtaining informed consent, and preventing cyberattacks are essential issues, further complicated by inquiries regarding data ownership. A convoluted curriculum and insufficient faculty competency hinder implementation, while AI models operate as "black boxes," producing opaque analyses that users must understand to avoid errors. [15,16]

Launching experimental efforts through interdisciplinary collaboration among healthcare professionals, engineers, and policymakers may offer a cost-efficient approach to enhance resident education and surgical outcomes.

Conclusion

AI, including large language models, virtual reality, and adaptive learning systems, presents significant potential to improve orthopedic residency training, especially in settings with limited resources. Addressing difficulties such as high costs, regulatory ambiguity, data privacy concerns, faculty preparedness, and the opaque nature of AI is essential. Strategic, interdisciplinary collaboration can facilitate the successful implementation of new technologies while ensuring educational quality and patient safety.

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Adel Ebrahimpour MD [1,2]
Mohammadreza Dolikhani MD [1,2]
Ghazaleh Shakibamaram MD [1,2]

1. Emergency Care Promotion Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran

2. Department of Orthopedic Surgery, Shohada-e Tajrish Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran

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