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Mini Review

Digital Twins in Healthcare: A New Frontier for Personalized Medicine

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Abstract

Digital twin technology virtual replicas of physical systems has emerged as a transformative innovation in healthcare. By integrating patient-specific data with computational models, digital twins enable real-time monitoring, predictive analytics and personalized treatment planning. This article reviews advances in digital twin applications across cardiology, oncology, orthopedics, and dentistry. Literature published between 2020 and 2026 was systematically analyzed using PubMed, Scopus, and Google Scholar.

Results demonstrate that digital twins improve diagnostic accuracy, optimize surgical planning and enhance patient engagement. In cardiology, digital heart models predict arrhythmia risk and guide ablation therapy. Oncology applications include tumor growth simulations for personalized chemotherapy dosing. Orthopedic digital twins simulate joint biomechanics, aiding prosthesis design. Dentistry benefits from occlusal simulations and implant stress analysis.

Challenges include data integration, computational complexity and ethical concerns regarding patient privacy. Regulatory frameworks are evolving to ensure transparency and safety. The review concludes that digital twins represent a paradigm shift toward precision medicine, augmenting clinician expertise with computational foresight.

Keywords: *Digital Twins; Personalized Medicine; Artificial Intelligence; Healthcare Innovation; Predictive Analytics; Patient-Centered Care; Computational Modeling; Clinical Research*

Introduction

The concept of a digital twin originated in engineering, where virtual models replicate aircraft engines or industrial systems. In healthcare, digital twins extend this principle to human physiology, creating dynamic, patient-specific models that evolve with real-time data [1]. Unlike static electronic health records, digital twins continuously update, reflecting changes in lifestyle environment, and treatment response.

The integration of digital twins into healthcare represents a convergence of computational modeling, artificial intelligence and biomedical engineering. These systems allow clinicians to simulate disease progression, predict treatment outcomes and personalize interventions. The potential impact spans preventive medicine, chronic disease management and surgical planning.

Globally, adoption is accelerating. The European Union has invested heavily in digital twin research through Horizon Europe programs, while the United States FDA has begun exploring regulatory frameworks for digital health technologies [2,3]. Asia, particularly China and Japan, is advancing digital twin applications in cardiology and oncology.

Methods

A systematic review was conducted following PRISMA guidelines. Databases searched: PubMed, Scopus, Google Scholar. Keywords: digital twin healthcare, personalized medicine, predictive analytics. Boolean operators combined terms (e.g., digital twin AND cardiology, digital twin OR oncology).

Inclusion criteria

- Peer-reviewed articles (2020-2026).
- Clinical applications of digital twins.
- Quantitative outcomes reported.

Exclusion criteria

- Purely theoretical or engineering studies without clinical relevance.
- Non-English publications.

Data extraction focused on domain, application, algorithm type, accuracy metrics and ethical considerations.

Results

Cardiology

Digital heart models simulate electrophysiology, predicting arrhythmia risk and guiding ablation therapy. Studies report improved procedural success rates and reduced recurrence [4]. Digital twins also model hemodynamics predicting heart failure progression and optimizing drug therapy [5].

Oncology

Tumor growth simulations enable personalized chemotherapy dosing. AI-driven twins predict tumor response reducing toxicity and improving survival outcomes [6]. Radiation oncology benefits from digital twins that simulate dose distribution and tissue response [7].

Orthopedics

Digital twins of joints simulate biomechanics, aiding prosthesis design and rehabilitation planning. Patient-specific models reduce implant failure rates and improve surgical outcomes [8].

Dentistry

Occlusal simulations and implant stress analysis enhance prosthodontic planning. Digital twins predict restoration longevity and optimize material selection [9].

Discussion

Clinical impact

Digital twins enable predictive medicine, shifting healthcare from reactive to proactive. They allow clinicians to test interventions virtually before applying them to patients, reducing risk and improving outcomes.

Ethical and regulatory considerations

Challenges include data privacy, algorithmic bias and clinician accountability. Explainable AI frameworks are essential to maintain trust. Regulatory bodies such as FDA and EU MDR are developing guidelines for digital twin validation [10,11].

Educational implications

Clinicians must acquire literacy in computational modeling and data interpretation. Medical curricula should integrate digital twin concepts to prepare future practitioners [12-20].

Future Directions

Emerging trends include multimodal twins integrating genomic, proteomic and behavioral data. Quantum computing may accelerate simulations, enabling real-time decision support. The ultimate goal is empathetic intelligence machines that understand not only data but also human emotion.

Conclusion

Digital twins are redefining personalized medicine by enabling real-time, patient-specific simulations. They augment clinician expertise, improve outcomes and foster patient engagement. Ethical stewardship and interdisciplinary education will ensure their responsible integration into healthcare.

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