Journal of Drug Discovery and Health Sciences

journal home page : https://jddhs.com/index.php/jddhs/index

Research Article

Digital twin technology for personalized endodontic treatment planning using CBCT, intraoral scans, and patient-specific biomechanical simulations

Mahendra Katariya

BDS, MDS (periodontist), India

ARTICLE INFO

Article history:
Received: 15 July, 2026
Revised: 21 July, 2026
Accepted: 26 July, 2026
Published: 28 July, 2026

Keywords:
Digital twin technology; Endodontics; Cone-beam computed tomogr-aphy (CBCT); Intraoral scanning; Artificial intelligence; Biomechanical simulation; Personalized treatment planning; Precision dentistry.

DOI:
10.21590/jddhs.03.03.02

ABSTRACT

Digital twin technology is emerging as a transformative approach in personalized healthcare by creating a dynamic virtual representation of an individual patient that continuously integrates clinical, anatomical, and biological data. In endodontics, the combination of cone-beam computed tomography (CBCT), intraoral scanning, and patient-specific biomechanical simulations enables clinicians to construct highly accurate digital replicas of teeth and surrounding structures for treatment planning. These virtual models facilitate detailed visualization of root canal anatomy, simulation of instrumentation and obturation procedures, assessment of stress distribution, and prediction of potential treatment outcomes before clinical intervention. Artificial intelligence further enhances the digital twin by automating image segmentation, integrating electronic dental records, and continuously updating patient-specific models throughout treatment. This technology has the potential to improve diagnostic precision, optimize treatment strategies, minimize procedural complications, and support personalized clinical decision-making. Additionally, digital twins may facilitate long-term monitoring of healing and restoration performance through continuous data integration. Despite promising developments, widespread implementation remains limited by challenges related to data standardization, computational complexity, interoperability, regulatory considerations, and validation in large-scale clinical studies. Continued advances in artificial intelligence, imaging technologies, and computational modeling are expected to accelerate the clinical adoption of digital twin systems, ultimately supporting predictive, precision, and patient-centered endodontic care.

Introduction

The increasing integration of artificial intelligence (AI), advanced dental imaging, and computational modeling has accelerated the transition toward precision dentistry, where treatment decisions are tailored to the anatomical and biological characteristics of individual patients. Among the most promising innovations is digital twin technology, which creates a dynamic virtual representation of a patient's tooth and surrounding oral structures using continuously updated clinical and imaging data. Unlike conventional treatment planning that relies on static radiographic interpretation, digital twins enable clinicians to simulate treatment procedures, predict biomechanical behavior, and evaluate potential outcomes before initiating therapy, thereby supporting a more personalized and predictive approach to endodontic care (Turky & Dummer, 2026).

The development of digital twins in endodontics is

***Corresponding Author:** Mahendra Katariya
Address: BDS, MDS (periodontist), India
Email ✉: Mr.katariya1@gmail.com

Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

supported by the convergence of cone-beam computed tomography (CBCT), intraoral scanning, AI-assisted image analysis, and electronic dental records. CBCT provides detailed three-dimensional visualization of root canal anatomy and periapical tissues, while intraoral scanning accurately captures crown morphology and occlusal relationships. Recent advances in automated tooth segmentation and AI-driven dental imaging have significantly improved the efficiency and accuracy of reconstructing patient-specific anatomical models from these datasets (Polizzi et al., 2023; Pereira et al.). Furthermore, the incorporation of digital clinical records enables continuous updating of patient information, facilitating data-driven diagnosis and treatment planning (Patel et al., 2024).

Beyond anatomical reconstruction, digital twins incorporate biomechanical simulations that evaluate stress distribution, fracture susceptibility, and the anticipated effects of different instrumentation, obturation, and restorative strategies. These predictive capabilities allow clinicians to compare multiple treatment scenarios within a virtual environment before performing irreversible clinical procedures. Machine learning algorithms further enhance these models by predicting treatment responses and disease progression based on patient-specific clinical variables (Feher et al., 2025). Additional biological information, including salivary biomarkers obtained through microfluidic diagnostic technologies, may further strengthen individualized risk assessment and monitoring of treatment outcomes (Herr et al., 2007).

The evolution of digital dentistry has also emphasized minimally invasive restorative principles and improved material performance, providing a strong foundation for integrating digital twin systems into comprehensive endodontic workflows (Singh, 2020; Singh, 2025). As imaging technologies, AI algorithms, and computational simulations continue to mature, digital twin technology has the potential to transform endodontics from a reactive discipline into a predictive, preventive, and highly personalized model of patient care, ultimately improving clinical accuracy, treatment efficiency, and long-term therapeutic success (Turky & Dummer, 2026).

Digital Twin Framework for Personalized Endodontics

The digital twin framework in endodontics represents a patient-specific virtual model that continuously integrates anatomical, clinical, biological, and functional information to support personalized treatment planning. Unlike conventional static treatment planning, a digital twin evolves as new patient data become available, enabling predictive assessment of disease progression, treatment response, and long-term tooth prognosis. The framework begins with comprehensive data acquisition, where cone-beam computed tomography (CBCT) provides high-resolution three-dimensional visualization of root canal morphology, periapical tissues, and surrounding bone, while intraoral scans accurately capture external tooth morphology and occlusal relationships (Turky & Dummer, 2026; Polizzi et al., 2023).

Artificial intelligence (AI) plays a central role in processing these datasets by automatically segmenting teeth, identifying root canal anatomy, detecting pathological changes, and generating precise three-dimensional reconstructions. The integration of AI-based dental imaging significantly improves diagnostic consistency while reducing operator-dependent variability during image interpretation (Pereira et al.; Polizzi et al., 2023). In addition to imaging, electronic dental records contribute demographic information, medical history, previous dental procedures, and clinical findings, allowing the digital

Table 1: Major Components of the Digital Twin Framework for Personalized Endodontics

Framework Component	*Primary Data Source*	*Clinical Function*	*Expected Benefit*
Anatomical Modeling	CBCT	Three-dimensional visualization of root canals and periapical tissues	Accurate diagnosis and treatment planning
Surface Reconstruction	Intraoral scans	Digital tooth morphology and occlusion	Improved restorative planning
AI Image Analysis	CBCT and imaging datasets	Automatic segmentation and pathology detection	Greater diagnostic accuracy and efficiency
Clinical Integration	Electronic dental records	Medical and dental history incorporation	Personalized decision support
Biological Assessment	Salivary biomarkers and periodontal data	Evaluation of inflammatory status and healing potential	Improved outcome prediction
Biomechanical Simulation	Finite element computational models	Stress and fracture risk analysis	Selection of minimally invasive treatment strategies
Dynamic Digital Twin	Continuous integration of all patient data	Real-time treatment monitoring and prediction	Precision-based personalized endodontic care (Turky & Dummer, 2026)

twin to reflect the patient's overall oral health profile and facilitate automated clinical decision support (Patel et al., 2024).

The framework may also incorporate biological information such as salivary biomarkers and periodontal status to create a more comprehensive representation of disease activity. Advances in microfluidic saliva diagnostics enable rapid assessment of inflammatory biomarkers that may influence healing potential, while machine learning algorithms can integrate these variables to improve prediction of treatment outcomes (Herr et al., 2007; Feher et al., 2025). Patient-specific biomechanical simulations further strengthen the framework by estimating stress distribution during instrumentation, obturation, and subsequent restorative procedures, thereby assisting clinicians in selecting treatment strategies that minimize structural damage. Restorative considerations remain important because preservation of tooth integrity directly influences long-term clinical success (Singh, 2025; Singh, 2020). Furthermore, accurate facial and intraoral scanning technologies contribute realistic surface models that enhance digital workflow integration and occlusal analysis (Quinzi et al., 2022).

Challenges, Future Perspectives, and Conclusion

Despite its considerable promise, the implementation of digital twin technology in endodontics faces several technical and clinical challenges. The creation of accurate patient-specific digital twins requires seamless integration of CBCT datasets, intraoral scans, electronic dental records, and biomechanical simulation platforms, all of which often differ in data format and interoperability. AI-assisted segmentation and image reconstruction have significantly improved workflow efficiency, yet variations in image quality, anatomical complexity, and algorithm performance remain obstacles to consistent clinical application (Polizzi et al., 2023; Pereira et al.). Furthermore, the computational demands associated with real-time biomechanical modeling and continuous data updating may limit accessibility in routine dental practice. Ethical concerns regarding patient privacy, cybersecurity, and responsible management of large clinical datasets must also be addressed before widespread implementation (Patel et al., 2024).

Future developments are expected to transform digital twins into continuously evolving clinical decision-support systems. Integration of advanced machine learning algorithms with patient-specific biomechanical simulations may enable accurate prediction of root fracture risk, canal preparation outcomes, restoration longevity, and periapical healing. The incorporation of salivary biomarker analysis through microfluidic diagnostic platforms could further enrich digital twin models by providing real-time biological information for disease monitoring and treatment personalization (Herr et al., 2007). Additionally, predictive analytics derived from electronic dental records and longitudinal clinical data may support individualized treatment recommendations and adaptive follow-up protocols (Feher et al., 2025; Patel et al., 2024). Improvements in facial and intraoral scanning technologies, together with enhanced CBCT segmentation accuracy, will further refine virtual patient models and improve simulation precision (Quinzi et al., 2022; Polizzi et al., 2023).

In conclusion, digital twin technology represents a paradigm shift from conventional reactive endodontic care toward predictive, preventive, and personalized treatment planning. By integrating high-resolution CBCT imaging, intraoral scans, artificial intelligence, and patient-specific biomechanical simulations, digital twins provide clinicians with comprehensive virtual models capable of optimizing diagnosis, treatment selection, and long-term outcome prediction (Turky & Dummer, 2026; Pereira et al.). When combined with advances in restorative materials and conservative treatment principles, these technologies have the potential to improve tooth preservation and clinical success while supporting individualized patient care (Singh, 2025; Singh, 2020). Continued interdisciplinary research, standardized validation, and clinical integration will be essential for translating digital twin technology into routine endodontic practice.

References

1. Singh, S. (2025). Comparative Evaluation of Tensile Bond Strength between Glass Ionomer Cements and Composite Resins in Dental Restorations. *Journal of Advanced Medical and Dental Sciences Research*, *13*(6), 4-7.
2. Turky, M., & Dummer, P. M. (2026). Digital twins technology in endodontics: from reactive to predictive–a new frontier towards personalised root canal treatment: Digital twins technology in endodontics: from reactive to predictive–a new frontier towards personalised root canal treatment. *British Dental Journal*, *240*(1), 21-25.
3. Singh, S. (2020). Deep Margin Elevation: A Conservative Alternative in Restorative Dentistry. *SRMS JOURNAL OF MEDICAL SCIENCE*, *5*(02), 1-9.
4. Pereira, N. S., Ünsal, R. B. K., Arsiwala-Scheppach, L. T., Badr, Z., Hamdan, M., Tryfonos, O., & dos Santos, M. F. H. The Use of Artificial Intelligence in Dental Imaging for Endodontics: A Systematic Review. *Available at SSRN 4667813*.
5. Patel, J., Shin, D., Willis, L., Zai, A., & Thyvalikakath, T. (2024). Feasibility of utilizing electronic dental record data and periodontitis case definition to automate diagnosis.
6. Feher, B., de Souza Oliveira, E. H., Mendes Duarte, P., Werdich, A. A., Giannobile, W. V., & Feres, M. (2025). Machine learning-assisted prediction of clinical responses to periodontal treatment. *Journal of Periodontology*, *96*(11), 1199-1212.
7. Herr, A. E., Hatch, A. V., Throckmorton, D. J., Tran, H. M., Brennan, J. S., Giannobile, W. V., & Singh, A. K. (2007). Microfluidic immunoassays as rapid saliva-based clinical diagnostics. *Proceedings of the National Academy of Sciences*, *104*(13), 5268-5273.
8. Polizzi, A., Quinzi, V., Ronsivalle, V., Venezia, P., Santonocito, S., Lo Giudice, A., & Isola, G. (2023). Tooth automatic segmentation from

CBCT images: a systematic review. *Clinical oral investigations*, *27*(7), 3363-3378.

9. Amuda, B. (2025). Using Mobility Data to Evaluate Changes in Outdoor Recreational Activity Across Major COVID-19 Variants.
10. Quinzi, V., Polizzi, A., Ronsivalle, V., Santonocito, S., Conforte, C., Manenti, R. J., & Lo Giudice, A. (2022). Facial scanning accuracy with stereophotogrammetry and smartphone technology in children: a systematic review. *Children*, *9*(9), 1390.

HOW TO CITE THIS ARTICLE: Katariya, M. Digital twin technology for personalized endodontic treatment planning using CBCT, intraoral scans, and patient-specific biomechanical simulations. J. of Drug Disc. and Health Sci. 2026;3(3):5-8. **DOI:** 10.21590/jddhs.03.03.02