REVIEW ARTICLE

Revolutionizing Nano-Orthodontic Diagnosis and Treatment through AI-Enhanced CBCT Image Analysis: New Frontiers in Deep Learning

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ABSTRACT

This review paper explores the transformative integration of artificial intelligence (AI) and nanotechnology in orthodontics, focusing on how AI-enhanced cone-beam computed tomography (CBCT) image analysis is revolutionizing diagnosis and treatment. The paper details advances in digital imaging, emphasizing the impact of deep learning algorithms, such as Convolutional Neural Networks and Vision Transformers, which automate image interpretation, improve diagnostic accuracy, and enable personalized treatment strategies. It also highlights the role of nanomaterials in improving orthodontic components through enhanced biocompatibility, antimicrobial protection, and smart functionalities. The convergence of AI and nanotechnology marks a paradigm shift in precision orthodontics, though challenges such as data privacy, algorithmic bias, and clinical integration remain. Addressing these challenges is essential to achieve safe, effective, and widely adopted deployment of these technologies in clinical practice.

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INTRODUCTION

Orthodontics has experienced a profound transformation driven by rapid advances in digital technology, shifting from conventional analog methods to sophisticated digital platforms. The adoption of tools such as digital radiography and, most notably, CBCT has revolutionized 3D craniofacial analysis, enabling clinicians to visualize complex anatomical structures with unprecedented clarity [1]. This leap in imaging technology has not only improved diagnostic accuracy but also expanded the scope of orthodontic applications, including implant dentistry, endodontics, and temporomandibular joint assessment [2-5]. The integration of AI further amplifies these capabilities, automating image interpretation, detecting pathologies, and facilitating personalized treatment planning. Together, these innovations have redefined orthodontic workflows, enhancing both clinical outcomes and patient-centered care [4].

The convergence of nanotechnology and AI marks a new frontier in orthodontic diagnosis and treatment, offering transformative potential for precision and efficiency [6-8]. AI-driven deep learning algorithms excel at processing vast datasets, enabling rapid analysis of dental images and the development of highly customized treatment strategies [3, 9]. When combined with

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nanotechnology, these tools promise even greater accuracy in diagnosis and therapeutic interventions. However, alongside these advancements come significant challenges, including ethical considerations, data privacy concerns, and the need for human oversight to ensure the reliability and safety of AI-driven decisions. Addressing these issues is essential to harness the full potential of these technologies, ensuring that the future of orthodontics remains both innovative and responsible.

FUNDAMENTALS OF CBCT IMAGING IN ORTHODONTICS

Orthodontics has evolved remarkably with the introduction of digital technologies that have improved accuracy, efficiency, and patient-focused care. The transition from conventional diagnostic tools to digital systems such as digital radiography and CBCT has enhanced clinical outcomes by enabling more precise evaluation and streamlined treatment planning [10-12]. AI has further redefined orthodontic practice by supporting detailed cephalometric analysis, automated image interpretation, and predictive simulations for treatment outcomes. These AI-driven advancements, combined with emerging technologies like 3D printing, have facilitated the development of highly customized treatment appliances and improved patient experience through tailored therapeutic strategies [13-15].

CBCT imaging now serves as a central element in orthodontics, offering detailed three-dimensional visualization of craniofacial structures far superior to traditional two-dimensional images. Its application extends to implant dentistry, endodontics, and temporomandibular joint assessment, providing accurate diagnostics while maintaining low radiation exposure [10, 16]. The integration of AI with CBCT systems enables automated detection of pathologies, elevating both diagnostic accuracy and clinical efficiency. As nanotechnology converges with AI, orthodontics is entering a new phase of innovation, where nanoscale precision and intelligent data analysis merge to enhance treatment outcomes. Continued progress in these fields promises transformative applications, though it also calls for careful consideration of ethical implications, data governance, and clinical validation to ensure safe and effective integration into practice.

EMERGENCE OF ARTIFICIAL INTELLIGENCE IN IMAGE-BASED ORTHODONTIC DIAGNOSIS

The integration of AI, particularly machine learning (ML) and deep learning (DL), into orthodontics is transforming diagnostic and treatment planning processes, especially through image-based analysis using CBCT. These technologies automate the interpretation of complex datasets, enhancing diagnostic accuracy, streamlining workflows, and improving patient outcomes [3, 6, 17]. ML and DL frameworks enable the processing of multimodal data, including CBCT images, with high precision and efficiency. Key algorithms such as Convolutional Neural Networks (CNNs) are widely employed for tasks like automatic landmark detection and tooth segmentation, while U-Net architectures and emerging Vision Transformers are being explored to further refine the segmentation and contextual analysis of dental structures in CBCT images [18, 19].

AI-driven tools have significantly advanced orthodontic diagnostics, achieving accuracy rates of 88–92% in cephalometric analysis and reducing both human error and time consumption [7]. Automated landmark detection and tooth segmentation facilitate precise anatomical assessments and support detailed morphological evaluations, aiding in the diagnosis of dental conditions and the customization of treatment plans [3, 18, 19]. AI systems also contribute to predicting treatment outcomes, further enhancing patient care and clinical efficiency. However, challenges such as limited data availability, algorithm transparency, and ethical concerns persist, highlighting the need for standardized data practices, regulatory compliance, and ongoing human oversight to ensure safe and effective integration of AI into orthodontic practice [17, 19, 20]. Despite these hurdles, AI continues to offer transformative potential for personalized, accurate, and efficient orthodontic care.

NANO-ORTHODONTICS: BRIDGING THE MICROSCALE AND THE DIGITAL REALM

Nanomaterials have introduced significant advancements in orthodontic components by improving their functionality, durability, and biocompatibility. Nanocoatings applied to brackets and wires reduce friction during tooth movement, leading to greater treatment efficiency and patient comfort while enhancing resistance to wear and corrosion[21, 22]. Similarly, incorporating nanomaterials into orthodontic adhesives increases bonding strength and longevity, while nanoparticle-based coatings provide antimicrobial protection that helps prevent enamel demineralization and white spot lesions [21]. The integration of smart materials, such as shape memory alloys at the nanoscale, enables controlled and efficient orthodontic force application, resulting in faster, more predictable outcomes and improved overall treatment performance [23].

In addition to material innovation, nanotechnology plays a pivotal role in bone remodeling and regenerative therapy within orthodontics. Nanosensors and nanoelectromechanical systems allow real-time monitoring and modulation of orthodontic forces, optimizing bone remodeling processes. In regenerative applications, bioactive nanomaterials like nano-hydroxyapatite promote tissue repair and osseointegration of orthodontic devices [24, 25]. Furthermore, nanoscale characterization techniques, when paired with AI-enhanced CBCT imaging, provide highly detailed structural insights that refine diagnostic precision. The combination of AI-based mapping and high-resolution imaging enables accurate 3D visualization of craniofacial structures, facilitating personalized treatment strategies and predictive modeling, thereby advancing the future direction of nano-orthodontic diagnostics and therapy [25].

AI-ENHANCED CBCT ANALYSIS FOR PRECISION NANO-ORTHODONTICS

The integration of AI-enhanced CBCT analysis in precision nano-orthodontics represents a significant advancement in the field, offering personalized treatment options and improved diagnostic capabilities. This approach leverages the power of AI to analyze complex datasets, providing insights into patient-specific conditions and optimizing treatment outcomes. The following sections explore the integration of radiomic and nanomic data, AI-assisted detection of orthodontic conditions, and predictive analytics for treatment optimization.

AI technologies have significantly advanced the integration of radiomic and nanomic data, enabling a more comprehensive and precise approach to patient-specific orthodontic care. Radiomic data derived from CBCT scans provide detailed visualization of dental anatomical structures, while nanomic data reveal molecular and cellular information. This synergistic use of imaging and molecular-level data enhances the accuracy of orthodontic diagnosis and facilitates the development of highly individualized treatment plans that account for genetic, clinical, and lifestyle factors [26]. Consequently, this integration leads to improved patient outcomes and satisfaction by allowing orthodontists to tailor treatments more precisely to patient needs [27].

AI algorithms have demonstrated remarkable accuracy in detecting orthodontic issues such as root resorption and alveolar bone density assessment, both critical for optimal orthodontic treatment planning [28]. Deep learning approaches applied to CBCT images enable early identification of microstructural changes in dental tissues, thereby allowing the detection of complications like root resorption and bone density loss at nascent stages [29]. These AI-driven capabilities significantly enhance clinicians' ability to monitor treatment progression in real time, facilitating timely adjustments that minimize adverse outcomes and improve overall patient care [7].

AI-driven predictive analytics have revolutionized orthodontic treatment by enabling precise simulation of tooth movement trajectories, which allows orthodontists to anticipate treatment outcomes and optimize the sequence of interventions [3]. By leveraging historical treatment data alongside patient-specific factors, these AI models can forecast the most effective strategies, thereby reducing treatment duration and enhancing clinical efficiency [29]. Furthermore, this dynamic approach supports continuous treatment adjustments, ensuring therapies remain aligned with the patient's evolving condition and needs, ultimately minimizing risks and improving long-term results [28].

While AI-enhanced CBCT analysis offers numerous benefits for precision nano-orthodontics, challenges remain in areas such as data privacy, algorithmic bias, and the cost of technology implementation. Addressing these challenges is essential for the widespread adoption of AI in orthodontic practice. Additionally, ongoing research and development are needed to refine AI algorithms and expand their applications, ensuring that they continue to meet the evolving needs of orthodontic care.

DEEP LEARNING ARCHITECTURES AND HYBRID MODELS

The integration of deep learning architectures and hybrid models in nano-orthodontic diagnosis and treatment through AI-enhanced CBCT image analysis is a burgeoning field. This review explores the comparative performance of various deep learning models, the potential of multimodal data fusion, and example frameworks for automated CBCT interpretation in nano-orthodontic contexts. These advancements promise to revolutionize orthodontic diagnostics and treatment planning by enhancing accuracy, efficiency, and clinical outcomes.

CNNs have emerged as a dominant tool in the analysis of CBCT images within orthodontics, particularly excelling in tasks like image classification and segmentation. Their ability to accurately identify and extract dental features outperforms many traditional algorithms, facilitating automated and precise orthodontic diagnostics [30]. In parallel, Generative Adversarial Networks (GANs) contribute by synthesizing and augmenting CBCT images, which enhances image quality and diversifies datasets for more robust model training. Complementing these, Vision Transformers (ViTs) offer a novel approach by capturing global image features, thereby providing deeper insights alongside CNNs in medical imaging applications [31]. Moreover, ensemble models that combine multiple architectures, such as multi-channel ensembles, have achieved remarkable accuracies exceeding 93% in classifying skeletal malocclusions from CBCT scans, surpassing the performance of single-channel counterparts [32]. This synergy of advanced deep learning methods is paving the way for more accurate, reliable, and efficient orthodontic image analysis.

The integration of CBCT imaging with clinical data, including patient history and nano-scale structural information offers a powerful multimodal approach that significantly enhances the accuracy of orthodontic diagnostics and treatment planning [33]. By combining diverse data types, clinicians gain a more holistic understanding of the patient's condition, facilitating personalized and effective interventions. However, despite the promise of multimodal data fusion, several challenges remain. Issues related to data integration, standardization across diverse datasets, and the computational complexity of processing large-scale multimodal data must be addressed to enable seamless clinical application of these advanced technologies [19]. Overcoming these obstacles is essential to fully harness the potential of multimodal approaches in improving orthodontic care outcomes [32].

Deep learning has become a transformative force in orthodontic imaging, advancing the automated diagnosis and classification of dental conditions through CBCT image analysis. Contemporary models excel in accurately identifying and differentiating various dental structures and pathologies, significantly alleviating clinician workload [34]. These AI-driven frameworks also enable real-time diagnostic capabilities and personalized treatment planning, which are especially critical in the precision-demanding field of nano-orthodontics [19]. To foster transparency and clinical trust, explainable AI techniques such as Class-selective Relevance Mapping (CRM) have been employed, offering insights into the decision-making processes of these models [32]. Collectively, these advances enhance diagnostic accuracy, optimize treatment strategies, and support clinician confidence in deploying AI-assisted orthodontic care. The main clinical applications and comparative advantages of AI and nanotechnology in orthodontics are summarized in Table 1.

ETHICAL, CLINICAL, AND TECHNICAL CHALLENGES

The integration of AI-enhanced CBCT image analysis in nano-orthodontics presents a transformative potential for diagnosis and treatment, yet it also introduces several ethical, clinical, and technical challenges. These challenges encompass data quality, model bias, image privacy, integration barriers in clinical workflows, and the need for validation, regulatory compliance, and clinician training. Addressing these issues is crucial for the successful implementation of AI technologies in orthodontic practice.

In the field of orthodontics, the success of AI applications heavily depends on the availability of high-quality, standardized datasets. Robust training data are crucial to develop reliable AI models that provide accurate predictions and diagnoses [35]. However, a significant challenge is the presence of bias within AI systems caused by training on homogenous datasets, which can lead to poor performance for underrepresented populations and exacerbate healthcare disparities [36]. Furthermore, the use of patient information

Table 1. Major AI and nanotechnology advances in orthodontic diagnosis and treatment, AI in 3D dental imaging

Application/Technology	Main Functionality	Advantages	Reference
AI-Enhanced CBCT Image Analysis	Automated 3D diagnostics and treatment planning	Improved diagnostic accuracy, reduced workload	[6]
Deep Learning in Orthodontics (CNNs)	Image segmentation, landmark detection	High precision, real-time processing	[33]
Nano-Coated Orthodontic Brackets	Nanocoating of wires and brackets	Reduced friction, increased wear resistance	[19]
Smart Nanomaterials in Therapy	Shape-memory alloys, nanosensors	Controlled force, real-time monitoring	[21]
Hybrid Deep Learning Models (Ensembles)	Multimodal and multi-channel AI system	Enhanced accuracy in malocclusion classification	[30]

raises critical privacy concerns, necessitating strict adherence to regulations such as HIPAA and GDPR to maintain data confidentiality and ensure trust in AI-driven clinical tools [37]. Addressing these challenges by improving data diversity, quality, and privacy compliance is essential to realizing the full potential of AI in orthodontic care.

Despite the promising advancements of AI in orthodontics, its integration within clinical practice faces several significant challenges. One core obstacle is technological resistance, where clinicians may be hesitant to adopt new AI-driven tools due to their complexity and perceived threat to traditional workflows [35].Additionally, incorporating AI into existing clinical processes often disrupts established workflows and necessitates resource investment and extensive training to ensure smooth adaptation [37].Technical interoperability also remains a critical issue, as AI systems must be compatible and seamlessly integrate with a variety of dental technologies and software platforms already in use [38]. Overcoming these challenges is essential for the successful deployment of AI technologies that can transform orthodontic care and optimize patient outcomes.

For AI systems to be effectively integrated into orthodontic practice, rigorous validation processes are essential to ensure accuracy, reliability, and safety in clinical contexts. This includes extensive testing phases and continuous performance monitoring to uphold high standards. Moreover, navigating the evolving regulatory landscape is critical to maintain legal and ethical compliance, requiring adherence to current statutes and the flexibility to adapt as AI technologies advance [39]. Equally important is comprehensive clinician training that educates practitioners about AI functionalities, limitations, and best practices, fostering competent use and encouraging ongoing professional development to maximize the benefits of AI in orthodontics [40].

While AI-enhanced CBCT image analysis offers significant advancements in orthodontic diagnosis and treatment, it is essential to consider the broader implications of its integration. Ethical concerns, such as data privacy and model bias, must be addressed to ensure equitable and secure patient care. Additionally, overcoming clinical and technical barriers requires collaboration among stakeholders, including healthcare providers, policymakers, and AI developers, to create a supportive environment for AI adoption. By addressing these challenges, the orthodontic community can harness the full potential of AI to improve patient outcomes and advance the field.

CONCLUSION AND FUTURE HORIZONS: THE AI–NANOTECHNOLOGY NEXUS IN ORTHODONTICS

The integration of AI and nanotechnology stands to fundamentally transform orthodontics by enabling unprecedented levels of precision and personalization in diagnosis and treatment planning. AI-enhanced systems offer real-time guidance for nano-orthodontic treatments, utilizing vast datasets and predictive models to simulate tooth movement and dynamically adjust therapies, thereby improving outcomes and efficiency. Concurrently, smart nanomaterials embedded with sensors can continuously monitor tooth movement and oral health, with AI analyzing this data to optimize treatment adjustments. The vision of a fully digital, patient-specific orthodontic ecosystem is becoming increasingly viable, where digital models and simulations design customized appliances, streamlining the entire clinical workflow from diagnosis through treatment monitoring.

Key findings emphasize AI's role in enhancing diagnostic accuracy, cephalometric analysis, and patient monitoring, coupled with nanotechnology's contribution to real-time treatment efficacy and personalization. Together, AI-enhanced CBCT imaging and nanotechnologies offer a synergistic approach to redefine precision orthodontics by enabling detailed structural analysis and adaptive, evidence-based interventions. Future research must focus on refining AI algorithms, expanding interdisciplinary collaborations across AI, orthodontics, and nanotechnology fields, and tackling challenges such as data privacy, algorithmic bias, and cost constraints. While these innovations promise significant advancements, successful adoption will rely on addressing these complex issues, ensuring that the full transformative potential of AI and nanotechnology in orthodontic care can be achieved.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest related to the research, authorship, or publication of this manuscript. All authors have disclosed any financial or personal relationships that could potentially influence or bias the work presented.

REFERENCES

1. Manek P, Laddha R. The evolution of orthodontics: advancements, innovations, and transformative technologies. Acad J Med. 2022;5(2):11-7. https://doi.org/10.62245/ajm.v5.i2.3
2. Park JH. CBCT imaging in orthodontics. JSM. 2013;1(1002).
3. Thakur SM, et al. Transforming orthodontics with artificial intelligence: a comprehensive review. J Adv Dent Pract Res. 2024:1-9.
4. Abidin ZZ, et al. Treatment strategies in dentistry: core concepts and future issues. In: Handbook of Dental Education Technology. Springer; 2025. p. 1-35. https://doi.org/10.1007/978-981-97-0275-6_10-1
5. Solhmirzaei R, Noorinasab MG, Samiee A, Dehpagaee WSH, Hamid W, Tavakol O. Investigating the effect of dental implant treatment on mental health and quality of life. Int J Chem Biochem Sci. 2023;24(6):279-84.
6. Kayastha Y, et al. Machine minds, perfect smiles: the future of AI in orthodontics-a contemporary review. Int J Innov Sci Res Technol. 2025;10(9):304-10. https://doi.org/10.38124/ijisrt/25sep389
7. Bucur SM, Olteanu CD, Crişan IM. Artificial intelligence enhancing orthodontic diagnosis and treatment. Med Mater. 2025;5(1):29-36. https://doi.org/10.36868/MEDMATER.2025.05.01.29
8. Baghi S, et al. An assay on the antibacterial performance of Co doped ZnO nanoparticles in dental microbes. Nanomed Res J. 2023;8(2):210-7.
9. Tomášik J, et al. AI and face-driven orthodontics: a scoping review of digital advances in diagnosis and treatment planning. AI. 2024;5(1):158-76. https://doi.org/10.3390/ai5010009
10. Sandhu SK. Cone beam computed tomography in orthodontics. Saint's Int Dent J. 2017;3(1):1-3. https://doi.org/10.4103/sidj.sidj_1_18
11. Nasti S, et al. Advancing dental diagnostics: the significance of cone-beam computed tomography (CBCT) in modern dentistry. IP Int J Maxillofac Imaging. 2023;9:182-5. https://doi.org/10.18231/j.ijmi.2023.032
12. Meimandinezhad M, et al. Comparison of different surface treatment methods on flexural strength and elasticity modules of quartz and glass fiber-based posts: a narrative review. J Family Med Prim Care. 2022;11(12):7616-20. https://doi.org/10.4103/jfmpc.jfmpc_239_21
13. Singh D. Cone-beam computed tomography: a new era in clinical orthodontics. Int J Health Sci. 2021:411-27. https://doi.org/10.53730/ijhs.v5nS1.5677
14. Nervina JM. Cone beam computed tomography use in orthodontics. Aust Dent J. 2012;57:95-102. https://doi.org/10.1111/j.1834-7819.2011.01662.x
15. Huang Anderson T, Huang D. The use of cone beam computed tomography in orthodontics: a review. Radiology. 2012;44(1):20140282.
16. Thirunavukkarasu R, et al. CBCT in orthodontics: a boon for the millennial generation. Int J Health Sci. 2022(I):676-86. https://doi.org/10.53730/ijhs.v6nS1.4814
17. Fawaz P, El Sayegh P, Vande Vannet B. Artificial intelligence in revolutionizing orthodontic practice. World J Methodol. 2025;15(3):100598. https://doi.org/10.5662/wjm.v15.i3.100598
18. Płotka S, et al. Convolutional neural networks in orthodontics: a review. arXiv preprint arXiv:2104.08886. 2021.
19. Vinu M, et al. AI-driven innovations in orthodontics and periodontics: a comprehensive analysis. AI Insights Nucl Med. 2025:271-94. https://doi.org/10.4018/979-8-3373-1275-0.ch013
20. Kazimierczak N, et al. AI in orthodontics: revolutionizing diagnostics and treatment planning. 2023. [Journal not specified]. https://doi.org/10.20944/preprints202312.1259.v1
21. Hikmetnur D. The application of nanotechnology in orthodontics: current trends and future perspectives. 2023. [Journal not specified].
22. De Stefani A, et al. Application of nanotechnology in orthodontic materials: a state-of-the-art review. Dent J. 2020;8(4):126. https://doi.org/10.3390/dj8040126
23. Dakhale R, et al. Nanotechnology innovations transforming oral health care and dentistry: a review. Cureus. 2023;15(10). https://doi.org/10.7759/cureus.46423
24. Lekhadia DR. Nanotechnology in orthodontics-futuristic

approach. In: Dental Applications of Nanotechnology. Springer; 2018. p. 155-75. https://doi.org/10.1007/978-3-319-97634-1_9
25. Sharan J, et al. Applications of nanomaterials in dental science: a review. J Nanosci Nanotechnol. 2017;17(4):2235-55. https://doi.org/10.1166/jnn.2017.13885
26. Kapila S, et al. Connecting the dots towards precision orthodontics. Orthod Craniofac Res. 2023;26:8-19. https://doi.org/10.1111/ocr.12725
27. Almishkha SI, et al. Precision orthodontics in the digital era: AI, teledentistry, and 3D innovations for individualized treatment. J Angiother. 2023;7(1):1-8. https://doi.org/10.25163/angiotherapy.7110289
28. Guo X, Shao Y. AI-driven dynamic orthodontic treatment management: personalized progress tracking and adjustments-a narrative review. Front Dent Med. 2025;6:1612441. https://doi.org/10.3389/fdmed.2025.1612441
29. Lee SC, Hwang HS, Lee KC. Accuracy of deep learning-based integrated tooth models by merging intraoral scans and CBCT scans for 3D evaluation of root position during orthodontic treatment. Prog Orthod. 2022;23(1):15. https://doi.org/10.1186/s40510-022-00410-x
30. Płotka S, et al. Machine learning methods as an aid in planning orthodontic treatment on the example of cone-beam computed tomography analysis: a literature review. J Educ Health Sport. 2021;11(1):94-104. https://doi.org/10.12775/JEHS.2021.11.01.010
31. Shobayo O, Saatchi R. Developments in deep learning artificial neural network techniques for medical image analysis and interpretation. Diagnostics. 2025;15(9):1072. https://doi.org/10.3390/diagnostics15091072
32. Kim I, et al. Malocclusion classification on 3D cone-beam CT craniofacial images using multi-channel deep learning models. In: 42nd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC). IEEE; 2020. https://doi.org/10.1109/EMBC44109.2020.9176672
33. Chaudhary VK, Singh NP. Deep learning and machine learning techniques in dental disease detection and classification. 2025. [Journal not specified].
34. Fan W, et al. The application of deep learning on CBCT in dentistry. Diagnostics. 2023;13(12):2056. https://doi.org/10.3390/diagnostics13122056
35. Birje DA, et al. Integrating AI into orthodontics: opportunities and challenges-a systematic review. Int J Innov Sci Res Technol. 2025;10(7):3114-7. https://doi.org/10.38124/ijisrt/25jul1910
36. Allareddy V, et al. Call for algorithmic fairness to mitigate amplification of racial biases in artificial intelligence models used in orthodontics and craniofacial health. Orthod Craniofac Res. 2023;26:124-30. https://doi.org/10.1111/ocr.12721
37. Liu TY, et al. AI in dentistry: innovations, ethical considerations, and integration barriers. Bioengineering. 2025;12(9):928. https://doi.org/10.3390/bioengineering12090928
38. Verma SK, Bais DRS, Yadav PK. Impact of technology on orthodontic practice. J Dent Specialities. 2024;12(1). https://doi.org/10.18231/j.jds.2024.006
39. Pandey A, Sureja D, Kaldate S. The implications of AI in dentistry: revolutionizing patient care and clinical precision. Mathews J Dent. 2024;8(2):48. https://doi.org/10.30654/MJD.10048
40. Umer MF. Impact of artificial intelligence on oral health diagnostics. In: Innovation and Transformation of Public Health. IGI Global Scientific Publishing; 2026. p. 363-90. https://doi.org/10.4018/979-8-3373-1992-6.ch012