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REVIEW ARTICLE

Convergence of Artificial Intelligence and Nanomedicine in Prosthodontics, Orthodontics, and Endodontics: Toward Predictive, Personalized, and Regenerative Dental Care

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ABSTRACT

The convergence of artificial intelligence (AI) and nanomedicine is reshaping contemporary dental practice, offering a path toward predictive, personalized, and regenerative care in prosthodontics, orthodontics, and endodontics. AI techniques including machine learning, deep learning, and computer vision enhance diagnostic accuracy, support evidence-based treatment planning, and optimize patient management by integrating multimodal clinical and imaging datasets. In parallel, dental nanomedicine harnesses diverse nanoscale platforms such as inorganic and organic nanoparticles, nanocomposites, nanobiosensors, and nanorobotics to achieve targeted antimicrobial therapy, controlled drug delivery, and tissue regeneration at the molecular level. This review synthesizes current evidence on the standalone and synergistic use of AI and nanotechnologies in prosthodontics, where AI-driven CAD/CAM workflows and nanomaterials improve prosthesis design, fit, and durability; in orthodontics, where AI-guided outcome prediction and nano-enhanced appliances enable more efficient and aesthetic tooth movement; and in endodontics, where AI-based imaging analysis and nanoparticle-assisted disinfection and regeneration advance minimally invasive, biologically oriented treatments. We further highlight emerging paradigms in predictive modeling, AI-driven nano-therapeutics, and regenerative dentistry that integrate stem cells, nanoscaffolds, and bioinformatics to move from reparative toward true tissue reconstruction. Finally, the review critically discusses ethical, safety, and regulatory challenges including data privacy, algorithmic bias, nanotoxicology, and translational hurdles and outlines key research and policy priorities needed to responsibly implement AI–nanomedicine ecosystems in routine dental care.

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INTRODUCTION

The convergence of artificial intelligence (AI) and nanomedicine in dentistry is emerging as a transformative development with the potential to redefine prosthodontics, orthodontics, and endodontics. AI techniques such as machine learning and deep learning have already demonstrated improvements in diagnostic accuracy, treatment planning, and patient management across dental specialties [1, 2]. At the same time, nanomedicine introduces innovative materials and devices including nanobots and lab-on-a-chip systems that can refine clinical procedures, advance regenerative endodontics, and enhance prosthetic design [3, 4].

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These technologies are complementary: AI excels at processing large, complex datasets and building predictive models that identify risk factors and forecast treatment outcomes, while nanomedicine provides targeted, molecular-level interventions that improve therapeutic precision and tissue regeneration [5-7]. The synergy between data-driven decision-making and nanoscale therapeutics supports a shift from traditional, reactive dental care toward proactive, personalized strategies that prioritize prevention and long-term patient outcomes.

Despite these opportunities, successful integration requires overcoming several challenges. Key issues include data privacy and ethical considerations, the need for standardized clinical and technical protocols, significant investment in research and development, and training for dental professionals to adopt these advanced tools effectively [8, 9]. Addressing these barriers will be essential to translate the combined promise of AI and nanomedicine into routine clinical practice and meaningful improvements in oral healthcare[10].

ARTIFICIAL INTELLIGENCE IN DENTISTRY: CORE CONCEPTS AND CAPABILITIES

AI is increasingly becoming integral to dentistry, offering transformative capabilities in diagnostics, treatment planning, and patient management [11, 12]. The core concepts of AI in dentistry revolve around machine learning (ML), deep learning (DL), and computer vision, which are applied across various dental specialties to enhance precision and efficiency. These technologies are pivotal in improving diagnostic accuracy, optimizing treatment strategies, and personalizing patient care. However, despite their potential, there are limitations and challenges that need to be addressed for broader clinical adoption. The following sections delve into the specific applications and current roles of AI in dentistry, as well as the limitations faced by these technologies.

AI technologies, particularly convolutional neural networks (CNNs), have significantly improved the ability to diagnose dental pathologies such as caries, periodontal disease, and oral cancers. These tools provide more accurate and faster results, reducing diagnostic errors and increasing reliability [13, 14]. Artificial neural networks (ANNs) are used for predictive modeling in treatment planning, offering data-driven predictions of patient outcomes and enabling customized treatment strategies [13]. Generative algorithms and automated design tools facilitate the creation of individualized prosthetic appliances, such as crowns and dentures, ensuring better fit, comfort, and aesthetics [13]. AI applications in these fields improve treatment precision through the simulation of tooth movements and prediction of success in procedures like root canal therapy [13]. This technology enhances the analysis of radiographs and 3D imaging, leading to early detection of dental diseases and anomalies [15].

AI models demonstrate high diagnostic validity, with pooled diagnostic accuracy of 92.4%, sensitivity of 90.1%, and specificity of 91.7% in various dental applications [14]. AI systems facilitate personalized treatment plans by predicting outcomes and optimizing procedures based on vast datasets (Rastogi et al., 2024). AI enhances patient management through automated appointment scheduling, virtual consultations, and real-time communication platforms, improving overall patient experience and compliance [15]. Despite the benefits, challenges such as data privacy concerns, transparency of AI models, high costs, and the need for standardized validation protocols hinder widespread [13, 14]. Issues like inconsistent data quality, bias risk, and lack of transparency in AI models pose significant barriers to effective integration into routine dental practice [16].

While AI holds significant promise for revolutionizing dental care, it is crucial to address the challenges associated with its implementation. Ethical considerations, data privacy, and the need for continuous training and education for dental professionals are critical factors that must be managed to ensure responsible and effective use of AI technologies in dentistry. Moreover, AI should be viewed as an adjunct to clinical expertise, enhancing rather than replacing the human element in dental care. Continued research, regulation, and collaboration among dental professionals, technologists, and policymakers are essential to unlock the full potential of AI in dentistry while addressing its associated challenges.

NANOMEDICINE IN DENTISTRY: MATERIALS AND MECHANISMS

Nanomedicine in dentistry is a rapidly evolving field that leverages the unique properties of nanomaterials to enhance dental care, particularly in prosthodontics, orthodontics, and endodontics. These advancements aim to provide predictive,

personalized, and regenerative dental treatments. Nanomaterials and nanostructures are central to these innovations, offering diverse functionalities such as antimicrobial action, regenerative capabilities, and efficient drug delivery systems. This section explores the types of nanomaterials used in dentistry and their specific functions, highlighting their transformative potential in dental care [17].

In dental nanomedicine, a diverse array of nanoscale platforms is being developed to restore, protect, and monitor oral tissues. Inorganic nanoparticles such as nano-hydroxyapatite and mesoporous silica are widely used for biomimetic mineralization and ion delivery, playing a central role in hard-tissue regeneration and repair [18]. Organic nanocarriers including chitosan, PLGA, and liposomes are favored for their biocompatibility and controlled-release properties, making them well suited for targeted drug delivery in a range of dental treatments [18]. Biological nanoplatforms, exemplified by exosomes and protein cages, add another layer of specificity through advanced biorecognition and targeting capabilities that enhance therapeutic precision. Hybrid nanocomposites that incorporate fillers such as silica, zirconia, and nanodiamonds boost mechanical performance and aesthetic outcomes in restorative dentistry [19]. Parallel advances in nanorobotics and nanobiosensors managing from experimental nanorobotic dentifrices to sensor networks for real-time biomarker detection promise continuous oral-health maintenance and earlier disease diagnosis, opening new possibilities for preventive and personalized dental care [20, 21].

Nanoparticles and nanosystems in dentistry offer multifunctional benefits that address infection control, tissue repair, and targeted therapy. Metallic and polymeric nanoparticles such as silver, zinc oxide, and chitosan exhibit potent antimicrobial activity that is essential for managing biofilms and preventing infection during dental procedures [19]. Beyond antimicrobial effects, nanotechnology advances regenerative dentistry by providing scaffolds and delivery platforms that promote cellular proliferation and tissue formation, with particular promise for endodontic and periodontal therapies [22, 23]. Nanoparticle-based drug-delivery systems further enhance treatment precision by enabling targeted, controlled release of therapeutics directly to sites of infection or tissue damage, improving efficacy while reducing systemic side effects an approach especially valuable in endodontics for delivering medicaments into complex root canal anatomies [22, 24].

While nanomedicine offers significant advancements in dental care, it is essential to consider the challenges and limitations associated with its application. Issues such as nanotoxicity, long-term biocompatibility, and regulatory hurdles pose significant barriers to the widespread adoption of nanotechnology in clinical settings [20, 25].Additionally, the high cost of production and the need for rigorous in vivo validation further complicate the translation of laboratory innovations into practical dental treatments. Addressing these challenges through interdisciplinary collaboration and research is crucial for the successful integration of nanomedicine into dentistry.

SYNERGISTIC INTEGRATION OF AI AND NANOMEDICINE

The integration of AI and nanomedicine is paving the way for transformative advancements in dental care, particularly in prosthodontics, orthodontics, and endodontics. This convergence aims to achieve predictive, personalized, and regenerative dental treatments by leveraging AI's capabilities in data analysis and predictive modeling alongside the precision of nanotechnology. AI enhances the design and optimization of nanomaterials, leading to more effective and personalized therapeutic interventions. Furthermore, smart nanosystems, driven by data, are revolutionizing therapeutic strategies, offering new possibilities for targeted and efficient dental care solutions.

AI-driven methods are transforming the design and deployment of nanomaterials for dental applications by enabling accurate prediction, rapid optimization, and generative design of nanoscale platforms. Machine learning and deep-learning models can predict key nanomaterial properties size, shape, surface charge that determine biodistribution, cellular uptake, and drug-release behavior, improving the selection of candidates for effective targeted delivery in dentistry [26]. Complementary AI algorithms accelerate the identification and optimization of nanocarriers, refining drug–carrier interactions and targeting mechanisms to produce carriers tailored for specific dental conditions and to minimize off-target effects [27]. Finally, generative approaches such as

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generative adversarial networks and reinforcement learning permit exploration of novel nanostructures with bespoke functionalities for example, stimuli-responsive release profiles or surface chemistries optimized for oral tissues opening new avenues for smart, adaptive therapeutics in dental care [28].

AI-driven technologies are paving the way for truly personalized and adaptive dental care by integrating multi-omics, imaging, and clinical data to tailor treatments to individual patients. Platforms such as CURATE.AI demonstrate how individualized dosing and treatment strategies can be derived from complex, patient-specific datasets, a capability that is directly applicable to optimizing dental therapeutics and improving outcomes [26]. At the diagnostic level, AI enhances the sensitivity and specificity of nanoscale sensors and diagnostics: nanosensors coupled with ML models can detect oral-disease biomarkers at extremely low concentrations, enabling earlier diagnosis and more timely interventions [28, 29]. Beyond detection, the coupling of AI with nanosystems supports real-time, closed-loop therapeutics that continuously adapt to incoming patient data, optimizing drug release, dosing, and other treatment parameters to maximize efficacy and minimize side effects an approach that promises to improve both short- and long-term patient outcomes in dentistry [28, 30].

While the integration of AI and nanomedicine holds immense potential for advancing dental care, several challenges must be addressed. These include ethical and regulatory issues, data privacy concerns, and the need for interdisciplinary collaboration to ensure responsible implementation. Additionally, the complexity of nanoscale operations and the variability in patient responses necessitate robust frameworks for clinical translation and validation. Despite these challenges, the synergy between AI and nanomedicine is poised to revolutionize dental care, offering more secure, efficient, and personalized treatment options for patients worldwide [27, 31, 32]

APPLICATIONS IN PROSTHODONTICS

The convergence of AI and nanomedicine in prosthodontics is paving the way for predictive, personalized, and regenerative dental care[33]. AI-assisted design and the use of nanomaterials are two significant applications in this field, enhancing the precision, efficiency, and functionality of prosthetic solutions. These advancements are transforming traditional prosthodontic practices by integrating cutting-edge technology to improve patient outcomes and streamline workflows. The following sections delve into the specific applications of AI-assisted design and nanomaterials in prosthodontics.

AI-driven digital workflows are significantly advancing prosthodontics by enabling high levels of precision, customization, and efficiency in prosthesis design and fabrication. Accurate intraoral data acquisition, combined with computer-aided design and manufacturing (CAD/CAM), allows for the production of highly individualized prosthetic components, further enhanced by three-dimensional printing technologies that ensure superior fit and accuracy [34, 35]. In parallel, AI applications streamline clinical and laboratory processes through automated classification of edentulous arches, AI-assisted impression tray selection, and machine learning–based design of removable partial denture frameworks, thereby reducing both time and manual effort in prosthetic development [34, 36].

Beyond fabrication, AI also improves treatment planning by optimizing casting and manufacturing workflows, predicting facial morphological changes associated with removable prostheses, and supporting the design of implants and maxillofacial prosthetics, ultimately leading to more predictable and efficient clinical outcomes [37]. However, despite these advantages, several challenges remain, including the need for large, high-quality datasets, robust validation and standardization protocols, and careful consideration of ethical and regulatory issues. Addressing these limitations will be essential to fully realize the potential of AI in prosthodontic practice [34, 35].

APPLICATIONS IN ORTHODONTICS

The convergence of AI and nanotechnology in orthodontics is paving the way for more predictive, personalized, and efficient dental care. AI models are increasingly being used to enhance treatment planning by predicting outcomes and personalizing treatment strategies, while nanotechnology is revolutionizing the materials and appliances used in orthodontics. These advancements promise to improve patient outcomes and streamline orthodontic procedures. Below, the applications of AI and nanotechnology in orthodontics are explored in detail.

AI models, particularly those utilizing ML and DL, are transforming orthodontic treatment

planning by providing predictive insights and personalized strategies.

AI enhances diagnostic accuracy by analyzing complex datasets, such as cephalometric radiographs and three-dimensional imaging, to identify anatomical landmarks and predict growth patterns. This allows for more precise treatment planning and outcome prediction [38, 39]. Customized Treatment Strategies: AI-driven solutions facilitate the customization of orthodontic appliances and aligner therapy, tailoring treatment to individual patient needs. This personalization is achieved through the integration of AI with digital workflows and 3D printing technologies [40].

Risk Assessment and Prognosis Prediction: AI models are used to assess risks and predict treatment outcomes, aiding in decision-making processes. These models can predict the likelihood of treatment success and identify potential complications, allowing for proactive management [41, 42].

Nanotechnology is being integrated into orthodontic appliances and biomaterials, offering enhanced properties and functionalities. Nanotechnology enhances the mechanical properties of orthodontic materials, such as wires and brackets, by increasing their strength, flexibility, and resistance to wear. This results in more durable and effective appliances.

Nanomaterials improve the biocompatibility and aesthetic appeal of orthodontic appliances. For instance, nanoparticles can be used to create transparent brackets and wires that are less visible, improving patient satisfaction. Incorporating nanoparticles with antimicrobial properties into orthodontic materials can reduce the risk of infections and improve oral hygiene during treatment. This is particularly beneficial in maintaining the health of the oral environment [41].

While AI and nanotechnology offer significant advancements in orthodontics, there are challenges and considerations that must be addressed. The integration of AI into clinical practice requires careful consideration of data privacy, algorithmic bias, and the need for clinician oversight to ensure ethical and effective use [40, 41]. Similarly, the application of nanotechnology must consider potential health risks associated with nanoparticles and ensure that materials are safe for long-term use [41]. Despite these challenges, the continued development and integration of AI and nanotechnology hold great promise for the future of orthodontic care.

APPLICATIONS IN ENDODONTICS

The convergence of AI and nanomedicine in endodontics is paving the way for predictive, personalized, and regenerative dental care. AI-based diagnostics and the use of nanoparticles for disinfection and regeneration are two key applications that are transforming endodontic practice. These technologies enhance diagnostic accuracy, improve treatment outcomes, and offer innovative solutions for complex dental issues. The following sections delve into these applications, highlighting their significance and potential impact on endodontics.

AI technologies are revolutionizing the diagnostic processes in endodontics, particularly for pulp and periapical diseases.

AI algorithms, especially deep convolutional neural networks (CNNs), have significantly improved the accuracy of diagnosing periapical and pulp diseases by analyzing radiographic images. These models can detect subtle changes in bone density and morphology, which are often missed by conventional methods, thus enabling early detection and intervention. AI-powered predictive models can assess the risk factors for endodontic failures and predict healing trajectories, aiding clinicians in making informed decisions. This predictive capability is crucial for tailoring personalized treatment plans and improving patient outcomes [43, 44]. AI systems are being integrated into digital workflows, enhancing the efficiency of clinical decision-making. These systems assist in identifying root canal anatomy, detecting lesions, and providing real-time analytics, which streamline the diagnostic process and improve procedural outcomes [45].

Nanotechnology offers innovative solutions for disinfection and regeneration in endodontics, addressing some of the limitations of traditional methods.

Nanoparticles, due to their small size and large surface area, can penetrate dentinal tubules more effectively than conventional disinfectants. This results in superior antimicrobial action, reducing the risk of reinfection and improving the success rate of root canal treatments [46, 47]. Nanoparticles facilitate targeted drug delivery and support stem cell differentiation, promoting pulp tissue regeneration. This capability is crucial

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for developing biologically responsive materials and treatment protocols that restore the vitality and function of the pulp-dentin complex [22, 46]. The incorporation of nanomaterials into dental materials enhances their mechanical properties, such as strength and fracture resistance, thereby increasing the durability of endodontic treatments [46].

While AI and nanotechnology offer promising advancements in endodontics, challenges remain in their widespread adoption. AI applications face issues such as biased datasets, ethical concerns, and the need for large, annotated datasets for training models [45, 48]Similarly, the long-term biocompatibility and safety of nanoparticles require further research to ensure their safe integration into clinical practice [46]. Addressing these challenges through interdisciplinary collaboration and ongoing research will be crucial for fully realizing the potential of these technologies in endodontics. An overview of the convergent applications of AI and nanomedicine across prosthodontics, orthodontics, and endodontics is summarized in Table 1.

PREDICTIVE AND PERSONALIZED DENTAL CARE

The convergence of AI and nanomedicine is poised to revolutionize dental care by enabling predictive and personalized treatment strategies. This integration is particularly transformative in fields such as prosthodontics, orthodontics, and endodontics, where precision and individualized care are paramount. AI's ability to analyze vast datasets and predict outcomes, combined with nanomedicine's targeted therapeutic capabilities, offers a new paradigm in dental care. This approach not only enhances diagnostic accuracy and treatment efficacy but also tailors' interventions to individual patient needs, thereby improving overall patient outcomes. The following sections delve into the specific roles of risk prediction and outcome modeling, as well as patient-specific, AI-driven nano-therapeutics in dental care.

AI algorithms, particularly those based on machine learning, are enhancing diagnostic accuracy and outcome prediction in endodontics by integrating clinical, radiographic, and biological datasets. These predictive models can identify risk factors for endodontic failure and estimate healing trajectories, aiding clinicians in making evidence-based decisions [44]. In prosthodontics, AI is used for outcome prediction, enhancing the precision of treatment planning and decision-making. AI's role extends to predicting facial changes in patients with removable prostheses, thereby improving patient satisfaction and treatment outcomes [49]. AI's predictive capabilities in orthodontics include predicting tooth movement and optimizing treatment times. This allows for highly individualized treatment plans that improve clinical outcomes and patient satisfaction [50].

Nanotechnology offers promising solutions for periodontal therapy by enhancing diagnostic accuracy and enabling targeted drug delivery. Nanoparticles can precisely detect periodontal pathogens and biomarkers, while nanotechnology-based therapies provide localized and controlled release of therapeutic agents [23]. The integration of AI with nanomaterial-enhanced drug delivery systems has shown potential in improving dental caries diagnosis and treatment. AI-driven diagnostics, combined with fluoride-nanomaterial formulations, offer targeted and effective treatment options [51]. AI is being used to identify optimal scaffold designs and predict cellular responses in regenerative endodontics. This integration with bioinformatics and stem cell research accelerates the development of biologically responsive materials for tissue regeneration [43].

While the integration of AI and nanomedicine in dental care offers significant advancements, challenges such as data privacy, algorithmic bias, and the cost of adopting these technologies remain. Ethical considerations, including patient privacy and informed consent, are critical as personalized dental care becomes more prevalent. Additionally, the limited availability of extensive datasets can hinder the widespread implementation of AI in prosthodontics. Despite these challenges, the potential for AI and nanomedicine to transform dental care is immense, promising more predictive, personalized, and effective treatments in the future.

REGENERATIVE DENTISTRY AND FUTURE THERAPEUTICS

Regenerative dentistry is at the forefront of transforming dental care by integrating advanced technologies such as stem cells, nanoscaffolds, and AI-guided strategies. These innovations aim to move beyond traditional reparative methods to achieve true biological reconstruction of dental tissues. The convergence of artificial intelligence and nanomedicine in prosthodontics,

Table 1. Convergence of artificial intelligence and nanomedicine in prosthodontics, orthodontics, and endodontics.

Dental field	Key AI capabilities	Key nanomedicine tools and mechanisms	Main clinical benefits	Principal challenges and limitations
Prosthodontics	AI-assisted CAD/CAM design; automated classification of edentulous arches; ML-based framework and implant planning.	Nanocomposites, nano-hydroxyapatite fillers, nano-enhanced restorative materials improving strength, wear, and esthetics.	More precise fit and function of prostheses; streamlined digital workflows; improved long-term prosthesis performance.	Need for large, high-quality datasets; validation and standardization; cost and training barriers for digital AI workflows.
Orthodontics	ML/DL-based diagnosis on cephalometric and 3D images; prediction of tooth movement and growth patterns; risk and prognosis modeling; aligner personalization.	Nano-modified wires and brackets, aesthetic nano-enhanced appliances, antimicrobial nanoparticles integrated into orthodontic materials.	More predictive, individualized treatment; improved comfort and esthetics; reduced infection risk and better oral hygiene during treatment.	Data privacy and algorithmic bias; need for clinician oversight; long-term safety and biocompatibility of nano-modified appliances.
Endodontics	CNN-based detection of pulp and periapical pathology; automated identification of root anatomy and lesions; predictive models for healing and treatment success.	Antibacterial nanoparticles for disinfection; nano-based drug delivery into complex canal anatomy; nanoscaffolds and nano-bioactive systems for pulp-dentin regeneration.	Enhanced diagnostic accuracy; more effective canal disinfection; progress toward biologically oriented, regenerative endodontic therapies.	Biased or limited datasets; need for robust annotation; uncertainties about long-term nanoparticle safety; translational and regulatory hurdles.

orthodontics, and endodontics is paving the way for predictive, personalized, and regenerative dental care. This section explores the role of stem cells, nanoscaffolds, tissue engineering, and AI-guided strategies in advancing regenerative dentistry.

Dental stem cells, including dental pulp stem cells (DPSCs) and periodontal ligament stem cells (PDLSCs), are pivotal in regenerative dentistry due to their ability to differentiate into various cell types necessary for dental tissue regeneration. These cells are used in conjunction with bioactive molecules and scaffolds to promote the regeneration of dentin-pulp complexes, periodontal tissues, and alveolar bone [52, 53].

The use of nanotechnology in creating scaffolds has significantly enhanced the precision and effectiveness of regenerative therapies. Nanoscaffolds provide a biomimetic environment that supports cell attachment, proliferation, and differentiation. They are designed to mimic the natural extracellular matrix, facilitating the regeneration of complex dental structures [54]. Tissue Engineering: This field combines stem cells, scaffolds, and growth factors to engineer tissues that can replace damaged dental structures. Techniques such as 3D bioprinting and computer-aided design are revolutionizing tissue engineering by enabling the fabrication of patient-specific scaffolds that guide tissue regeneration [55, 56].

AI algorithms, particularly those based on machine learning, are enhancing the predictive capabilities in regenerative dentistry. These models can analyze vast datasets to predict outcomes of regenerative procedures, optimize scaffold designs, and simulate cellular responses, thereby improving the precision of regenerative treatments. AI facilitates the development of personalized regenerative strategies by analyzing patient-specific data, such as genetic profiles and systemic health parameters. This allows for the customization of treatment protocols to suit individual patient needs, moving away from the traditional one-size-fits-all approach. The synergy between AI and bioinformatics accelerates the development of biologically responsive materials and treatment protocols. AI can process complex biological data to identify optimal conditions for tissue regeneration, enhancing the efficacy of regenerative therapies [43].

While regenerative dentistry holds immense promise, challenges such as high costs, regulatory hurdles, and variability in clinical outcomes remain. The integration of AI and nanotechnology offers potential solutions by improving the predictability and personalization of treatments. However, widespread adoption requires overcoming these barriers through continued research and development. The future of regenerative dentistry lies in refining these technologies and establishing standardized protocols to ensure their effective clinical application [52, 53].

CHALLENGES, REGULATORY CONSIDERATIONS, AND FUTURE PERSPECTIVES

The convergence of AI and nanomedicine in dental fields such as prosthodontics, orthodontics, and endodontics holds significant promise for advancing predictive, personalized, and regenerative dental care. However, this integration is not without its challenges, particularly concerning ethical, safety, and regulatory issues, as well as translation barriers and future research directions. These challenges must be addressed to fully realize the potential of AI and nanomedicine in dentistry.

The integration of AI in dentistry raises ethical issues related to data privacy, algorithm transparency, and potential biases in AI systems. Ensuring that AI systems are free from bias and that patient data is protected is crucial for ethical AI deployment in dental care [57, 58]. Safety Considerations: Nanomedicine introduces concerns about biocompatibility and nanotoxicology. The potential for nanoparticles to cause adverse biological effects necessitates rigorous safety evaluations and monitoring to ensure patient safety [59]. The lack of a well-defined regulatory framework for nanomedicine poses significant challenges. The hybrid nature of nanomedicine products, which often fall between traditional drug, device, and biologic classifications, complicates regulatory pathways. There is a need for a coherent and globally synchronized regulatory framework to facilitate the safe and effective use of nanomedicine in clinical practice [59].

The translation of AI and nanomedicine from research to clinical practice is hindered by technical complexity, high initial costs, and the need for high-quality data. Additionally, the variability in manufacturing and the unpredictability of in vivo performance of nanomedicine systems pose significant challenges [35]. Future research should focus on developing standardized characterization methods and adaptive regulatory frameworks

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to address these challenges. Interdisciplinary collaboration and open-source innovation are essential for advancing AI and nanomedicine technologies. Emerging technologies such as quantum computing and digital twins offer promising avenues for enhancing personalized dental care [26]. Educational and Training Needs: Adequate training for dental professionals in AI and nanomedicine technologies is crucial for successful implementation. Continuous education and robust data management practices are necessary to ensure that these technologies are used responsibly and effectively [35]. While the convergence of AI and nanomedicine in dentistry presents numerous opportunities for enhancing patient care, it also necessitates careful consideration of ethical, safety, and regulatory issues. Addressing these challenges requires a collaborative effort among researchers, clinicians, and regulatory bodies to ensure that these technologies are integrated into dental practice in a manner that is both safe and effective. Future research should focus on overcoming translation barriers and exploring new technologies to fully harness the potential of AI and nanomedicine in dentistry.

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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. Roy R, Sivaraman K, Chopra A. Applications of Artificial Intelligence (AI) in Dentistry: a review. F1000Res. 2026;15:803. https://doi.org/10.12688/f1000research.171119.1
2. Farrokhi M, et al. Current applications, challenges, and future directions of artificial intelligence in emergency medicine: a narrative review. Arch Acad Emerg Med. 2025;13(1):e45.
3. Lu Y. Artificial intelligence: a survey on evolution, models, applications and future trends. J Manag Anal. 2019;6(1):1-29. https://doi.org/10.1080/23270012.2019.1570365
4. Solhmirzaei R, et al. Investigating the effect of dental implant treatment on mental health and quality of life. Int J Chem Biochem Sci. 2023;24(6):279-284.
5. Schwendicke F, Samek W, Krois J. Artificial intelligence in dentistry: chances and challenges. J Dent Res. 2020;99(7):769-774. https://doi.org/10.1177/0022034520915714
6. Khanagar SB, et al. Developments, application, and performance of artificial intelligence in dentistry-A systematic review. J Dent Sci. 2021;16(1):508-522. https://doi.org/10.1016/j.jds.2020.06.019
7. Kalbasi GN, et al. The Evaluation of: General Dental practitioner Knowledge in Isfahan about Odontogenic cyst and tumor. J Isfahan Dent Sch. 2020;16(2):140-148. https://doi.org/10.52547/jrds.17.3.229
8. Pandey D, Lakhanam D. Artificial intelligence in dentistry: the new opportunity to discover. Int J Dent Oral Sci. 2024;11(7):1-8. https://doi.org/10.47191/ijmra/v7-i12-30
9. Wright JT. Artificial intelligence and the reshaping of oral health care. J Am Dent Assoc. 2023;154(11):957-958. https://doi.org/10.1016/j.adaj.2023.09.001
10. Sabzehie H, Farrokhi M, Nochian MA. Statistical analysis in CBCT-based third molar evaluation. Oral Maxillofac Surg. 2025;30(1):10. https://doi.org/10.1007/s10006-025-01500-w
11. Arshadi Fard M, Kalbasi N. Evaluation of the Use of Artificial Intelligence (AI) for Low & High-Grade OSCC Diagnosis from Normal Mucosa. Contemp Orofac Sci. 2023;1(1):13-16.
12. Maghsoudi H, et al. Physics-aware imaging AI for quantitative MASLD biomarker mapping: a systematic review of deep learning and radiomics across ultrasound, CT, and MRI. Abdom Radiol (NY). 2026;51(6):2919-2931. https://doi.org/10.1007/s00261-025-05317-9
13. Vardhe R, et al. The Role of Artificial Intelligence in Dentistry: A Narrative Review. Oral Sphere J Dent Health Sci. 2025;1(1):41-47. https://doi.org/10.63150/osjdhs.2025.35
14. Thurzo A, et al. Where is the artificial intelligence applied in dentistry? Systematic review and literature analysis. Healthcare (Basel). 2022;10(7):1269. https://doi.org/10.3390/healthcare10071269
15. Siddiqui SR, Rastogi I, Khan FR. Artificial intelligence up fronting dentistry. J Orofac Health Sci. 2025;11(2):47-49. https://doi.org/10.18231/j.johs.2024.012
16. Sitaras S, et al. Applications of artificial intelligence in dental medicine: a critical review. Int Dent J. 2025;75(2):474-486. https://doi.org/10.1016/j.identj.2024.11.009
17. Baghi S, et al. An assay on the antibacterial performance of Co doped ZnO nanoparticles in dental microbes. Nanomed Res J. 2023;8(2):210-217.
18. Xu S, et al. Nanomaterials in Oral Regeneration: current Advances and Future Directions. Regen Med Dent. 2025;2(4):16. https://doi.org/10.53941/rmd.2025.100016
19. AlKahtani RN. The implications and applications of nanotechnology in dentistry: A review. Saudi Dent J. 2018;30(2):107-116. https://doi.org/10.1016/j.sdentj.2018.01.002
20. Chaturvedi A, Bhardwaj A, Sheokand V. The Role of Nanotechnology in Modern Periodontal Practice. Curr Trends Dent. 2025;2(2):73-77. https://doi.org/10.4103/CTD.CTD_28_25
21. Niknam S, Shabani-Nooshabadi M, Adabi M.

Nanoarchitectonics of aptamer-based electrochemical sensor using electrospun carbon nanofibers and Au nanoparticles for Cd(II) analysis. Sci Rep. 2026;16(1):9271. https://doi.org/10.1038/s41598-026-39085-3
22. Afkhami F, et al. Application of nanomaterials in endodontics. BME Front. 2024;5:0043. https://doi.org/10.34133/bmef.0043
23. D'Amico E, et al. How will nanomedicine revolutionize future dentistry and periodontal therapy? Int J Mol Sci. 2025;26(2):592. https://doi.org/10.3390/ijms26020592
24. Khosrowshahi HI. Nanomedicine in Dentistry: A New Frontier in Oral Healthcare. 2025.
25. Cheraghiyan M. Nanotechnology in dentistry: Potential applications and future perspectives. J Oral Dent Health Nexus. 2025;2(1):1-13. https://doi.org/10.61838/kman.jodhn.2.1.1
26. Kataria S. AI-Guided design of personalized nanomedicine: a review of data-driven approaches in nanoparticle formulation. Int J Multidiscip Res. 2025;7(4):1-15. https://doi.org/10.36948/ijfmr.2025.v07i04.53283
27. Sarkar S, Das D. Artificial Intelligence in Nanomedicine Formulation and Applications. In: Nanobiomedicine: Fundamentals and Implementation in Theranostic Applications. Bentham Science Publishers; 2025. p. 171-200. https://doi.org/10.2174/9798898813123125010012
28. Tivay S, et al. Next-generation drug delivery: smart nanomaterials for precision healthcare (focusing oral cancer). J Oral Dent Health Nexus. 2025;2(2):6-18. https://doi.org/10.61838/kman.jodhn.2.2.2
29. Girigoswami K, Girigoswami A. Integration of Data-Driven Techniques in Nanomedicines to Address Diagnosis and Drug Delivery Strategy for Therapy. Biopharm Drug Dispos. 2025;46(2):78-92. https://doi.org/10.1002/bdd.70016
30. Hayat H, et al. A concise review: the synergy between artificial intelligence and biomedical nanomaterials that empowers nanomedicine. Biomed Mater. 2021;16(5):052001. https://doi.org/10.1088/1748-605X/ac15b2
31. Chou WC, et al. Machine learning and artificial intelligence in nanomedicine. Wiley Interdiscip Rev Nanomed Nanobiotechnol. 2025;17(4):e70027. https://doi.org/10.1002/wnan.70027
32. Izanker SV, Dhole A, Kumar P. Navigating the nexus: exploring the fusion of AI and nanotechnology for cutting-edge advances. In: 2023 1st DMIHER International Conference on Artificial Intelligence in Education and Industry 4.0 (IDICAIEI). IEEE; 2023. https://doi.org/10.1109/IDICAIEI58380.2023.10406387
33. Amini P, et al. Nanotechnology in Endodontics and Prosthodontics: Current Advances and Future Perspectives. Nanomed Res J. 2026;11(1):41-50.
34. Zubair A, et al. Artificial Intelligence in Prosthodontics: Revolutionizing Removable Partial Denture Design and Fabrication. Oral Health Res Clin Evid. 2025;2(2):86-89. https://doi.org/10.4103/ORCL.ORCL_15_25
35. Selvam D, Selvam D. Artificial intelligence in prosthodontics: current applications, emerging challenges, and future perspectives-a narrative review. Tanta Dent J. 2025;22(2):187-189. https://doi.org/10.4103/tdj.tdj_68_24
36. Ali IE, et al. Applications and performance of artificial intelligence models in removable prosthodontics: A literature review. J Prosthodont Res. 2023;68(3):358-367. https://doi.org/10.2186/jpr.JPR_D_23_00073
37. Geevarghese SS, et al. Precision Smiles 2.0: Revolutionizing prosthodontics with artificial intelligence ingenuity. J Prosthodont Res. 2023. https://doi.org/10.5005/djas-11014-0028
38. Kunz F, Stellzig-Eisenhauer A, Boldt J. Applications of artificial intelligence in orthodontics-an overview and perspective based on the current state of the art. Appl Sci (Basel). 2023;13(6):3850. https://doi.org/10.3390/app13063850
39. Azizi S, Hatampoor S, Tahamtan S. Applications of artificial intelligence in diagnosis and treatment planning of orthodontics: a narrative review. Saudi Dent J. 2025;37(7):70. https://doi.org/10.1007/s44445-025-00077-0
40. 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):304-310. https://doi.org/10.38124/ijisrt/25sep389
41. Nordblom N, Büttner M, Schwendicke F. Artificial intelligence in orthodontics: critical review. J Dent Res. 2024;103(6):577-584. https://doi.org/10.1177/00220345241235606
42. Asiri SN, et al. Applications of artificial intelligence and machine learning in orthodontics. APOS Trends Orthod. 2020;10(1):17-24. https://doi.org/10.25259/APOS_117_2019
43. Parinitha M, et al. Impact of artificial intelligence in endodontics: precision, predictions, and prospects. J Med Signals Sens. 2024;14(9):25. https://doi.org/10.4103/jmss.jmss_7_24
44. Dennis D, et al. Artificial intelligence application in endodontics: A narrative review. Imaging Sci Dent. 2024;54(4):305-316. https://doi.org/10.5624/isd.20240321
45. Huang X, et al. Revolutionizing endodontics: the impact and innovations of artificial intelligence. BMC Oral Health. 2026;26(1):45. https://doi.org/10.1186/s12903-025-07632-5
46. Shrestha A, Kishen A. Antibacterial nanoparticles in endodontics: a review. J Endod. 2016;42(10):1417-1426. https://doi.org/10.1016/j.joen.2016.05.021
47. Roig-Soriano X, et al. Nanoparticles in endodontics disinfection: state of the art. Pharmaceutics. 2022;14(7):1519. https://doi.org/10.3390/pharmaceutics14071519
48. Mukhopadhyay A, Mukhopadhyay S, Mandal PS. Artificial Intelligence in the Field of Endodontics: A Narrative Review. J Prim Care Dent Oral Health. 2025;6(2):50-54. https://doi.org/10.4103/jpcdoh.jpcdoh_9_25
49. Karnik AP, Chhajer H, Venkatesh SB. Transforming prosthodontics and oral implantology using robotics and artificial intelligence. Front Oral Health. 2024;5:1442100. https://doi.org/10.3389/froh.2024.1442100
50. Olawade DB, et al. AI-driven advancements in orthodontics for precision and patient outcomes. Dent J (Basel). 2025;13(5):198. https://doi.org/10.3390/dj13050198
51. Nabeel M, et al. Advancing Oral Healthcare: AI-Driven Caries Detection and Nanomaterial-Enhanced Treatment. In: Proceedings of the 3rd International Conference on Optimization Techniques in the Field of Engineering (ICOFE-2024). 2024. https://doi.org/10.2139/ssrn.5076026
52. Ayad A, et al. Next-Gen Dental Therapies: Bridging Bioengineering with Pharmacological Science. 2025. https://doi.org/10.20944/preprints202501.0996.v2
53. Abdelrahman MRA. Unlocking regenerative potential: stem cell and tissue engineering innovations for permanent dental restoration. Discov Med. 2024;1(1):113. https://doi.org/10.1007/s44337-024-00087-7

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54. Alsuraifi A, et al. Next-Gen Dental Therapies: Bridging Bioengineering with Pharmacological Science "Stem to Structure: Orchestrating Oral Renewal". 2025. https://doi.org/10.20944/preprints202501.0996.v1
55. Thalakiriyawa DS, Dissanayaka WL. Advances in regenerative dentistry approaches: an update. Int Dent J. 2024;74(1):25-34. https://doi.org/10.1016/j.identj.2023.07.008
56. Torvi SJ, Munniswamy K. Regenerative dentistry: Current and future perspectives to rejuvenate and reclaim dental tissues. J Int Clin Dent Res Organ. 2014;6(2):112-117. https://doi.org/10.4103/2231-0754.143496
57. Surlari Z, et al. Current Progress and challenges of using artificial intelligence in clinical dentistry-A Narrative review. J Clin Med. 2023;12(23):7378. https://doi.org/10.3390/jcm12237378
58. Dettori M, et al. Artificial Intelligence and Innovation in Oral Health Care Sciences: A Conceptual Review. Healthcare (Basel). 2025;13(3):245. https://doi.org/10.3390/healthcare13243327
59. Mangla B, et al. Regulating nanomedicines: challenges, opportunities, and the path forward. Nanomedicine (Lond). 2025;20(15):1911-1927. https://doi.org/10.1080/17435889.2025.2533107

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