REVIEW ARTICLE

Artificial Intelligence-Driven Nanotechnology in Dental Prosthesis: Advancements, Biocompatibility, and Clinical Outcomes

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ABSTRACT

This review paper explores the transformative integration of artificial intelligence (AI) and nanotechnology in dental prosthetics, emphasizing their combined potential to enhance patient-specific outcomes in prosthodontics. Nanotechnology enables the fabrication of dental prostheses that closely mimic natural teeth, while AI utilizes machine learning and neural networks to optimize diagnostic imaging, treatment planning, and prosthesis customization. This synergy reduces clinical time and improves therapeutic success. The paper addresses current clinical demands for personalized dental care, highlighting how AI-driven analysis of patient data, combined with advanced nanomaterials, meets these needs. Despite promising progress, challenges such as limited high-quality data for AI training, high initial costs, and technical complexity limit widespread clinical adoption. This review outlines the rationale, scope, and challenges of integrating AI and nanotechnology in dental prosthetics, providing a comprehensive overview of this innovative approach.

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INTRODUCTION

The integration of artificial intelligence (AI) and nanotechnology in dental prosthetics represents a significant advancement in the field of prosthodontics, offering enhanced precision, efficiency, and patient outcomes. AI's ability to process large datasets and perform complex analyses complements the unique properties of nanomaterials, which can mimic natural tooth aesthetics and improve the durability of dental prostheses. This synergy addresses current clinical needs by providing more personalized and effective dental care solutions. The following sections will explore the rationale for integrating these technologies, define their scope, and discuss the current clinical needs and constraints in dental prosthetics.

Nanotechnology allows for the creation of dental prosthetics that closely resemble natural teeth in appearance and strength. Nanomaterials can be engineered to have superior wear resistance and antibacterial properties, which extend the lifespan of dental restorations and improve oral health [1, 2]. AI enhances the precision of prosthetic design and fabrication by utilizing machine learning algorithms to optimize treatment planning and prosthesis customization. This results in reduced chairside time and improved clinical outcomes [3]. AI-driven tools facilitate better diagnostic imaging and predictive analytics, allowing for more accurate treatment planning and outcome prediction. This leads to more effective and personalized patient care [4, 5].

In the context of dental prosthetics, AI refers to the use of machine learning, deep learning, and neural networks to enhance diagnostic, treatment planning, and prosthesis fabrication processes. AI applications include automated diagnostics, treatment optimization, and predictive modeling [6, 7]. This involves the use of nanomaterials to improve the aesthetics, durability, and functionality

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of dental prosthetics. Nanotechnology enables the development of prosthetics with lifelike appearance and enhanced mechanical properties [1, 2]. This field also encompasses the design and fabrication of dental restorations, including crowns, bridges, dentures, and implants, to replace missing teeth and restore oral function [8].

There is a growing demand for dental prosthetics that are tailored to individual patient needs, which can be addressed through AI's ability to analyze patient-specific data and optimize prosthesis design [5, 9]. The effectiveness of AI in prosthodontics is limited by the availability of high-quality datasets, which are essential for training AI models and ensuring accurate predictions [3, 4]. The high initial costs associated with AI and nanotechnology integration, along with technical complexity, pose significant barriers to widespread adoption in clinical practice [4, 9].

AI and Nanotechnology Landscape in Dentistry

The integration of AI and nanotechnology in dentistry, particularly in the design and application of dental prostheses, represents a significant advancement in the field. AI methods such as machine learning, deep learning, and reinforcement learning are being utilized to enhance material design, imaging, and optimization processes. Concurrently, nanotechnology is revolutionizing the materials used in dental prostheses, offering improved biocompatibility and clinical outcomes. This synergy between AI and nanotechnology is paving the way for more efficient, personalized, and effective dental treatments. The following sections delve into the specific AI methods used, the role of nanomaterials, and the synergistic workflows that are emerging in this innovative landscape.

Machine Learning and Deep Learning are extensively used for diagnostic purposes, particularly in analyzing radiographic and optical images to improve diagnosis accuracy and treatment planning in dentistry [10, 11]. Although less commonly applied, reinforcement learning holds potential for optimizing treatment protocols and decision-making processes in dental care [11]. AI assists in the design and optimization of dental materials by predicting material behavior and performance, thus enhancing the development of more durable and effective dental prostheses[10].

Nanoceramics and nanopolymers are used to improve the mechanical properties and aesthetic appearance of dental prostheses. These materials offer enhanced strength, wear resistance, and a natural appearance [1, 12]. Nanometals and Metal-Organic Frameworks (MOFs) are incorporated into dental materials to enhance their antibacterial properties and biocompatibility, contributing to better clinical outcomes [12, 13]. Various nanoparticles, including hydroxyapatite, zirconia, and silver, are used for their ability to mimic natural tooth structures and promote biointegration, thus improving the longevity and functionality of dental prostheses [13, 14].

AI-driven design tools enable the creation of customized dental prostheses that meet specific patient needs, while nanotechnology enhances the synthesis of these materials to ensure optimal performance [10, 15]. AI algorithms are employed to analyze and predict the properties of nanomaterials, ensuring that they meet the required standards for dental applications. This integration enhances the quality control processes in dental prosthesis manufacturing [11, 12]. The combination of AI and nanotechnology facilitates the development of advanced diagnostic and therapeutic tools, such as nanorobots for precise drug delivery and AI-powered imaging systems for accurate diagnosis [12, 16].

Design and Fabrication of AI-Driven Nanostructured Prostheses

The integration of AI with nanotechnology in dental prosthesis design and fabrication represents a significant advancement in the field of prosthodontics. This approach leverages AI for material selection, optimization, and precision manufacturing, enhancing the biocompatibility and clinical outcomes of dental prostheses. AI-driven methodologies enable the development of prostheses that are not only functionally superior but also aesthetically pleasing, addressing both the mechanical and cosmetic needs of patients. The following sections delve into the specific aspects of AI-driven nanotechnology in dental prosthesis, highlighting advancements, strategies, and outcomes.

AI algorithms are employed to process large datasets and model nanoscale interactions, which aids in the selection and optimization of materials for dental prostheses. This ensures that the materials used are tailored to meet specific mechanical and biocompatibility requirements[17]. The integration of AI in material selection has been shown to enhance the mechanical properties of prosthetics, such as tensile strength and modulus, by incorporating nano-hydroxyapatite (HA) into high-density polyethylene (HDPE)[18]. AI-driven optimization also facilitates the design of patient-specific prostheses, improving comfort and functionality by tailoring the prosthetic to the individual's anatomical data[18].

Nanostructuring involves the use of nano-sized materials to enhance the strength, wear resistance, and esthetic appeal of dental prostheses. AI supports the discovery and design of novel nanostructures with tailored properties[17, 19, 20]. The use of biomimetic laminated zirconia materials, developed through AI-guided processes, has significantly improved the bionic performance and esthetic quality of dental prostheses[21]. AI-driven design technologies have doubled the efficiency of bionic design and manufacturing accuracy, providing functional and aesthetic matches for patients[21].

Additive manufacturing (AM), enhanced by AI, allows for the precise fabrication of complex dental prostheses. AI-AM systems improve process reliability and efficiency by enabling real-time monitoring and adaptive control of printing parameters[22]. AI integration in AM has led to the development of intricate, performance-optimized components, reducing material waste and supporting rapid, on-demand fabrication[22]. The use of AI in AM has also been shown to reduce the development time and material usage in the production of patient-specific scaffolds for mandibular bone reconstruction[23].

AI technologies facilitate process monitoring and predictive maintenance, ensuring the quality and longevity of dental prostheses. Machine learning algorithms enable automated defect detection and adaptive control, reducing failure rates and enhancing output quality[22].

Predictive maintenance, supported by AI, helps in anticipating potential issues in the manufacturing process, thereby minimizing downtime and ensuring consistent production quality[22].

Biocompatibility and Biological Interactions

The integration of artificial intelligence-driven nanotechnology in dental prosthesis has opened new avenues for enhancing biocompatibility and clinical outcomes. This section delves into the biocompatibility and biological interactions of nanomaterials in the dental context, focusing on in vitro assessments, immune responses, surface modifications, and long-term compatibility in the oral environment. These aspects are crucial for ensuring the safe and effective use of nanomaterials in dental applications.

In vitro biocompatibility testing is essential for evaluating the safety of dental materials. These tests assess the interaction of nanomaterials with cells and tissues to predict potential adverse effects such as inflammation, cytotoxicity, and mutagenicity [24, 25]. Studies on yttria-stabilized nanozirconia have shown promising results, with no significant cytotoxic damage observed in three-dimensional oral mucosal models, indicating its potential as a restorative material[26].

The immune response to nanomaterials is a critical factor in their biocompatibility. Nanomaterials can trigger immune reactions, which may lead to chronic inflammation or tissue necrosis if not properly managed [24]. Titanium dental implants, for example, demonstrate a controlled immune response that supports osseointegration, highlighting the importance of managing local immunity for successful integration[27].

Surface engineering strategies are employed to enhance the biocompatibility of nanomaterials. Techniques such as polymer coatings, lipid layer modifications, and bioinspired approaches can reduce cytotoxicity and improve hemocompatibility[28]. These modifications also aim to prevent fouling by oral biofilms, which can compromise the longevity and effectiveness of dental prostheses[29].

Long-term compatibility of nanomaterials in the oral environment is influenced by factors such as saliva flow, protein corona formation, and interactions with the pellicle layer and oral biofilm[29]. The dense crystalline structure of tooth enamel acts as a barrier to nanomaterial penetration, but underlying dentinal tubules may allow for beneficial applications such as dentine strengthening and pulp tissue regeneration[29].

Imaging, Diagnostics, and Monitoring

The integration of AI and nanotechnology in dental prosthesis is revolutionizing the field by enhancing imaging, diagnostics, and monitoring capabilities. These advancements are crucial for improving the precision and effectiveness of prosthetic treatments, ultimately leading to better patient outcomes. This response will explore AI-enhanced imaging modalities, nanomaterial-enabled sensors, and data integration from various dental technologies.

AI is transforming imaging technologies in prosthodontics, including intraoral scanners and cone-beam computed tomography (CBCT), by improving the precision of prosthesis fitting and the detection of defects. By analyzing imaging data, AI algorithms can identify dental pathologies and enhance treatment planning, which leads to greater diagnostic accuracy and more efficient clinical workflows [30, 31]. Machine learning and deep learning methods further support the automation of dental condition detection, such as caries and periodontal disease, through sophisticated image analysis. These advances allow for precise simulation of treatment outcomes and optimization of prosthetic parameters, contributing to better patient care [31]. Additionally, AI-powered imaging techniques assist in predicting facial changes in patients using removable prostheses, thereby improving the customization and comfort of dental devices [32].

The incorporation of nanomaterial-enabled sensors into dental prostheses provides the ability to monitor health in real time. These highly sensitive and selective nanosensors detect even minute amounts of analytes, enabling early diagnosis of diseases. By converting physical, chemical, optical, electrochemical, or biological signals into readable data, nanosensors support point-of-care and home-based monitoring, making them especially useful for managing oral health and facilitating timely interventions [33]. Additionally, microchip implants in prosthetics enhance continuous health monitoring by delivering ongoing information about oral conditions, which helps tailor treatment plans and improve patient outcomes.

The integration of data from intraoral scanners, CBCT, and wear analysis plays a vital role in comprehensive diagnostics and treatment planning within prosthodontics. AI systems can combine information from these diverse sources to offer a complete overview of a patient's oral health status [34]. By facilitating the seamless fusion of multi-modal imaging data, AI algorithms empower clinicians to make well-informed decisions about prosthesis design and fitting, thereby improving treatment accuracy and minimizing errors[31]. Incorporating wear analysis data with imaging results enables evaluation of occlusal forces and bite balance, which are essential factors for the success of prosthetic therapies [35]. Despite the transformative impact of AI and nanotechnology on dental prosthetics, barriers remain, including concerns about data privacy, ethical issues, and the necessity for high-quality datasets. Furthermore, the substantial initial costs and technological complexity involved pose challenges to widespread clinical adoption [4].

Preclinical and Clinical Outcomes

The integration of AI and nanotechnology in dental prosthesis has shown promising advancements in preclinical and clinical outcomes. These technologies have enhanced the precision, durability, and aesthetics of dental prostheses, leading to improved patient satisfaction and clinical performance. The following sections delve into the specific outcomes observed in in vivo studies, clinical performance metrics, comparative effectiveness, and safety considerations.

In vivo studies have demonstrated that AI-assisted technologies significantly enhance clinical outcomes in prosthodontics, including improved accuracy in implant placement, better prosthesis fitting, shorter procedural times, and reduced post-operative complications [36]. Nanotechnology plays a crucial role in replicating the natural aesthetics of teeth by creating prosthetics that are both visually lifelike and mechanically superior, offering enhanced strength and wear resistance that prolong the lifespan of dental restorations [1]. Moreover, AI systems facilitate real-time modifications and dynamic adjustments during prosthetic fittings, leading to increased precision and greater comfort for patients.

AI-driven prosthetic systems have notably enhanced the fit and durability of dental prostheses by utilizing real-time sensory data to make precise adjustments, resulting in improved clinical performance [1]. The use of nanocomposite materials in 3D printed dentures has demonstrated positive clinical outcomes, with no significant functional complications reported over an eighteen-month follow-up period. Additionally, nanomaterials contribute to increased wear resistance and improved aesthetics of dental restorations, which helps reduce the frequency of replacements and lowers associated costs[1]. From the patient perspective, AI-assisted prosthodontics have led to higher satisfaction levels due to better-fitting prostheses and shorter procedural times[36].

AI-assisted prosthodontics have demonstrated superior effectiveness compared to traditional approaches, offering enhanced diagnostic accuracy, more predictable treatment outcomes, and increased workflow efficiency[36]. Additionally, AI models excel in shade matching for tooth selection and automated restoration design, outperforming conventional visual methods and improving the overall quality of dental prosthetics.

AI integration in prosthodontics has notably improved patient safety by reducing errors and allowing early identification of risks before restorative procedures, which contributes to safer clinical outcomes. However, ethical and regulatory considerations remain critical in ensuring these technologies are implemented without compromising patient safety. Challenges such as limited availability of large, high-quality datasets restrict the full clinical validation and efficacy of AI applications in this field. Widespread adoption also faces hurdles due to the need for evolving ethical standards and regulatory frameworks that keep pace with technological advancements. Large-scale studies are essential to thoroughly assess AI and nanotechnology performance, safety, and long-term effects, ensuring their benefits can be realized responsibly. Despite these challenges, AI-driven prosthodontics hold great promise for enhancing precision, personalization, and overall patient care when combined with rigorous oversight and continued research[37].

Regulatory, Ethical, and Safety Considerations

The integration of AI and nanotechnology in dental prosthesis presents a promising frontier in dental medicine, yet it also raises significant regulatory, ethical, and safety considerations. These considerations are crucial to ensure the safe and effective application of AI-enabled nanomaterials in dental devices. This response will explore the regulatory pathways, data privacy and bias in AI models, and the environmental and occupational safety of nanomaterials in this context.

The regulation of AI-enabled nanomaterials in dental devices involves stringent oversight to ensure patient safety and clinical efficacy. In the European Union, nanostructured medical devices are regulated under the Medical Device Regulation (MDR 2017/745) and are typically classified as Class III devices when they pose a high or medium risk of internal exposure to nanomaterials, necessitating rigorous evaluation and Notified Body involvement[38]. Ompliance with biocompatibility and toxicity assessments is mandatory before clinical application, ensuring safety and effectiveness[39]. Globally, regulatory frameworks are fragmented; thus, efforts like the proposed Nanotechnology Risk Management and Public Health Protection Act aim to harmonize oversight to balance innovation with public health protection [40]. Additionally, agencies like the FDA emphasize rigorous testing of AI algorithms for accuracy and ethical standards, along with continuous monitoring to safeguard patient data privacy and algorithm reliability. China's NMPA has also introduced technical guidelines specifically for nanomaterials in medical devices, reflecting a growing global trend toward detailed regulation. Despite progress, challenges remain in meeting evolving international standards, managing risks related to nanomaterial biocompatibility, and addressing ethical concerns such as informed consent and data security. Therefore, manufacturers and clinicians must navigate a complex regulatory landscape combining risk classification, conformity assessments, and ongoing ethical considerations to ensure the safe, effective use of AI-enabled nanomaterials in dental prosthetics [38].

The European Artificial Intelligence Act (AIA), approved in 2024, mandates that AI systems in dentistry be trustworthy and human-centered, focusing on generalizability, fairness, and transparency to build user trust[41]. AI models must undergo rigorous validation to ensure accuracy and reliability, with particular attention to eliminating biases that could lead to unequal treatment outcomes [42]. Furthermore, given the sensitive nature of dental patient data, strict compliance with data privacy regulations is essential to safeguard personal information and maintain patient trust [41].

The use of nanomaterials in dental prosthetics raises important concerns regarding toxicity and environmental impact. Nanoparticles exhibit unique properties that necessitate thorough toxicological evaluations to understand their potential adverse effects on human health and the environment. Studies reveal that nanoparticles can penetrate respiratory systems during clinical procedures, potentially causing respiratory issues and chronic inflammation similar to asbestos exposure. Furthermore, nanoparticles may translocate through the blood-brain barrier, inducing oxidative stress, neuroinflammation, and cellular damage in the central nervous system[43]. Occupational safety is also a significant concern, emphasizing the need for protective measures and protocols for handling nanomaterials to mitigate inhalation risks[44]. Ethically, transparent communication about risks and responsible practices are vital to balance technological innovation with societal well-being and build public trust in nanotechnology [45]. To ensure patient safety and environmental protection, comprehensive regulatory, ethical, and safety frameworks are crucial. These should include rigorous preclinical and clinical toxicological assessments, continuous monitoring, and development of international standards guiding the responsible use of AI-driven nanotechnology in dentistry. Such efforts will enable the benefits of these advanced materials to be harnessed without compromising health or environmental integrity [43].

Challenges and Barriers

The integration of AI and nanotechnology in dental prosthesis presents significant advancements, yet it also faces several challenges and barriers. These challenges are critical to address for the successful implementation and widespread adoption of these technologies in dental practices. The primary challenges include gaps in standardization, scalability issues, and integration into existing dental workflows.

In the evolving landscape of dental prosthetics, the integration of AI continues to present significant opportunities alongside notable challenges. One major hurdle is the absence of standardized protocols for reporting and evaluating AI applications, which limits the ability to effectively compare outcomes across various studies and clinical settings. This lack of consistency directly impacts the reproducibility of results and undermines the overall reliability of AI-driven solutions in dental practice[46]. Moreover, the success of AI in prosthodontics is highly contingent upon access to large, high-quality datasets. Unfortunately, such extensive datasets remain scarce, creating a substantial obstacle to the robust development and validation of AI models tailored for dental applications. In addition to these issues, the transparency of AI algorithms remains a pressing concern. The opaque nature of many AI systems makes it difficult for practitioners to understand how specific decisions or predictions are derived, which can erode trust and impede wider acceptance within the dental community [4]. Addressing this concern is crucial, as developing explainable AI models would foster greater confidence among clinicians, encouraging the responsible and informed use of these technologies. Overall, overcoming these interlinked challenges of standardization, data quality, and algorithmic transparency is essential for realizing the full potential of AI in dental prosthetics, ensuring the technology's safe, effective, and ethical deployment in clinical practice.

The integration of AI-driven nanotechnology in dental prosthetics faces significant manufacturing challenges that currently limit scalability. Producing prosthetics at the nanoscale demands advanced manufacturing techniques that are still not widely accessible or cost-effective, constraining large-scale adoption[47]. Additionally, maintaining consistent quality in mass production is difficult. Variations in materials and manufacturing processes can lead to inconsistencies in the final prosthetic products, which may impact their clinical performance and patient outcomes [48]. Beyond technical hurdles, high initial costs and the need for specialized equipment and training further restrict the widespread use of AI technologies in dental practices, especially among smaller or resource-limited clinics [4].

Integrating AI and nanotechnology into dental workflows presents several significant challenges that extend beyond technology itself. The adoption of these advanced tools requires major adjustments in clinical procedures and practice management, which can be complex and time-consuming for dental professionals. Without comprehensive training programs to familiarize practitioners with AI systems, many remain hesitant to fully embrace the technology due to concerns over potential errors or inefficiencies[9]. Additionally, ethical and legal issues such as patient data privacy, consent, and liability must be rigorously addressed to ensure responsible use and maintain practitioner and patient trust [4].

Future Directions and Opportunities

The future of AI-driven nanotechnology in dental prosthesis is poised for significant advancements, with emerging technologies offering promising opportunities for innovation and improved clinical outcomes. This section explores the potential future directions and opportunities in this field, focusing on the integration of AI algorithms with multi-omics data, the development of next-generation nanomaterials, personalized prosthetics, and smart prostheses with autonomous capabilities.

AI is playing an increasingly vital role in integrating multi-omics data which encompasses genomics, proteomics, and metabolomics to enhance the design and functionality of dental prostheses. This integration allows for a deeper understanding of patient-specific biological processes, enabling dental care that is more precisely tailored to individual needs [7, 49]. Machine learning and deep learning techniques are essential in managing and analyzing these complex datasets. They facilitate the identification of new biomarkers and therapeutic targets that can improve dental treatment outcomes.

The development of advanced nanomaterials, particularly high-density polyethylene reinforced with nano-hydroxyapatite (nano-HA), significantly enhances the mechanical properties and biocompatibility of dental prosthetics. Studies show that these nano-HA composites offer improved tensile strength and elastic modulus, crucial for supporting the biomechanical demands of dental applications. The nanoindentation and compression tests reveal that nano-HA incorporation boosts properties like toughness and scratch resistance, likely due to the compact structure and uniform distribution of nanoparticles within the polymer matrix[18]. Additionally, bioactive interfaces created by nanotechnology facilitate superior integration with surrounding biological tissues. This improved osseointegration reduces the risk of prosthesis rejection and enhances the longevity of dental implants and prostheses [50].

AI-driven design combined with additive manufacturing is revolutionizing the creation of dental prosthetics, enabling highly customized solutions that cater specifically to individual anatomical and biomechanical needs. By integrating patient-specific optimization through advanced AI models, these prosthetics not only fulfill but often exceed the functional and aesthetic demands of users, enhancing overall satisfaction. The precision of these customized prostheses is further refined by high-resolution imaging and sophisticated AI algorithms employed during the design phase, resulting in improved fit and comfort for patients[18].

The integration of AI with neural interfaces and sensor technologies is ushering in a new era of smart dental prostheses that offer autonomous sensing and real-time feedback capabilities. These advanced systems are designed to adapt dynamically to changing environmental conditions and user needs, providing enhanced control and functionality that significantly improve the user experience [51]. Real-time feedback mechanisms, such as haptic sensations and vibration alerts, play a crucial role in boosting user confidence and mobility by delivering immediate sensory information about the prosthesis's position and operational status [52].

While the future of AI-driven nanotechnology in dental prosthesis is promising, several challenges remain. Data scarcity, high costs, and ethical considerations such as data privacy and algorithmic transparency pose significant hurdles to widespread implementation[51, 53]. Addressing these challenges through collaborative research and ethical guidelines will be crucial in harnessing the full potential of these technologies for global betterment [50].

CONCLUSIONS

The integration of AI and nanotechnology is revolutionizing the field of dental prosthetics by significantly advancing precision, material properties, and clinical outcomes. AI enhances diagnosis, treatment planning, and outcome prediction, while nanotechnology introduces innovative nanocomposites that improve mechanical strength, durability, and biocompatibility of prosthetic materials. These advancements have led to highly personalized dental treatments, including tooth shade selection and restoration design, which elevate patient satisfaction and overall quality of life.

Nanomaterials bolster biocompatibility by minimizing adverse reactions and extending the longevity of dental devices, essential for patient safety and treatment success. AI-driven fabrication methods demonstrate high accuracy, although the establishment of standardized protocols remains crucial to ensure reproducibility and uniform clinical efficacy across applications. Patient-centric benefits arise from combining enhanced material properties with tailored AI applications, resulting in prostheses that are both aesthetically superior and functionally optimized.

Despite these promising developments, challenges persist, notably in data availability and standardization for AI systems, as well as the need for comprehensive safety assessments and clinical trials for nanotechnology-based interventions. The path forward requires interdisciplinary collaboration to address technological, biological, and social hurdles, alongside robust regulatory frameworks to facilitate the safe integration and equitable accessibility of these technologies in clinical practice.

In summary, AI and nanotechnology have profoundly transformed dental prosthetics, offering unprecedented improvements in customization, functionality, and biocompatibility. Continued research, standardization, and collaborative efforts will be essential to overcome existing barriers, ensuring these cutting-edge technologies realize their full potential in enhancing patient care and advancing prosthodontic practice.

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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.

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