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REVIEW ARTICLE

Nanomedicine Driven Prosthodontics: Integrating Oral Implantology and Periodontal Surgery for Regenerative Dental Rehabilitation

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ABSTRACT

Nanomedicine driven prosthodontics is redefining regenerative dental rehabilitation by integrating nano engineered materials into oral implantology and periodontal surgery to achieve restorations that more closely mimic natural dentition in structure, function, and biology. This narrative review summarizes the fundamentals of nanomedicine in dentistry, including metallic, ceramic, polymeric, and hybrid nanomaterials that enhance osseointegration, promote periodontal and peri implant tissue regeneration, and provide antimicrobial and immunomodulatory effects. It then examines nanoscale surface engineering of dental implants, nano enabled drug delivery and smart coatings, and nanofibrous membranes and nano enhanced bone grafts for guided tissue and bone regeneration, highlighting how these strategies support simultaneous or staged implant–periodontal surgical protocols within an integrated treatment framework. Emerging clinical evidence is discussed, indicating that nano modified implants and nano hydroxyapatite–based regenerative systems can improve hard and soft tissue outcomes, esthetics, and patient reported satisfaction, while also shortening healing times, although long term safety, durability, and cost effectiveness remain incompletely characterized. The review further addresses safety, regulatory, and translational challenges, including nanotoxicology, protein corona effects, fragmented regulatory pathways, manufacturing complexity, and the need for clinician training, which collectively constrain widespread adoption. Finally, future directions such as smart theranostic implants, nano enabled biosensing, AI assisted personalized planning, and 4D/biofabricated scaffolds are outlined as key avenues to translate nanomedicine driven prosthodontics into predictable, chairside clinical solutions that are safe, accessible, and patient centered.

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INTRODUCTION

The global burden of tooth loss remains a major public health challenge, predominantly resulting from periodontal disease, aging, trauma, and systemic health conditions[1-3]. Conventional prosthodontic interventions such as dentures and bridges have long served as the standard for tooth replacement; however, they often present limitations in durability, comfort, and aesthetics[4, 5]. The development of dental implants has transformed prosthodontic rehabilitation by providing functionally stable and more natural-looking restorations that substantially improve oral health-related quality of life[1, 4]. Despite these advances, achieving optimal outcomes in edentulous patients with compromised bone and gingival support continues to be a considerable challenge, emphasizing the need for interdisciplinary and technology-driven approaches.

Recent progress in nanotechnology has initiated a paradigm shift toward nanomedicine-driven prosthodontics, offering innovations that enhance material performance and biological integration. Nanotechnology enables the fabrication of biomaterials with superior mechanical strength, increased surface bioactivity, and enhanced osseointegration, vital for long-term implant success[6-8]. Beyond materials science, nanomedicine contributes targeted drug delivery systems and regenerative nanomaterials that support periodontal regeneration and peri-implant tissue healing [8, 9]. Such advancements not only improve clinical outcomes but also hold future potential for autonomous nanorobotic interventions in precision dental care [6, 10].

Integrating oral implantology and periodontal surgery has therefore emerged as a holistic strategy for regenerative dental rehabilitation, particularly in patients with complex defects and severe alveolar bone loss[11, 12]. This interdisciplinary approach synergizes surgical precision with biological regeneration, aiming to restore both function and aesthetics through coordinated therapeutic planning [11]. The application of nanotechnology further refines these interventions by enhancing surgical accuracy, improving regenerative outcomes, and enabling the use of bioactive nanomaterials for tissue engineering [8, 9]. Accordingly, this review explores the emerging role of nanomedicine in prosthodontic rehabilitationfocusing on its integration within oral implantology and periodontal surgerywhile examining current challenges, economic and ethical considerations, and the future direction of clinical translation [11, 13].

FUNDAMENTALS OF NANOMEDICINE IN DENTISTRY

Nanomedicine in dentistry represents a transformative paradigm that leverages advanced nanomaterials to enhance diagnosis and treatment in prosthodontics, oral implantology, and periodontal surgery. Metallic nanoparticles such as silver, zinc oxide, and titanium dioxide provide potent antimicrobial activity and can improve implant osseointegration, thereby supporting more predictable prosthetic rehabilitation[14-16]. Nanostructured polymers are used as biocompatible carriers for controlled drug delivery and as scaffolds for tissue engineering in periodontal and peri-implant regeneration [17, 18]. Likewise, nanoceramics such as hydroxyapatite closely resemble the mineral phase of bone, promoting hard tissue regeneration and stable implant anchorage, while hybrid nanomaterials combine complementary featuresmechanical reinforcement, bioactivity, and antimicrobial performanceto optimize clinical outcomes [16, 19]. Together, these systems take advantage of the high surface area-to-volume ratio and tunable physicochemical properties of nanomaterials to achieve precise control over material behavior, positioning nanomedicine as a promising foundation for regenerative dental rehabilitation[20].

The nanoscale size (typically 1–100 nm) of these structures allows deep penetration into oral tissues and lesions, improving therapeutic efficacy while enabling more intimate interactions with cells and extracellular matrices [20]. Key physicochemical parametersincluding particle size, surface charge, and surface functionalizationgovern their biological interactions, influencing cellular uptake, biodistribution, and targeting specificity in applications such as drug delivery, tissue engineering, and bioactive implant coatings [21]. Nanostructured implant surfaces enhance osseointegration by better mimicking the hierarchical architecture of natural bone, while selected nanomaterials can stimulate angiogenesis, which is critical for the success of regenerative procedures in periodontal and peri-implant tissues [17, 22]. In parallel, many nanoparticles exhibit strong antimicrobial effects that reduce biofilm formation and infection risk around

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prostheses and implants, and some systems have demonstrated immunomodulatory capabilities, attenuating inflammation and promoting more favorable healing responses in oral tissues[23]. Collectively, these attributes underscore the central role of nanomedicine in shaping next-generation prosthodontic and surgical strategies for regenerative dental rehabilitation.

NANOTECHNOLOGY IN ORAL IMPLANTOLOGY

Nanoscale surface engineering of dental implants has emerged as a key strategy to enhance early biological responses at the boneimplant interface, particularly by tailoring nano-topography, coatings, and functional layers. Nanoscale roughness and patterning increase surface energy and provide biomimetic cues that promote rapid cell adhesion, osteoblast differentiation, and earlier bone–implant contact, thereby supporting faster and more predictable osseointegration [22, 24]. Techniques such as plasma spraying, electrochemical anodization, sputtering, ion implantation, and acid etching are widely employed to generate hierarchical micro/nano features that better resemble the architecture of natural bone and extracellular matrix, improving both mechanical interlocking and biological integration [25]. In parallel, bioactive coatingsincluding titanium dioxide and calcium phosphate or hydroxyapatite-based nanoscale layersare applied to implant surfaces to enhance osteoconductivity and serve as reservoirs for growth factors, antimicrobial agents, or other biomolecules, thereby modulating local tissue responses at the implant site [24-26]. Collectively, these nanoscale modifications have been shown to improve early cell adhesion, osteoblast maturation, bone-to-implant contact, and may contribute to shorter healing times and reduced biological complications [24, 27].

In addition to surface texturing, the choice and nano-engineering of bulk biomaterials for fixtures and abutments are central to optimizing both functional and esthetic outcomes. Titanium and its alloys remain the gold standard for implant fixtures due to their favorable mechanical strength and biocompatibility; when their surfaces are nano-engineered (e.g., via nanotubes, nanoparticle coatings, or nano-roughened oxide layers), they exhibit enhanced osseointegration, improved bioactivity, and, in some designs, antimicrobial effects that reduce the risk of peri-implant infection [28, 29]. For esthetic zones, zirconia and advanced composite nanomaterials are frequently used for abutments, where nanoscale tailoring of surface characteristics aims to support soft-tissue adhesion, color stability, and a more natural emergence profile, contributing to superior esthetic integration [30, 31]. Beyond passive surface design, nanotechnology also enables local drug and growth factor delivery systems at implant sites, including nanoparticle- or nanotube-based reservoirs that release antimicrobials, anti-inflammatory agents, or osteoinductive molecules in a controlled manner to prevent peri-implant infections and accelerate tissue regeneration [28, 30]. More recently, smart and stimuli-responsive nanosystemstriggered by local pH, temperature, or enzymatic activityhave been proposed to achieve on-demand release of therapeutics and dynamic modulation of peri-implant tissue responses, potentially further improving long-term implant success [25, 29].

NANOMEDICINE IN PERIODONTAL SURGERY AND REGENERATION

Nanomedicine has emerged as a transformative approach in periodontal surgery and regeneration, offering innovative solutions to enhance tissue repair and regeneration. This field leverages nanotechnology to develop advanced materials and strategies that address the limitations of traditional periodontal treatments. The integration of nanomedicine in periodontal surgery is primarily focused on three key areas: nanofibrous scaffolds and membranes, nano-enhanced bone grafts and substitutes, and nano-based antimicrobial and anti-inflammatory strategies. Each of these areas contributes uniquely to the advancement of periodontal regeneration.

Electrospinning is a prominent technique used to create nanofibrous scaffolds that mimic the extracellular matrix, promoting cell attachment and proliferation. These scaffolds can be functionalized with bioactive molecules to enhance their regenerative capabilities[32-34]. Nanofibrous scaffolds have shown potential in promoting the regeneration of periodontal tissues, including the periodontal ligament, cementum, and alveolar bone. These scaffolds act as barriers to prevent epithelial downgrowth, facilitating the regeneration of underlying tissues[35].

Nano-enhanced materials such as nanocrystalline hydroxyapatite and bioactive glass are used in bone grafts to improve their osteoconductive and osteoinductive properties. These materials support bone regeneration by providing a scaffold for new bone growth[36, 37]. The integration of nano-enhanced grafts with host bone is crucial for successful regeneration. These materials exhibit superior mechanical properties and biocompatibility, which are essential for maintaining the structural integrity of regenerated bone[37].

Nanoparticles are employed in local delivery systems to provide targeted and controlled release of antimicrobial and anti-inflammatory agents. This approach enhances the efficacy of treatments by directly addressing the site of infection and inflammation[8, 9]. Nanoparticles can disrupt biofilms and control infections such as peri-implantitis and periodontitis. This is achieved through the enhanced penetration and retention of nanoparticles in periodontal pockets, leading to improved therapeutic outcomes[8, 9].

While nanomedicine offers promising advancements in periodontal surgery and regeneration, it is important to consider the challenges and limitations associated with its application. The translation of nanotechnology-based solutions from laboratory research to clinical practice requires rigorous testing and validation to ensure safety and efficacy. Additionally, the cost and complexity of developing and implementing these advanced materials may pose barriers to widespread adoption. Nonetheless, ongoing research and innovation in nanomedicine continue to drive progress in the field, with the potential to revolutionize periodontal therapy and improve patient outcomes.

INTEGRATING ORAL IMPLANTOLOGY AND PERIODONTAL SURGERY: A NANOMEDICINE-DRIVEN FRAMEWORK

Integrating oral implantology and periodontal surgery through a nanomedicine-driven framework involves a comprehensive approach that combines advanced treatment planning, surgical protocols, and prosthodontic considerations. This integration aims to enhance regenerative dental rehabilitation by leveraging nanotechnology to improve outcomes in both hard and soft tissue management. The following sections outline the key components of this framework.

Effective treatment planning begins with selecting suitable patients and assessing risks associated with periodontal and peri-implant diseases. Defect classification is crucial for tailoring regenerative strategies to individual needs, considering factors such as defect size and location, which influence treatment complexity and outcomes[38]. The use of digital tools, such as Digital Smile Design and 3D imaging, facilitates precise planning and execution of combined procedures. These technologies enable practitioners to visualize the treatment outcomes and make informed decisions regarding surgical interventions and prosthetic designs[39, 40].

In regenerative implant and periodontal surgery, clinicians must decide between simultaneous and staged protocols based on the specific clinical situation. Simultaneous interventions, such as immediate implant placement combined with bone augmentation, can shorten overall treatment time but may increase surgical complexity and risk in less favorable sites [11, 39]. In contrast, staged procedures separate the regenerative and implant placement phases, which can facilitate more predictable management of challenging defects and compromised tissues [11, 39]. Across both strategies, the incorporation of nano-enhanced biomaterials has become increasingly important. Nanoscale modifications, including the use of nano-hydroxyapatite and nanofiber-based scaffolds, have been shown to promote superior osseointegration and soft-tissue attachment, ultimately supporting more stable and favorable clinical outcomes in periodontal and peri-implant regeneration [38].

Nano-engineered components within prosthodontic systems influence occlusal schemes, load distribution, and overall prosthesis design by improving mechanical strength, wear resistance, and fit accuracy, which in turn supports long-term stability and higher patient satisfaction [41]. At the same time, nanotechnology-driven strategies increasingly target esthetic outcomes through refined soft-tissue management and optimized emergence profiles, as stable peri-implant mucosa and harmonious gingival contours are essential for natural-looking restorations and sustained peri-implant health [41]. Despite these advantages, the clinical translation of nanomedicine in oral implantology and periodontal surgery is tempered by several challenges, including the higher costs of nano-enhanced systems and the requirement for specialized training, which may limit their widespread adoption. Furthermore, the long-term safety, stability, and biological behavior

Table 1. Nanomedicinedriven strategies in prosthodontics, oral implantology, and periodontal surgery: principal applications, mechanisms, and clinical benefits

Domain/Section of review	Nanotechnology / nanomaterial strategy	Primary application	Mechanism / key features
Prosthodontics / smart prostheses	Nano-engineered restorative materials, nano-composites	Fixed and removable prostheses	Enhanced mechanical strength, wear resistance, and lifelike optical properties at the nanoscale
Oral implantology – surfaces	Nanoroughened titanium, titania nanotubes, nano-HA or CaP coatings	Implant fixtures and abutments	Increased surface energy and biomimetic nano-topography that promote osteoblast adhesion and bone–implant contact
Oral implantology – drug delivery	Nanotube / nanoparticle drug reservoirs on implant surfaces	Local delivery of antimicrobials, anti-inflammatories, growth factors	Controlled, stimuli-responsive release triggered by pH, enzymes, or time
Periodontal surgery – scaffolds/membranes	Electrospun nanofibrous membranes and scaffolds	Guided tissue regeneration, periodontal ligament and bone repair	ECM-mimicking nanofibers functionalized with bioactive molecules
Periodontal surgery – bone grafts	Nano-hydroxyapatite and nano-bioactive glass	Periodontal and alveolar bone grafting	High surface area, biomimetic mineral phase supporting osteoconduction and osteoinduction
Antimicrobial strategies	Metallic nanoparticles (Ag, ZnO, TiO_2), chitosan-based nanocoatings	Control of peri-implant and periodontal biofilms	Broad-spectrum antibacterial activity, biofilm disruption at the implant–tissue interface
Regenerative/theranostic systems	Theranostic nanoplatforms, nano-enabled scaffolds with stem cells	Combined diagnosis and therapy in complex defects	Targeted delivery plus real-time biosensing or imaging
Safety and regulation	Nanotoxicology and regulatory frameworks	Risk assessment and translation	Evaluation of size, surface chemistry, protein corona formation; harmonized evaluation protocols

of nano-modified materials still demand robust, long-term clinical evidence to confirm their efficacy and biocompatibility across diverse patient populations.

CLINICAL EVIDENCE AND OUTCOMES

The integration of nanotechnology in prosthodontics, particularly in oral implantology and periodontal surgery, has shown promising potential for regenerative dental rehabilitation. This approach leverages the unique properties of nanomaterials to enhance the outcomes of dental implants and periodontal regeneration. The following sections provide a detailed exploration of the clinical evidence and outcomes associated with nano-modified implants and periodontal regeneration. To provide an integrated overview of the current landscape, the main nanomedicine-based strategies discussed in this review are summarized in Table 1. The table organizes approaches according to their clinical domain, underlying nanoscale mechanisms, and anticipated or reported benefits in regenerative dental rehabilitation. This framework highlights how converging developments in materials science, drug delivery, and antimicrobial design collectively support more predictable prosthodontic and periodontal outcomes.

Nanomaterials have emerged as key tools in periodontal regeneration, where they are engineered to more closely reproduce the architecture and biology of native tissues. Nanostructured systems such as nano-hydroxyapatite can act as biomimetic scaffolds that resemble the mineral phase of alveolar bone, thereby supporting cell adhesion, proliferation, and osteogenic differentiation to promote more predictable regeneration of periodontal structures [42, 43]. In parallel, nano-scale surface modifications of dental implants, including titania nanotubes and other nanoroughened interfaces, have been designed to accelerate osseointegration by enhancing boneimplant contact and can also function as local reservoirs for drugs, growth factors, or other bioactive molecules, extending the therapeutic function of the implant beyond simple structural

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support [30]. Moreover, the incorporation of nanoparticles with intrinsic antibacterial activitysuch as certain metal nanoparticles or chitosan-based nanocoatingsoffers a strategy to inhibit biofilm formation and reduce the risk of peri-implantitis, thereby improving the long-term stability and survival of implant-supported prostheses [30].

Clinical data indicate that nano-hydroxyapatite can meaningfully enhance periodontal outcomes when used adjunctively with conventional nonsurgical therapy. In a clinical trial where nano-hydroxyapatite was applied in combination with scaling and root planing, patients demonstrated greater improvements in standard periodontal indices and esthetic parameters than those treated with traditional modalities alone, along with reduced inflammatory marker levels and faster postoperative recovery in the nano-treated sites [42]. Building on these findings, broader analyses and systematic reviews have underscored the promise of nanotechnology-based strategiesranging from nano-enabled scaffolds integrated with stem cells to nanocarrier-mediated gene deliveryin making periodontal regeneration more predictable and durable, with the overarching goal of increasing the success rates and stability of regenerative procedures over the long term [44].

Nano-modified implants have been linked to favorable functional outcomes, including faster and more robust osseointegration and reduced probing depths around implant sites, which together support greater stability and long-term functionality of implant-supported prostheses [30, 42]. At the same time, the application of nanomaterials in periodontal regeneration has been associated with superior esthetic results, reflected in higher postoperative esthetic scores, largely because these nanostructured materials can closely reproduce the architecture and optical properties of natural periodontal tissues [42]. From the patient's perspective, nano-based interventions often translate into higher satisfaction, as clinical studies report advantages such as shortened treatment times, fewer postoperative complications, and improved overall comfort, which in turn enhance quality of life and promote better adherence to maintenance protocols [8]. Nonetheless, the broader clinical adoption of nanotechnology in dental rehabilitation must be weighed against important limitations: the long-term biological behavior and potential adverse reactions of nano-modified implants remain incompletely characterized, and economic and logistical factorssuch as higher costs and limited access to specialized materials and trainingmay restrict routine use. Despite these challenges, ongoing advances in nanomedicine continue to drive innovative concepts in prosthodontics and periodontal therapy, opening new avenues for predictable, regenerative dental care.

SAFETY, REGULATORY, AND TRANSLATIONAL CONSIDERATIONS

The integration of nanomedicine into prosthodontics, particularly in oral implantology and periodontal surgery, presents a promising frontier for regenerative dental rehabilitation. However, this advancement is accompanied by significant safety, regulatory, and translational considerations. These considerations are crucial for ensuring the successful adoption and implementation of nanomaterials in clinical practice. The following sections delve into the key aspects of biocompatibility, regulatory challenges, and practical barriers to adoption.

Biocompatibility remains a central challenge in the clinical translation of nanomaterials, because their high surface area and unique reactivity at the nanoscale can trigger unexpected interactions with cells, proteins, and immune pathways. To systematically evaluate these risks, the dedicated field of nanotoxicology has developed, aiming to characterize how size, shape, composition, and surface chemistry influence potential adverse effects in medical applications [45]. In dental applications, inorganic metallic nanoparticles such as silver and zinc oxide are attractive for their strong antimicrobial activity against oral pathogens, yet at higher concentrations or with prolonged exposure they may exert cytotoxic effects on host cells, raising concerns about dose, exposure time, and delivery systems. Beyond biocompatibility, the long-term stability of nanoparticle systems in the oral cavity is equally critical, as fluctuations in pH, mechanical forces, saliva components, and enzymes can promote degradation, aggregation, or loss of functional coatings, thereby reduce efficacy and alter safety profiles over time [46]. A further layer of complexity arises from the formation of a protein coronaa dynamic layer of adsorbed salivary and serum proteins on the nanoparticle surfacewhich can dramatically change the particle's biological identity, affecting cell uptake, immune recognition, and overall biocompatibility.

The regulatory environment governing nanomedicine is highly fragmented, with no unified global framework, which creates substantial barriers to efficient clinical translation [47]. The lack of standardized evaluation protocols and internationally accepted guidelines makes it difficult to consistently assess the safety and efficacy of nanomaterials, complicating authorization procedures and slowing down approval processes [48]. As regulatory expectations differ across jurisdictions, this lack of harmonization can deter innovation and delay the widespread adoption of nanomedicine-based products [49]. At the same time, the distinctive, size-dependent properties of nanomaterials underscore the need for dedicated regulatory standards, analytical methods, and quality control frameworks tailored to nanoscale systems [49]. Establishing robust procedures to ensure reproducible quality and safety is essential if nanomaterials are to be reliably integrated into medical devices and therapeutic strategies [50].

Incorporating nanomaterials into routine dental care raises important economic, practical, and social considerations. The development and scale-up of nanoparticle-based systems often require highly controlled manufacturing processes, which can make these technologies expensive and challenge their overall cost-effectiveness; these expenses are further compounded by the need for specialized equipment and clinician training at the practice level [46]. For nanomedicine to be realistically adopted chairside, nano-enabled products must be sufficiently user-friendly and compatible with existing clinical workflows, as complex handling, preparation, or application procedures can deter busy practitioners from integrating them into daily practice [51]. Beyond cost and usability, broader adoption is also influenced by public and professional perceptions: concerns about long-term safety, potential toxicity, and ethical implications of nanotechnology may make both patients and clinicians cautious, slowing its introduction into clinical settings [52]. To overcome these barriers, transparent, evidence-based communication and education regarding the benefits, limitations, and safeguards of nanomedicine are essential, helping to build trust and informed acceptance [45]. Overall, while nanomedicine holds substantial promise for transforming prosthodontics, its successful integration into dental practice depends on a balanced strategy that promotes innovation while rigorously ensuring safety, efficacy, and practicality, supported by close collaboration among researchers, clinicians, regulators, industry, and the public.

FUTURE DIRECTIONS IN NANOMEDICINE - DRIVEN PROSTHODONTICS

The future of nanomedicine-driven prosthodontics is poised to revolutionize dental care by integrating advanced technologies such as smart implants, personalized treatment planning, and emerging nanomaterials. These innovations promise to enhance the precision, efficacy, and patient outcomes in oral implantology and periodontal surgery. The following sections explore these future directions in detail, highlighting the potential of nanotechnology to transform prosthodontics.

Smart, nanotechnology-enabled implant systems are poised to expand the functionality and durability of dental prostheses by integrating active biological and digital features into the implant–tissue interface. Next-generation "smart" implants can be nano-engineered to promote stronger osseointegration while incorporating antibacterial surfaces or drug-releasing coatings, thereby lowering infection risks and supporting more stable long-term bone anchorage [28]. Building on these advances, nanoscale biosensing elements can be embedded within restorative systems or adjunctive devices to continuously monitor key oral parameterssuch as pH, bacterial load, or specific inflammatory biomarkersin real time, enabling early detection of peri-implant disease or other complications and allowing clinicians to intervene before irreversible damage occurs. In parallel, theranostic nanoplatforms are being designed to combine targeted delivery of antimicrobial, anti-inflammatory, or regenerative agents with on-board diagnostic readouts, so that the same nano-system can both treat localized pathology and provide feedback on therapeutic response, ultimately supporting more personalized and adaptive management of complex oral conditions [51].

Artificial intelligence is increasingly reshaping prosthodontics by strengthening both diagnostic insight and treatment planning, enabling clinicians to move from standard protocols toward genuinely personalized rehabilitation. By processing large volumes of clinical, radiographic, and biomechanical data, AI systems can forecast

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treatment outcomes, optimize implant positioning, and customize prosthesis design so that occlusion, load distribution, and esthetics are better aligned with each patient's specific anatomical and functional profile. In parallel, individualized plans can be coupled with nano-regenerative strategies, including nanostructured scaffolds and bioactive nanomaterials that are selected or engineered to match the patient's defect morphology and regenerative capacity, thereby enhancing tissue repair around implants and periodontal surgical sites [53]. When AI-driven planning is integrated with these nano-enabled regenerative approaches, it supports more predictable osseointegration and soft-tissue healing, ultimately improving the long-term success of dental implants and periodontal interventions [53].

The development of 4D scaffolds, which can change shape or properties over time in response to environmental stimuli, represents a significant advancement in tissue engineering. These scaffolds can be used to guide tissue regeneration in a dynamic and controlled manner[53]. Nanotechnology enables the creation of bioactive coatings for dental implants that enhance biocompatibility and promote osseointegration. These coatings can also provide antimicrobial protection, reducing the risk of implant failure[28]. The use of cell-laden constructs in biofabrication allows for the creation of complex tissue structures that mimic natural tissues. These constructs can be used in regenerative dental therapies to repair and replace damaged tissues.

While the potential of nanomedicine-driven prosthodontics is immense, challenges remain in terms of regulatory compliance, long-term safety, and the clinical translation of these technologies. Addressing these challenges will be crucial for the successful integration of nanotechnology into routine dental practice. Additionally, the ethical implications of using AI and nanotechnology in healthcare must be carefully considered to ensure patient safety and privacy.

CONCLUSION

Nanomedicine is redefining contemporary prosthodontics by enabling restorations that more closely reproduce the appearance, biomechanics, and biology of natural dentition. Nano-engineered materials can be tailored to deliver highly lifelike optical properties alongside improved strength and wear resistance, supporting restorations that are both esthetic and long-lasting. At the same time, functionalization at the nanoscale allows for antibacterial activity and localized therapeutic delivery, adding a biological dimension to prosthetic components that traditionally served only structural or cosmetic roles. Within regenerative dental rehabilitation, nanoscale surface modifications of implants and adjunctive nano-enabled regenerative therapies in periodontal surgery have strengthened the link between osseointegration, soft-tissue health, and prosthetic success, promoting more stable and predictable long-term outcomes.

Despite these advances, important questions remain regarding the long-term safety, durability, and real-world performance of many nano-based systems, underlining the need for rigorous preclinical testing and well-designed clinical trials. Cost, manufacturing complexity, and the need for specialized expertise can also limit accessibility, particularly in resource-constrained settings, and may slow the routine integration of nanotechnologies into everyday dental practice. Future progress will depend on continued innovation in material design, careful assessment of biological responses over extended timeframes, and the development of clinically feasible workflows that translate sophisticated nano-regenerative concepts into reliable chairside solutions. Close collaboration among materials scientists, bioengineers, pharmacologists, and dental clinicians will be essential to address current knowledge gaps and ensure that nanomedicine-driven prosthodontics evolves in a way that is safe, effective, and genuinely beneficial for patients.

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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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