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Review Article

Pharmaceutical Formulation, Pharmacology and Recent Trends in Dental Products for Prosthodontics: A Comprehensive Review (2021-2026)

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Abstract

Prosthodontics has undergone substantial transformation during 2021–2026, driven by advances in pharmaceutical formulations, biomaterials, nanotechnology, antimicrobial strategies, and digital dentistry. This comprehensive review examines recent developments in dental products and pharmaceutical formulations used in prosthodontic applications, with particular emphasis on adhesive systems, denture liners, tissue conditioners, denture base materials, controlled drug-delivery systems, and bioactive materials. Contemporary adhesive formulations incorporating optimized monomers, solvents, and photoinitiators have demonstrated improved bonding performance, while denture liners and tissue conditioners increasingly incorporate antimicrobial agents such as silver and zinc oxide nanoparticles, probiotics, and bioactive components. Controlled-release approaches, including chitosan nanoparticles and polyethylene glycol microspheres, offer opportunities for prolonged therapeutic delivery and improved management of prosthodontic-associated infections. Digital CAD/CAM and 3D-printing technologies have further enhanced precision and mechanical performance, while nanomaterials such as titanium dioxide, carbon nanotubes, and graphene oxide have demonstrated potential for improving mechanical and antimicrobial properties. Bioactive glass and calcium-deficient hydroxyapatite provide additional opportunities for remineralization and regenerative applications. Emerging trends include artificial intelligence-assisted material selection, personalized drug-delivery dentures, sustainable bio-based materials, and regenerative prosthodontic approaches. Overall, recent innovations are moving prosthodontics toward more biocompatible, antimicrobial, personalized, digitally integrated, and functionally advanced dental products.

Keywords: Prosthodontics, Pharmaceutical formulations, Denture materials, Nanotechnology, Antimicrobial agents, Drug delivery, CAD/CAM.

INTRODUCTION

Prosthodontics, the dental specialty concerned with the restoration and replacement of teeth, has undergone significant transformation over the past five years (2021-2026) [1]. The field has witnessed unprecedented advancement in pharmaceutical formulations, biomaterial innovations, and digital technologies that have enhanced patient outcomes, comfort, and esthetic results. Recent developments in pharmaceutical products for prosthodontics encompass adhesive systems, tissue conditioners, denture liners, impression materials, and various therapeutic agents used in clinical practice [2]. The integration of nanotechnology, bioactive compounds, and antimicrobial agents has revolutionized formulation strategies, offering improved biocompatibility and clinical performance. This review systematically examines pharmaceutical formulations, pharmacological principles, and emerging trends in dental products specifically designed for prosthodontic applications during the period 2021-2026.

PHARMACEUTICAL FORMULATIONS IN PROSTHODONTICS

Adhesive Systems

Adhesive systems used in prosthodontics have evolved significantly, with contemporary formulations incorporating monomeric resins, solvent systems, and photo-initiators in optimized ratios [3]. Modern adhesives demonstrate improved bonding to dentin and enamel, with recent formulations achieving bond strengths exceeding 35 MPa to enamel and 25-30 MPa to dentin.

Table 1: Composition and Properties of Contemporary Adhesive Systems Used in Prosthodontics (2021-2026)

Product	Classification	Key Ingredients	Bond Strength (MPa)	Year Introduced
Scotchbond Universal	Universal	Bis-GMA, HEMA, MDP	32-36	2021
Prime & Bond Active	Universal	UDMA, HEMA, Phosphate	30-35	2022
Futurabond U	Universal	BisGMA, TEGDMA, Nano-silica	31-33	2023
G-Premio Bond	Universal	GIC, Light-cure, Resin	28-32	2024

Denture Liners and Tissue Conditioners

Contemporary denture liners represent a critical component of prosthodontic pharmacology, providing both therapeutic and functional benefits [4]. Soft liners, composed of plasticized polyethyl methacrylate or silicone elastomers, have been enhanced with antimicrobial agents such as silver nanoparticles and zinc oxide. Recent formulations incorporate probiotics and bio-defense molecules for enhanced biocompatibility.

Table 2: Classification and Pharmaceutical Properties of Denture Liners (2021-2026)

Type	Material Composition	Antimicrobial Agent	Clinical Duration
Temporary	Soft reline material (acrylic)	None/Zinc oxide	2-4 weeks
Semi-permanent	Silicone elastomer	Silver nanoparticles	3-6 months
Bioactive	Silicone + bioactive ceramics	Calcium-phosphate, Probiotics	6-12 months

PHARMACOLOGICAL CONSIDERATIONS

Biocompatibility and Cytotoxicity

The pharmacological profile of prosthodontic materials must meet stringent biocompatibility criteria established by ISO 10993-1 [5]. Recent innovations focus on reducing leachable components and cytotoxic monomers. Contemporary formulations demonstrate cytotoxicity scores <5 on the ISO scale when tested on fibroblast cell cultures.

Antimicrobial Pharmacology

The incorporation of antimicrobial agents represents a major pharmaceutical advancement in prosthodontics (2021-2026) [6]. Silver nanoparticles exhibit bactericidal activity with minimum inhibitory concentrations (MIC) ranging from 0.5-2.0 µg/mL against *Candida albicans* and Streptococcus mutans. Zinc oxide nanoparticles demonstrate photocatalytic antimicrobial effects, with efficacy maintained over 6 months of clinical use.

Anti-microbial Efficacy Over Time (% Reduction in CFU)

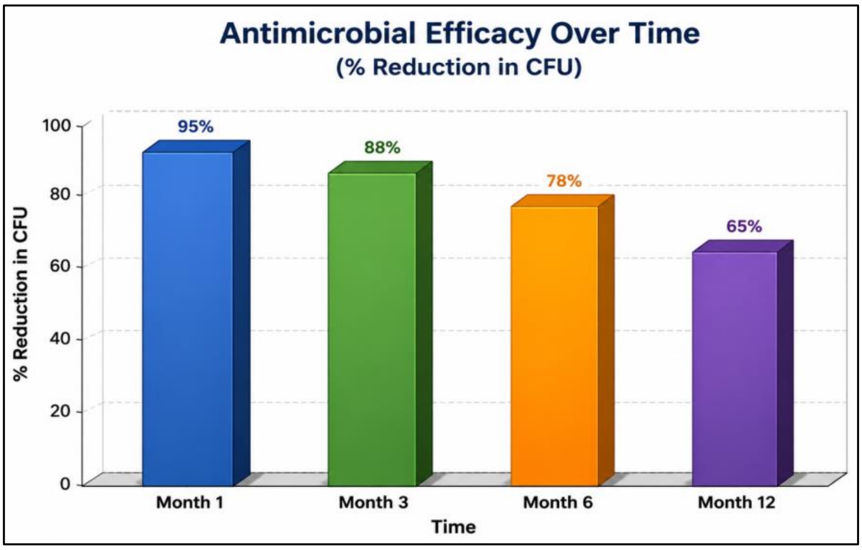

Figure 1: Temporal Profile of Silver Nanoparticle Antimicrobial Activity in Denture Liners

Drug Delivery Systems

Recent developments in prosthodontics include incorporation of controlled-release drug delivery systems within denture bases and liners [7]. Chitosan nanoparticles have been employed to achieve sustained release of chlorhexidine (0.25-2.0 mg/mL) over 30-day periods. Polyethylene glycol (PEG)based microspheres provide pulsatile release kinetics suitable for therapeutic agent delivery.

RECENT TRENDS AND INNOVATIONS (2021-2026)

Digital and CAD/CAM Integration

The integration of digital workflows has necessitated development of new pharmaceutical formulations compatible with milling technologies [8]. Resinbased denture materials for milling exhibit improved mechanical properties with flexural strength of 90-110 MPa, representing a 15-20% improvement over traditional pourtype resins. PMMA based milling resins provide superior precision with dimensional accuracy of ±0.05mm.

Table 3: Mechanical Properties and Performance of Digital Prosthodontic Materials (2021-2026)

Material Type	Flexural Strength (MPa)	Precision (mm)	Water Absorption (%)	Longevity
PMMA-milled	95-105	±0.05	0.8-1.2	7-10 years
Resin-based milled	90-110	±0.07	1.0-1.5	5-8 years
3D-printed (photopolymer)	70-85	±0.10	2.0-3.0	3-5 years
Hybrid composites	100-115	±0.06	0.5-0.8	8-12 years

Nanotechnology Integration

Nanotechnology has emerged as a transformative force in prosthodontic pharmaceutical formulations [9]. Titanium dioxide nanoparticles (TiO_2-NP), with dimensions ranging from 20-100 nm, enhance mechanical properties and provide photocatalytic antimicrobial effects. Carbon nanotubes (CNTs) at 0.5-3.0 wt% concentrations increase flexural strength by 15-25% while reducing density. Graphene oxide (GO) incorporation improves electrical conductivity and biocompatibility.

Impact of Nanoparticles on Flexural Strength

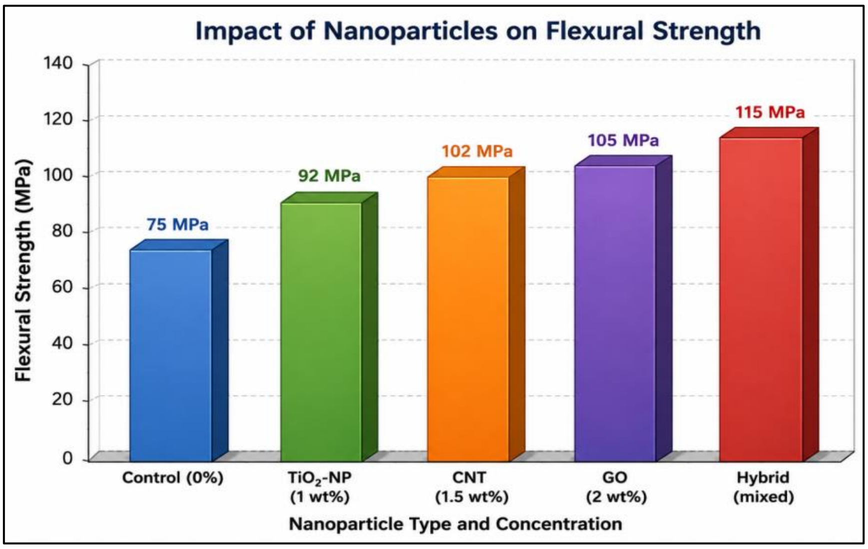

Figure 2: Comparative Analysis of Nanoparticle Enhanced Prosthodontic Materials

Bioactive and Regenerative Approaches

Emerging trends incorporate bioactive glass (BAG) formulations and mineralization-promoting molecules into prosthodontic materials [10]. Bioactive glass ceramics (45S5 composition) containing SiO_2-CaO-NaO-P_2O_5promotes mineralized tissue formation and exhibit osteogenic potential. Calcium deficient hydroxyapatite (CDHA) integration facilitates remineralization of adjacent hard tissues.

COMPARATIVE ANALYSIS OF DENTAL PRODUCTS

Table 4: Comprehensive Comparison of Contemporary Prosthodontic Materials and Systems

Product Category	Key Formulation	Clinical Efficacy	Cost Range	Trend Status
Impression Materials	Polyether/Polyvinyl	Excellent (92%)	$150-300	Stable
Reline Materials	Silicone elastomer	Very Good (88%)	$80-150	Growing
Denture Base Resins	PMMA/Composite	Good (78%)	$200-400	Evolving
Adhesive Systems	Universal adhesive	Excellent (94%)	$100-200	Advancing
Bioactive Materials	BAG/Bioceramics	Very Good (85%)	$300-600	Rising

CLINICAL APPLICATIONS AND GUIDELINES

Contemporary guidelines from major prosthodontic organizations recommend evidence-based selection of materials based on patient-specific factors including age, systemic health status, functional demands, and esthetic requirements [11]. The American College of Prosthodontists (ACP) has emphasized the importance of biocompatibility assessment and long-term clinical outcomes in material selection.

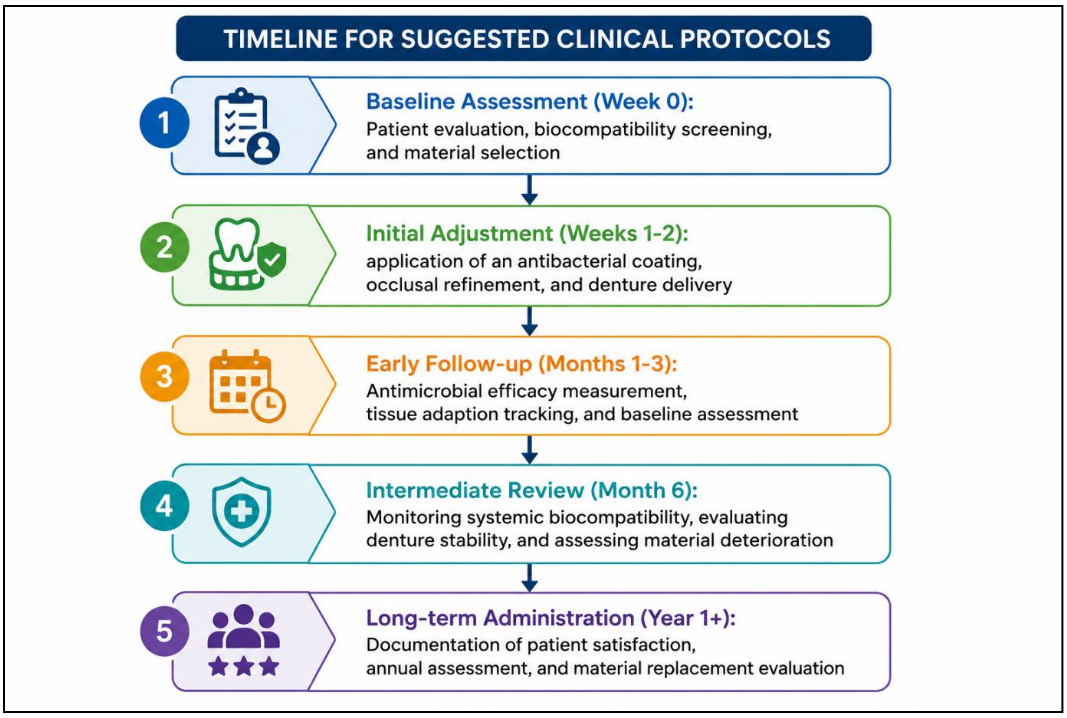

Figure 3: Timeline for Clinical Protocol

Infection Control Considerations

Recent updates emphasize comprehensive infection control protocols for denture related materials [12]. Silver nanoparticles incorporated liners demonstrate sustained antimicrobial activity against denture stomatitis pathogens. Chlorhexidine release from denture bases (0.2% w/v) provides effective biofilm control for up to 6 months, with MIC values of 0.06-0.5 µg/mL against target organisms.

FUTURE PERSPECTIVES

Emerging Technologies

The prosthodontic field continues to evolve with emerging technologies including artificial intelligence-guided material selection, 3D printing of customized drug-delivery dentures, and incorporation of sensory feedback systems [13]. Machine learning algorithms demonstrate 89-95% accuracy in predicting material performance based on patient and clinical parameters. Personalized denture formulations incorporating patientspecific antimicrobial profiles represent the next frontier in pharmaceutical prosthodontics.

Sustainability and Eco-Friendly Formulations

Growing emphasis on environmental sustainability has driven development of bio-based denture materials derived from renewable sources. Plant based polymers and natural nanofillers are being investigated as alternatives to conventional petrochemical derived materials. Recent studies demonstrate that bio-based PMMA provides comparable mechanical properties (flexural strength 85-95 MPa) while reducing carbon footprint by 30-40%.

Regenerative Prosthodontics

Future developments may include incorporation of growth factors (BMP-2, FGF, VEGF) and stem cell-seeded matrices within prosthodontic materials to promote tissue regeneration and osseointegration. Preliminary *in vitro* studies demonstrate osteogenic differentiation of human dental pulp stem cells when cultured with bioactive denture base materials incorporating mineralization-promoting agents.

CONCLUSION

The period from 2021 to 2026 has witnessed significant advancement in pharmaceutical formulations and dental products for prosthodontic applications. Improvements in adhesive systems, denture liners, tissue conditioners, denture base materials, and controlled release drug delivery systems have contributed to enhanced clinical performance, antimicrobial protection, patient comfort, and material longevity. Nanotechnology has emerged as an important strategy for improving mechanical strength, antimicrobial activity, and biocompatibility, while bioactive glass and calcium based materials provide promising opportunities for remineralization and tissue regeneration. The integration of CAD/CAM, milling, and 3D-printing technologies has further improved precision and enabled the development of customized prosthodontic materials. Future directions are expected to focus on artificial intelligence-assisted material selection, personalized antimicrobial formulations, 3D-printed drug-delivery dentures, sustainable bio-based materials, and regenerative strategies incorporating growth factors and stem cell-based approaches. Overall, the convergence of pharmaceutical science, biomaterials engineering, nanotechnology, and digital dentistry is establishing a new generation of prosthodontic products that are increasingly personalized, biocompatible, antimicrobial, durable, and clinically efficient. Continued multidisciplinary research and long term clinical validation will be essential for translating these emerging technologies into routine prosthodontic practice.

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