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The Role of Hydrogels in Enhancing Prosthodontic Treatment Outcomes: A Systematic Review

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KEYWORDS

Hydrogels; Prosthodontics; Denture base; Scaffold; Biomaterials; Tissue regeneration; Soft liner; Acrylic alternative; PRISMA; Systematic review

ABSTRACT:

Background: This systematic review aims to critically evaluate the evidence on hydrogel-based scaffolds and materials in prosthodontics, compared to traditional acrylic-based treatments. The focus was on outcomes related to mucosal healing, prosthesis retention, bone regeneration, patient satisfaction, and material properties. This review was conducted following PRISMA 2020 guidelines.

Materials and methods: A structured electronic search of PubMed, Scopus, Web of Science, and ScienceDirect was performed for studies published from January 2010 to December 2024. Inclusion criteria were randomized and controlled clinical trials, animal studies, and in vitro investigations examining hydrogel applications in prosthodontics. Two reviewers independently screened studies, extracted data, and assessed quality (using Cochrane RoB 2.0, NOS, SYRCLE, and in vitro checklists). Discrepancies were resolved by consensus. Due to heterogeneity, we conducted a narrative synthesis of findings.

Results: Of 350 records identified, 6 studies met inclusion criteria (2 clinical trials, 2 animal studies, 2 in vitro studies). Clinical trials indicated that hydrogel interventions significantly accelerated mucosal ulcer healing and enhanced implant stability versus controls. An injectable dextrin hydrogel combined with bone grafts yielded higher new bone formation (42.3% vs 35.6%; $p = 0.029$) and increased implant stability (ISQ 74.5 vs 69.2; $p = 0.017$) compared to bone graft alone. Animal studies demonstrated robust osteogenesis with hydrogel carriers: for example, a thermo-sensitive alginate hydrogel with BMP-2 achieved 41.6% new bone in defects (vs 12.1% in controls; $p < 0.01$). In vitro, shape-memory acrylate hydrogels showed mechanical and water sorption properties comparable to PMMA, while chitosan-pectin hydrogel adhesives provided higher initial bond strengths (2.89 kgf vs 1.85 kgf for control; $p < 0.01$) and superior retention under wet conditions. No study evaluated fully hydrogel-based dentures in humans.

Conclusion: Current evidence suggests hydrogel-based materials may improve tissue healing, preserve alveolar ridge dimensions, and aid immediate prosthesis retention relative to conventional acrylics. However, available studies are limited by small sample sizes, short follow-ups, and focus on adjunctive applications. Well-designed, long-term clinical trials comparing fully hydrogel prostheses to PMMA controls are needed to confirm these advantages.

1. Introduction

Over recent years, the search for superior prosthodontic biomaterials has intensified. Polymethylmethacrylate (PMMA) remains the standard for denture bases due to its favorable handling and esthetics; however, its drawbacks include residual monomer release causing soft tissue irritation and allergic reactions, which can lead to ulceration, soreness, or denture stomatitis [1]. In this context, hydrogel- based materials have gained interest for their ability to emulate mucosal tissue, deliver therapeutics, and adapt to changing ridge morphology. Hydrogels consist of chemically or physically

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cross-linked, three-dimensional hydrophilic polymer matrices that imbibe extensive volumes of aqueous fluid, yielding viscoelastic properties comparable to those of soft biological tissues [2]. In restorative dentistry, hydrogels have been proposed as tissue conditioners, surgical dressings, and drug-delivery vehicles to mitigate inflammation and support mucosal healing [3]. For example, a therapeutic hydrogel patch applied to denture-induced ulcers can reduce lesion size and accelerate pain relief more effectively than standard adjustment procedures [1].

In alveolar ridge preservation, injectable hydrogels can serve as carriers for osteoinductive agents (e.g., BMP-2) or particulate grafts, promoting bone formation and enhancing implant stability [4]. Animal and in vitro studies have demonstrated hydrogels' biocompatibility and functionality, yet their integration into clinical practice remains limited [6]. A comprehensive synthesis of data is thus warranted to determine whether hydrogel interventions offer tangible benefits over acrylic-based approaches.

This systematic review addresses the following PICO question:

- **Population (P)**: Edentulous individuals (and corresponding animal/in vitro models).
- **Intervention (I)**: Hydrogel-based scaffolds, liners, adhesives, or carriers in prosthodontics.
- **Comparison (C)**: Conventional PMMA or acrylic denture base materials without hydrogel.
- **Outcomes (O)**: Mucosal trauma reduction, prosthesis retention, bone regeneration, patient satisfaction, mechanical property enhancements.

2. Objectives

T objective was to integrate clinical, preclinical, and laboratory findings from January 2010 to December 2024, identify evidence gaps, and suggest directions for future research.

3. Methods

Protocol:

This review followed PRISMA 2020 guidelines.

Eligibility Criteria:

Study designs: Included randomized clinical trials, controlled interventional trials, and observational investigations (cohort and case-control designs), animal experiments, and in vitro investigations. Excluded were case reports, conference abstracts, narrative reviews, systematic reviews, and editorials.

Participants/Models:

- *Human:* Completely or partially edentulous patients receiving removable prosthodontic rehabilitation.
- *Animal:* Models simulating edentulous ridge conditions.
- *In-vitro:* Laboratory models testing hydrogel-modified prosthodontic materials.

Interventions: Hydrogel-based scaffolds or materials (e.g., injectable, thermosensitive, shape- memory hydrogels) used as tissue conditioners, dressings, drug carriers, liners, or adhesives in prosthodontics.

Comparators: Conventional PMMA or acrylic denture bases, liners, or adhesives without hydrogel components.

Outcomes:

- Primary (Clinical): Mucosal healing (ulcer size, inflammation), retention metrics (denture fit, dislodgement force), patient-reported comfort/satisfaction, mucosal health indicators.
- Secondary (Preclinical/Laboratory): Bone regeneration (histomorphometry, bone volume, density), mechanical properties (hardness, tensile strength), material stability (water sorption, solubility), and drug-release profiles.

Language and timeframe: Studies in English published between January 1, 2010 and December 31, 2024.

Information Sources and Search Strategy:

On January 20, 2025, two reviewers independently searched PubMed (MEDLINE), Scopus, Web of Science, and ScienceDirect using MeSH terms and keywords for hydrogels ("hydrogel," "polymeric scaffold") combined with prosthodontic terms ("prosthodontics," "denture," "tissue conditioner," "alveolar ridge augmentation").

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Equivalents were used for other databases. Results were exported to EndNote X9 for deduplication.

Study Selection:

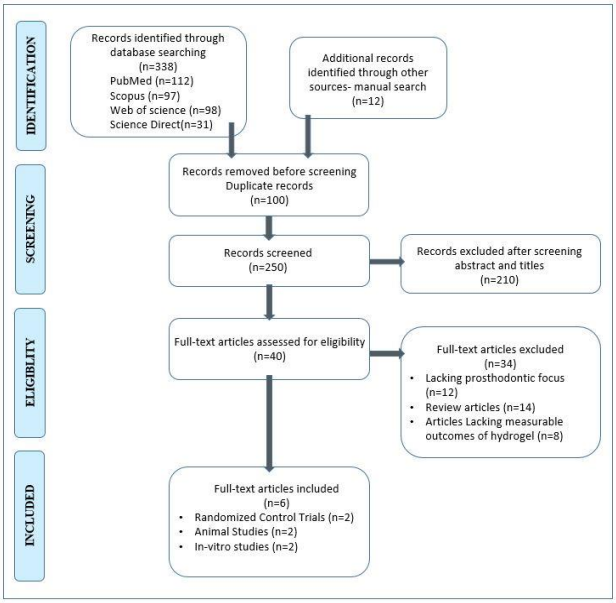

Figure 1- PRISMA 2020 flow diagram outlining study selection

• Deduplication: Duplicate records were removed.
• Title/Abstract Screening: Two reviewers independently screened titles and abstracts. Studies not meeting inclusion criteria were excluded; disagreements were resolved by discussion or a third reviewer.
• Full-Text Assessment: Full texts of potential studies were retrieved and reviewed. Exclusion reasons (e.g., non-prosthodontic focus, no hydrogel usage, lack of outcomes) were documented.

The study selection process is summarized in Figure 1, following PRISMA guidelines.

Data Extraction and Management:

Two reviewers independently conducted data extraction using a standardized Excel template, capturing: study ID (author, year, journal, country), design/model, sample details (patient or animal specifics), hydrogel composition and application (type, additives, form), comparator details, outcomes measured (clinical parameters, bone metrics, mechanical tests, material properties), follow-up duration, and main findings (quantitative results, p-values). Quality assessment was conducted using Cochrane RoB 2.0 for RCTs, Newcastle–Ottawa Scale for observational studies, SYRCLE's RoB for animal studies, and a tailored checklist for in vitro studies (focusing on replicates, blinding, statistical analysis). Discrepancies in extraction or assessment were resolved by consensus or consultation.

Data Synthesis:

Due to heterogeneity in designs, interventions, and outcomes, we synthesized results narratively. Findings were grouped by study type: Clinical human studies, animal studies, and in vitro studies. Quantitative data (means ± SD, p-values) are reported when available; effect sizes were not calculated due to sparse data.

4. Results

A total of 350 records were identified through database searches (Figure 1). After removing 100 duplicates, 250 unique records were screened. Screening titles and abstracts led to the exclusion of 210 records. Of the 40 full-text articles assessed, 34 were excluded for reasons such as non-prosthodontic focus, review articles, or lack of measurable hydrogel outcomes. Ultimately, 6 studies (2 randomized clinical trials, 2 animal studies, 2 in vitro studies) met all inclusion criteria (Figure 1). Table 1 summarizes the key design characteristics of the six included studies: study design, hydrogel intervention, comparator, and main outcomes.

Table 1: DEMOGRAPHIC AND METHODOLOGICAL CHARACTERISTICS OF INCLUDED STUDIES

AUTHOR (YEAR)	DESIGN/MODEL	HYDROGEL INTERVENTION	COMPARATOR	KEY OUTCOMES
Jivanescu et al. (2015) [1]	RCT (complete dentures; n = 23)	Hydrogel wound-healing patch for denture ulcers	Standard denture adjustment	Ulcer area ↓ 60–75% vs 45–55% by day 7 ($p<0.05$); Pain ↓ 7.2→2.8 vs 7.0→5.5 ($p<0.01$)
Machado et al. (2023) [5]	RCT (post-extraction ridge; n = 12)	Injectable dextrin-based hydrogel + synthetic bone granules (DEXGEL Bone)	Synthetic bone granules alone (BL®)	New bone 42.3% vs 35.6% ($p=0.029$); Implant stability (ISQ) 74.5 vs 69.2 ($p=0.017$)
Li et al. (2015) [4]	Animal (rabbit maxillary defect)	Thermosensitive alginate hydrogel (TSAH) ± rhBMP-2	PBS control	Mineralized bone 41.6% (TSAH+BMP-2) vs 31.3% (TSAH) vs 12.1% (control) ($p<0.01$)
Narde et al. (2025) [8]	Animal (rat femoral critical defect)	Gelatin hydrogel + Bio-Oss + Ag nanoparticles + quercetin	Empty defect	Bone volume 426.5 vs 215.4 mm^3; Trabecular thickness 0.509 vs 0.287 mm ($p<0.01$)
Harada et al. (2024) [2]	In vitro (material testing)	Shape-memory acrylate hydrogel (SMG)	3D-printed PMMA denture resin	Shore A hardness 60 vs 62 (PMMA); Shape recovery in 15 s at 45°C; Water sorption 4.2% vs 5.8% ($p<0.05$); >95% cell viability
Raveendran et al. (2023) [7]	In vitro (adhesive testing)	Chitosan-pectin hydrogel adhesive	Commercial adhesive pastes (Fixon, Corey™, Dermavisc™)	Dry bond strength 2.89 kgf vs 1.85 kgf (Fixon) ($p<0.01$); 82% strength retained after 6h vs 54–60% for controls

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Clinical Human Studies

Jivanescu et al. (2015) (n = 23 denture wearers) reported that a hydrogel wound dressing significantly improved healing of traumatic ulcers. By Day 7, ulcer area was reduced by 60–75% in the hydrogel group versus 45–55% in controls ($p < 0.05$). Pain (VAS 0–10) decreased from 7.2 ± 1.0 to 2.8 ± 0.9 in the hydrogel group by Day 1, whereas the control group's pain reduced from 7.0 ± 1.1 to 5.5 ± 1.2 ($p < 0.01$). No adverse events were reported [1]. These findings suggest hydrogels' high water content and potential for local drug delivery can foster a more favorable environment for mucosal regeneration.

Machado et al. (2023) (n = 12) conducted an RCT on post-extraction ridge preservation. Patients received DEXGEL Bone (dextrin-based hydrogel combined with synthetic bone granules) versus bone granules alone. At 6 months, the hydrogel group exhibited 42.3 ± 3.8% new bone formation, significantly higher than 35.6 ± 4.1% in controls ($p = 0.029$). Implant stability (ISQ) at placement averaged 74.5 ± 2.3 in the hydrogel group versus 69.2 ± 2.6 in controls ($p = 0.017$). Both groups healed uneventfully [5]. These results indicate that incorporating a hydrogel carrier enhances bone regeneration and implant support.

Animal Studies

Li et al. (2015) (rabbit maxillary defects) evaluated an injectable thermo-sensitive alginate hydrogel (TSAH) with and without BMP-2. After 8 weeks, the TSAH+BMP-2 group achieved 41.6 ± 4.3% mineralized bone, significantly higher than TSAH alone (31.3 ± 3.9%) and PBS control (12.1 ± 2.8%) ($p < 0.01$). Bone mineral density was also significantly greater with BMP-2, demonstrating effective osteoinductive delivery via the hydrogel [4].

Narde et al. (2025) created critical-size defects in rat femora. A gelatin-based hydrogel loaded with xenograft (Bio-Oss), silver nanoparticles, and quercetin was compared to empty defects. After 12 weeks, mean bone volume was 426.5 ± 32.7 mm³ in the hydrogel group versus 215.4 ± 28.9 mm³ in controls. Trabecular thickness was 0.509 ± 0.042 mm vs 0.287 ± 0.035 mm ($p < 0.01$). Histology confirmed more mature trabecular bone in the hydrogel group [8]. These findings underscore hydrogels' potential to combine osteoconduction and antimicrobial action for bone repair.

In Vitro Studies

Harada et al. (2024) compared a shape-memory acrylate hydrogel (SMG) to conventional PMMA resin. At 37 °C, SMG's Shore A hardness (60 ± 3) was nearly identical to PMMA's (62 ± 2). Upon heating to 45 °C, SMG regained its original shape within 15 seconds, illustrating reversible deformation. Water sorption was 4.2 ± 0.3% for SMG versus 5.8 ± 0.4% for PMMA ($p < 0.05$). In osteoblast cytotoxicity assays, SMG extracts maintained >95% cell viability over 72 hours, confirming biocompatibility [2].

Raveendran et al. (2023) tested a chitosan-pectin hydrogel adhesive against three commercial denture adhesives (Fixon, Corey™, Dermavisc™) on an acrylic–silicone model. The hydrogel adhesive achieved an initial dry bond strength of 2.89 ± 0.15 kgf, significantly higher than 1.85 ± 0.12 kgf for Fixon ($p < 0.01$). After 6 hours of wet immersion, the hydrogel retained 82% of its bond strength, whereas controls retained only 54–60% [7]. These results indicate superior adhesive performance and water resilience for hydrogel-based adhesives.

5. Discussion

The evidence suggests that hydrogel-based materials may address several limitations of acrylic resins in prosthodontics. In clinical trials, hydrogel wound dressings significantly accelerated ulcer healing and reduced pain more rapidly than standard adjustments [1]. These outcomes support the idea that hydrogels' high water content and drug-delivery capacity create a more conducive environment for soft tissue regeneration. In alveolar ridge preservation, combining a hydrogel with synthetic bone granules (DEXGEL Bone) resulted in higher new bone percentages and improved implant stability versus bone granules alone [5]. Greater bone volume directly benefits prosthesis support, whether for complete dentures or implant overdentures. Injectable hydrogel carriers, especially those loaded with osteoinductive factors (e.g., BMP-2), offer a minimally invasive approach to maintain ridge dimensions and quality [5].

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Preclinical animal studies corroborate hydrogels' osteogenic potential. Li et al. showed a BMP-2–loaded alginate hydrogel achieved a 41.6% mineralized bone fraction at 8 weeks—over triple that of controls [4]. Similarly, a multifunctional gelatin hydrogel with graft material, silver nanoparticles, and quercetin more than doubled bone volume and trabecular thickness in rat defects [8]. These findings highlight hydrogels' ability to combine osteoconductive and antimicrobial properties for robust bone regeneration.

In vitro results further demonstrate that hydrogel-based liners and adhesives can rival or exceed acrylic standards. The shape-memory acrylate hydrogel (SMG) exhibited mechanical properties (hardness, water sorption) comparable to PMMA, with the added benefit of reversible deformation at elevated temperature [2]. This thermally triggered shape change could reduce the need for frequent relining as residual ridge morphology evolves. The chitosan-pectin hydrogel adhesive achieved higher initial bond strength and much greater wet retention than commercial adhesives [7], suggesting promise for immediate denture retention and patient confidence during function.

Despite these encouraging outcomes, several caveats apply. All clinical trials to date have small sample sizes ($n \leq 23$) and follow-ups under 6 months, limiting generalizability. No study evaluated a fully hydrogel-based complete denture system; research has focused on adjuncts (wound dressings, adhesives, graft carriers). Consequently, data on long-term wear, microbial colonization (e.g., Candida), patient quality of life, and material longevity are lacking.

Future research should address these gaps by:

- **Conducting Large-Scale RCTs:** Trials comparing fully hydrogel-fabricated dentures or liners/adhesives to PMMA, with ≥12-month follow-up, assessing retention, oral health–related quality of life, mucosal lesion incidence, and maintenance needs.

- **Standardizing Hydrogel Formulations:** Harmonizing polymer types (alginate, chitosan, dextrin, gelatin, acrylate), crosslinking methods, and additive concentrations (growth factors, antimicrobials) to enable direct comparisons.

- **Evaluating Safety Profiles:** Long-term studies on hydrogel biodegradation products, cytotoxicity across cell types, and susceptibility to microbial adhesion (especially Candida).

- **Biomechanical Simulations:** Testing hydrogel liners under chewing simulations to evaluate wear, hydrogel-reinforced denture durability, and adhesive retention under functional loading.

- **Cost-Effectiveness Analyses:** Comparing fabrication costs, maintenance needs (relining, repairs), complication rates, and overall patient satisfaction relative to conventional acrylic solutions.

Addressing these priorities will clarify hydrogels' role in mainstream prosthodontics and guide clinicians in their judicious use.

6. Conclusion:

Current evidence indicates that hydrogel-based materials hold promise for enhancing tissue healing, preserving alveolar ridge dimensions, and improving immediate denture retention. Clinical trials show accelerated mucosal repair and enhanced implant stability with hydrogel use, supported by animal data demonstrating robust bone regeneration using osteoinductive hydrogel scaffolds. In vitro studies highlight mechanical and bonding properties comparable or superior to acrylics. However, the lack of comprehensive clinical trials on fully hydrogel-fabricated prostheses warrants caution. Well-designed, long-term clinical studies with patient-centered outcomes are essential before hydrogels can be endorsed as mainstream alternatives or adjuncts to acrylic resins in prosthodontic practice.

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