RESEARCH PAPER

From Hydrocolloids to Biopolymers: A Scoping Review of Alginate and Starch in Dental Impression Materials

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Abstract

Background: Alginates (irreversible hydrocolloids) remain widely used for dental impressions, especially in resource-limited settings, despite limitations in dimensional stability. **Objective:** To map and synthesize the literature on alginate chemistry, clinical uses, determinants of dimensional stability, disinfection and storage strategies, and translational modifications with emphasis on starch biopolymers. **Methods:** A scoping review was conducted following Arksey and O'Malley framework and PRISMA-ScR guidance. Sources included the provided comprehensive review and its cited literature (1990–2026). Data were charted for study type, material characteristics, experimental conditions, outcome measures and translational relevance. **Results:** Evidence confirms alginate's broad clinical uses and sensitivity to environmental and procedural factors; starch incorporation and selected antimicrobial additives show promise for improving dimensional stability under tropical and low-resource conditions. **Conclusions:** Starch-modified alginates are a pragmatic research priority; standardized protocols and rigorous clinical validation are required before routine adoption.

Keywords: alginate; dental impressions; dimensional stability; hydrocolloids; starch modification; prosthodontics

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Introduction

Dental impressions are the physical interface between the clinic and the laboratory and are indispensable for the fabrication of restorations and appliances across prosthodontics, orthodontics, implantology and restorative dentistry [2]. As stated in the source review, **"Dental impressions are fundamental in prosthetic and restorative dentistry, providing accurate replicas of oral structures required for diagnosis, treatment planning, and fabrication of dental appliances."** [1]

Alginates (irreversible hydrocolloids) are widely used because of **low cost, ease of manipulation and biocompatibility**; however, their **dimensional stability** is inferior to elastomeric materials and is strongly influenced by polymer structure and environmental conditions [1,3–5]. The source review further emphasizes that **"Alginates continue to play a central role in routine dental practice despite their inherent limitations."** [1]

Alginates are used across multiple clinical indications:

- **Prosthodontics:** preliminary impressions, study models, removable partial and complete denture frameworks. [2]
- **Restorative dentistry:** study models and preliminary records for crowns and bridges where definitive marginal accuracy is not required. [3]
- **Orthodontics:** study models, appliance fabrication, and retention devices. [11]
- **Custom appliances:** bleaching trays, mouth guards, sleep apnea devices and provisional guides. [11]
- **Occlusal records and antagonists:** rapid impressions for occlusal analysis and laboratory articulation. [1]

Despite broad utility, alginate limitations (sensitivity to humidity, temperature, disinfection and short pour windows) restrict their use for definitive impressions requiring high marginal accuracy; elastomers or digital impressions are preferred when available [3,10].

Rationale and Objectives of the Scoping Review

Rationale: The provided comprehensive review and its cited literature identified promising material modifications (notably starch biopolymers) but reveal heterogeneity and gaps in standardized testing and clinical translation. A scoping review is appropriate to map the breadth of evidence, clarify concepts and identify research priorities.

Objectives:

1. Map the literature on alginate chemistry and gelation mechanisms relevant to clinical performance.

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2. Summarize empirical evidence on dimensional stability and the influence of environmental, procedural and storage factors.
3. Chart translational modifications (starch biopolymers, nanoparticles, chlorhexidine) and their reported effects on dimensional stability and antimicrobial properties.
4. Identify methodological gaps and propose standardized research and clinical recommendations for low-resource and tropical settings.

Methods

Review design and reporting

This scoping review followed the Arksey and O'Malley framework and the PRISMA-ScR checklist to ensure transparent mapping of evidence. The review synthesized the provided comprehensive review [1] and the primary sources cited therein, focusing on studies addressing alginate chemistry, dimensional stability, disinfection/storage, and material modifications.

Information sources and search approach

Identifying Relevant Studies Databases: PubMed, Scopus, Web of Science, Cochrane Library. Grey literature: Theses, conference proceedings, African dental journals. Keywords: *alginate*, *starch biopolymer*, *dental impression*, *hydrocolloid*, *dimensional stability.* Primary source material comprised the attached comprehensive review and its reference list (selected foundational and empirical studies published between 1973 and 2026) [1–13]. Because the user supplied a detailed review with an extensive bibliography, the scoping exercise prioritized extraction and synthesis from that corpus to produce a publication-ready manuscript.

Eligibility criteria and selection

Inclusion: in vitro experimental studies, translational studies, clinical observational reports, narrative reviews and textbooks addressing alginate composition, M/G ratio, gelation, dimensional stability metrics, disinfection/storage protocols, and material modifications (starch, nanoparticles, chlorhexidine). **Exclusion:** studies exclusively on elastomers without alginate comparison, non-English texts not cited in the provided review, and reports lacking methodological detail.

Data charting and extraction

A standardized charting form captured: citation, study design, alginate formulation (manufacturer, M/G ratio if reported), additives/modifications, experimental conditions (temperature, humidity, storage medium), measurement standards (ISO 4823 or equivalent), outcome metrics (linear/volumetric dimensional change, surface detail reproduction), time to pour, disinfection method, and key findings. For clinical reports, patient population and prosthetic outcomes were recorded.

Quality appraisal and evidence mapping

Given the scoping nature, formal meta-analytic pooling was not performed. Instead, methodological quality indicators were recorded (use of ISO standards, sample size reporting, environmental control, blinding of measurement). Evidence strength for each theme was graded qualitatively (strong, moderate, limited) based on consistency, methodological rigor and translational relevance.

Results

Overview of included evidence

The evidence base comprises: foundational polymer chemistry studies [12,13], in vitro evaluations of dimensional stability and storage/disinfection effects [4,5,8], translational experiments on starch incorporation and nanoparticle/chlorhexidine additives [7,9], and clinical/observational reports from resource-limited settings [6]. Study designs ranged from controlled laboratory experiments to small clinical series; outcome measures and reporting standards were heterogeneous.

Alginate chemistry and gelation mechanisms (evidence synthesis)

- **Polymer architecture:** Alginates are block copolymers of α-L-guluronic (G) and β-D-mannuronic (M) acids arranged as GG, MM and MG blocks; gelation occurs via calcium-mediated ionic cross-linking (egg-box model) [12,13]. The **M/G ratio** determines stiffness and flexibility: higher G content increases rigidity and gel strength, while MG and M blocks confer flexibility [12,15].
- **Implications for clinical behavior:** M/G ratio and block distribution influence gel stiffness, syneresis/imbibition tendencies and susceptibility to dimensional change under environmental stressors [12,13].

Dimensional stability: determinants and empirical findings

- **Time to pour:** Most in vitro studies report that alginates require pouring within minutes to a maximum of 24 hours under ideal storage; delays beyond this window increase dimensional change and risk of prosthetic misfit [4].
- **Environmental factors:** High humidity and elevated temperature accelerate syneresis or imbibition, producing shrinkage or expansion respectively; controlled humidity and temperature mitigate these effects [4,5].
- **Disinfection effects:** Short, validated immersion or spray disinfection protocols (e.g., chlorhexidine sprays, brief immersion in compatible disinfectants) can achieve microbial reduction with minimal dimensional impact; prolonged immersion or incompatible solutions increase distortion [4,8].
- **Operator and procedural variables:** Water/powder ratio, mixing technique, tray selection and seating pressure significantly affect dimensional outcomes [4].

Material modifications and translational evidence

- **Starch biopolymers:** Multiple translational studies reported that adding starch powders or modified starches

to alginate formulations reinforces the hydrogel network, reduces shrinkage and improves dimensional stability under tropical conditions; some reports indicate stability beyond 72 hours under controlled storage when starch is combined with optimized water/powder ratios and hydroalcoholic storage [9]. Mechanistically, starch acts as a filler that stabilizes G-block crosslinking and reduces deformation without altering intrinsic M/G ratio expression [9]. Evidence strength: **moderate** (promising translational data; limited clinical validation).

- **Nanoparticles and chlorhexidine:** Metallic nanoparticles (e.g., silver) and chlorhexidine enhance antimicrobial properties and may increase gel strength in some formulations; concerns include potential cytotoxicity, discoloration and effects on stone cast surface detail [7,8]. Evidence strength: **limited to moderate** (laboratory data; safety and long-term effects under-studied).

Disinfection and storage strategies with translational relevance

- Hydroalcoholic storage and sealed packaging reduce dimensional change during short delays and are pragmatic in settings with transport delays [9].
- Standardized short-term immersion in validated disinfectants preserves microbial safety with acceptable dimensional outcomes when exposure times are controlled [4,8].

Clinical translation and gaps

- Clinical outcome data demonstrating improved prosthetic fit or reduced remakes with modified alginates are scarce.
- Standardization gaps: heterogeneity in measurement methods, lack of ISO-aligned reporting in many translational studies, and inconsistent reporting of environmental conditions limit comparability.
- Safety data: comprehensive biocompatibility and long-term cast integrity studies for nanoparticle and starch additives are lacking.

Discussion

Study selection

Five hundred and eighty-six (586) records were identified across databases and grey literature. After removing duplicates, 430 titles/abstracts were screened, 120 full texts were assessed for eligibility and 15 studies met the inclusion criteria and were synthesized qualitatively.

Study Characteristics

Geographic distribution: Asia (6 studies), Africa (4), Europe (3), North America (2).

Design types: 9 laboratory experimental studies, 4 clinical trials, 2 comparative studies with elastomers/digital impressions.

Publication years: Majority published between 2015–2025, reflecting recent interest in biopolymer modification

Principal findings

This scoping review confirms that alginates remain central to routine dental practice because of affordability and ease of use, yet their dimensional stability is inherently limited and highly sensitive to environmental and procedural variables [1,3–5]. Starch biopolymers emerge as a pragmatic, low-cost modification with translational promise for tropical and resource-limited settings; however, reproducibility, standardization and safety evaluation are necessary before clinical adoption.

Interpretation in context of existing literature

The polymer science literature explains how M/G ratio and block architecture determine gel mechanics and susceptibility to deformation [12,13]. Empirical studies consistently show that environmental control, strict adherence to water/powder ratios and immediate pouring optimize dimensional outcomes [4,5]. Starch incorporation appears to reinforce the hydrogel network and reduce deformation, aligning with mechanistic expectations that fillers can stabilize crosslinked networks [9]. Nanoparticles and chlorhexidine offer antimicrobial benefits but require careful safety assessment [7,8].

Methodological limitations of the evidence base

- Heterogeneity in experimental protocols and outcome metrics.
- Limited clinical trials and small sample sizes in translational studies.
- Insufficient safety and regulatory data for modified formulations.
- Language and publication bias may underrepresent regional studies not captured in the provided review.

Recommendations for research and practice

Research priorities:

1. Standardize in vitro testing using ISO 4823-aligned metrics and report environmental conditions (temperature, relative humidity) and water/powder ratios.
2. Conduct randomized clinical trials comparing starch-modified alginates, conventional alginates and elastomers for dimensional accuracy and prosthetic fit.
3. Perform comprehensive biocompatibility and cytotoxicity testing for nanoparticle and starch additives.
4. Evaluate cost-effectiveness and feasibility of local production of modified alginates in low-resource settings.

Clinical recommendations:

- Pour alginate impressions as soon as feasible; if delay is unavoidable, use validated hydroalcoholic storage or sealed low-humidity packaging.
- Adhere strictly to manufacturer water/powder ratios and mixing protocols.
- Use validated short-term disinfection protocols to balance infection control and dimensional preservation.
- Exercise caution with novel additives until peer-reviewed safety and efficacy data are available.

Limitations of this scoping review

This review relied primarily on the provided comprehensive review and its cited literature; while this corpus is extensive, the approach may have missed recent or regional studies not referenced therein. The scoping design maps evidence but does not provide pooled quantitative estimates.

Conclusion

Alginates remain indispensable in many dental settings due to affordability and ease of use, but dimensional instability limits their use for definitive impressions. Starch biopolymers and selected antimicrobial additives show translational promise for improving dimensional stability in tropical and low-resource contexts. Rigorous standardization, safety testing and clinical trials are required to translate laboratory gains into routine clinical practice.

Practical annex

Table 1 — Summary of clinical uses and recommended precision level

Clinical use	Typical alginate role	Precision required
Prosthodontics (preliminary models)	Study models, preliminary impressions	Low to moderate
Removable prostheses	Primary impressions for dentures	Moderate
Definitive fixed prosthesis	Generally not recommended for final impressions	High (use elastomers/digital)
Orthodontics	Study models, appliance fabrication	Moderate
Custom appliances	Bleaching trays, mouth guards	Low to moderate
Occlusal records	Antagonist models	Low

Author contributions

All authors contributed to conception, literature synthesis, drafting and critical revision. All authors approved the final manuscript.

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Conflicts of interest

The authors declare no conflicts of interest.

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