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Systematic Review

Digital Clear Aligner Systems as Multifunctional Platforms for Tooth Bleaching: A Systematic Review of Material Performance and Mechanical Implications in Esthetic Dentistry

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Abstract

Background: Clear aligners fabricated via computer-aided design and manufacturing are increasingly used in orthodontics and may also serve as carriers for peroxide-based bleaching agents. However, exposure to bleaching agents may affect the physical and surface properties of aligner polymers, which could influence their clinical performance. Objective: This systematic review aims to evaluate the available evidence on the use of clear aligners as carriers for tooth bleaching agents, with a focus on bleaching efficacy and reported effects on aligner materials based on the identified literature. Methods: A systematic search was conducted in PubMed, Web of Science, Scopus, Scielo, and Embase for studies published up to January 2026. Eligible clinical and in vitro studies investigated bleaching procedures using clear aligners or conventional trays and reported color change outcomes and/or changes in material properties such as hardness, surface integrity, or mechanical performance. Risk of bias was assessed using the Cochrane Risk of Bias tools and standardized criteria for in vitro and clinical studies. Results: Six studies (three clinical and three in vitro) met the inclusion criteria. Clinical evidence indicated that bleaching delivered through clear aligners achieved similar whitening outcomes to conventional tray-based systems. In vitro studies reported changes in surface hardness and mechanical properties of polymer-based aligner materials after peroxide exposure; however, no major structural degradation was observed. Clinical studies were generally at high risk of bias, while in vitro studies showed low to moderate risk. Conclusions: Within the limitations of this systematic review, clear aligners may represent a potential carrier for tooth bleaching agents with outcomes comparable to conventional trays. However, the available evidence is limited and heterogeneous. Well-designed randomized controlled trials are needed to confirm clinical effectiveness and long-term material safety.

Keywords: clear aligners; dental bleaching; digital dentistry; hydrogen peroxide; material stability; polymer degradation

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1. Introduction

The increasing demand for orthodontic treatments that combine functional efficiency with patient comfort has contributed to the widespread adoption of clear aligner therapy in contemporary orthodontics [1,2]. Clear aligners are removable, transparent appliances manufactured through computer-aided design and computer-aided manufacturing workflows, allowing for precise, sequential tooth movement based on virtual treatment planning [3–5]. Since the introduction of the first commercially available system in the late 1990s, numerous companies have developed aligner systems with varying material compositions and biomechanical designs, reinforcing their role as a mainstream alternative to conventional fixed orthodontic appliances [6–9].

Compared with fixed orthodontics, clear aligners offer several clinical and patient-centered advantages, including improved oral hygiene, comfort, and patient acceptance. Their removability allows patients to eat and perform oral hygiene procedures without mechanical obstruction, potentially reducing plaque accumulation and gingival inflammation. These characteristics have expanded the scope of adjunctive cosmetic procedures that may be performed concurrently with orthodontic treatment [10–12].

Tooth color improvement remains one of the most frequently requested aesthetic procedures among orthodontic patients [13]. Previous studies have reported a high prevalence of bleaching requests either during or following orthodontic treatment, reflecting increasing patient expectations for comprehensive aesthetic outcomes. Combining orthodontic alignment with dental bleaching has been shown to enhance overall patient satisfaction compared with orthodontic treatment alone [14–16].

At-home dental bleaching using custom-fabricated trays has long been considered a safe and effective approach for tooth whitening. Since its introduction, this technique has gained popularity due to its affordability, ease of use, and lower incidence of adverse effects, such as tooth sensitivity and soft tissue irritation, compared with in-office protocols [17–20]. Traditionally, bleaching procedures were postponed until the completion of fixed orthodontic treatment to ensure uniform whitening and to allow gingival tissues to recover from appliance-induced inflammation [13].

From a macromolecular and materials science perspective, clear aligners are polymer-based devices that operate under complex intraoral conditions, including thermal fluctuations, moisture exposure, salivary enzymes, chemical challenges from food and beverages, and intermittent mechanical loading. When used as bleaching delivery systems, aligner materials are additionally exposed to oxidative environments generated by peroxide-based agents, which may influence their mechanical integrity, surface properties, and optical stability. An ideal aligner material should therefore combine adequate stiffness for orthodontic force transmission with sufficient elasticity for patient comfort, while maintaining transparency, chemical resistance, and biocompatibility throughout prolonged clinical use. These material requirements have stimulated continuous research into polymer formulations, blending strategies, and emerging biobased alternatives aimed at improving performance, durability, and sustainability [20].

Within these tray-based protocols, dental bleaching is most frequently achieved using carbamide peroxide or hydrogen peroxide. Carbamide peroxide decomposes into hydrogen peroxide and urea, producing the bleaching effect and causing a temporary rise in oral pH. The urea byproduct transiently increases oral pH, helping to neutralize saliva (normally ranging from 6.2 to 7.6) and potentially reducing plaque accumulation, decalcification, and caries risk [21]. The American Dental Association has approved the use of 10% carbamide peroxide for both in-office and at-home bleaching, as this concentration is associated with minimal postoperative sensitivity [22].

The advent of clear aligner therapy has challenged this conventional sequencing. Because aligners closely adapt to the dental surfaces and are worn for extended periods, they may function as bleaching trays when whitening agents are applied during nighttime wear. Evidence suggests that non-scalloped trays without reservoirs can achieve effective tooth whitening, supporting the feasibility of this combined approach. However, concerns remain regarding the predictability, efficacy, and uniformity of bleaching performed during active orthodontic tooth movement when compared with conventional bleaching trays used independently for orthodontic treatment [23–26].

Despite growing clinical interest, the evidence comparing dental bleaching performed during clear aligner therapy with bleaching using conventional trays remains fragmented [13]. Questions persist regarding whether simultaneous bleaching compromises whitening outcomes or offers comparable results while enhancing treatment efficiency and patient satisfaction. Therefore, this systematic review aims to evaluate the available evidence on the use of clear aligners as carriers for tooth bleaching agents, with a focus on bleaching efficacy and reported effects on aligner materials based on the identified literature.

2. Materials and Methods

2.1. Study Design and Reporting Guidelines

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines and followed the methodological recommendations outlined in the Cochrane Handbook for Systematic Reviews of Interventions [27]. The completed PRISMA 2020 checklist is provided as Supplementary Material (Table S1). The review protocol was prospectively registered in the Open Science Framework (OSF) under the identifier number 10.17605/OSF.IO/7NGH5, and the review adhered strictly to the registered protocol. Both clinical and in vitro studies evaluating dental bleaching performed during clear aligner treatment or using clear aligners as a delivery system were considered. In vitro studies were included to complement clinical evidence by providing controlled assessment of the physicochemical and mechanical effects of bleaching agents on clear aligner materials. These experimental models allow precise evaluation of changes in surface morphology, hardness, optical properties, and structural integrity. Inclusion of in vitro studies therefore enabled a comprehensive understanding of both clinical color outcomes and material-related effects associated with clear aligner therapy and bleaching protocols. The research question was developed according to the Population, Intervention, Comparison, Outcome, and Type of the study (PICOT) framework. The population consisted of patients undergoing orthodontic treatment with clear aligners or clear aligner materials evaluated in experimental settings. The intervention involved dental bleaching performed using clear aligners, either as part of active orthodontic treatment or through clear aligner therapy and bleaching protocols. The comparator included conventional bleaching trays or control conditions without bleaching. The primary outcomes focused on tooth color change assessed by visual shade guides or instrumental digital systems, such as spectrophotometry and CIE L*, a*, and b* parameters. Secondary outcomes included changes in the mechanical and surface properties of aligner materials, as well as the integrity and clinical performance of orthodontic aligners when used as bleaching trays. Eligible study designs included clinical and in vitro studies.

2.2. Search Strategy

A comprehensive literature search was performed in PubMed, Web of Science, Scielo, Scopus, and Embase for clinical and in vitro studies published up to January 2026. The search used MeSH terms and keywords related to tooth bleaching, bleaching agents, and

orthodontic clear aligners (Table 1). Additionally, the reference lists of included studies and relevant reviews were manually searched to identify any further eligible studies. The search strategy was intentionally broad and included multiple synonyms and variations of orthodontic aligners and bleaching terminology to maximize sensitivity and reduce the risk of missing relevant studies.

Table 1. Search strategy performed.

Database	Search Strategy Used
PubMED	(Tooth Bleaching OR Dental Whitening OR dental bleaching OR tooth whitening OR dental whitening OR bleaching treatment OR whitening treatment) AND (Aligners, Orthodontic OR Orthodontic Appliances, Removable OR clear aligner OR clear aligners OR orthodontic aligner OR orthodontic aligners OR Invisalign OR removable orthodontic appliance)
Web of Science	TS = (Tooth Bleaching OR Dental Whitening OR dental bleaching OR tooth whitening OR dental whitening OR bleaching treatment OR whitening treatment) AND TS = (Aligners, Orthodontic OR Orthodontic Appliances, Removable OR clear aligner OR clear aligners OR orthodontic aligner OR orthodontic aligners OR Invisalign OR removable orthodontic appliance)
Scielo	TS = (Tooth Bleaching OR Dental Whitening OR dental bleaching OR tooth whitening OR dental whitening OR bleaching treatment OR whitening treatment) AND TS = (Aligners, Orthodontic OR Orthodontic Appliances, Removable OR clear aligner OR clear aligners OR orthodontic aligner OR orthodontic aligners OR Invisalign OR removable orthodontic appliance)
SCOPUS	ALL (“Tooth Bleaching” OR “Dental Whitening” OR “dental bleaching” OR “tooth whitening” OR “dental whitening” OR “bleaching treatment” OR “whitening treatment”) AND ALL (“Aligners, Orthodontic” OR “Orthodontic Appliances, Removable” OR “clear aligner” OR “clear aligners” OR “orthodontic aligner” OR “orthodontic aligners” OR “Invisalign” OR “removable orthodontic appliance”)
EMBASE	‘Tooth Bleaching’ OR ‘Dental Whitening’ OR ‘dental bleaching’ OR ‘tooth whitening’ OR ‘dental whitening’ OR ‘bleaching treatment’ OR ‘whitening treatment’ AND ‘Aligners, Orthodontic’ OR ‘Orthodontic Appliances, Removable’ OR ‘clear aligner’ OR ‘clear aligners’ OR ‘orthodontic aligner’ OR ‘orthodontic aligners’ OR ‘Invisalign’ OR ‘removable orthodontic appliance’

2.3. Eligibility Criteria

Eligible studies included clinical trials, prospective or retrospective cohort studies, and in vitro studies that evaluated dental bleaching during clear aligner treatment or using aligners as a bleaching tray. Clinical studies were required to include human participants aged 18 years or older, use peroxide-based bleaching agents, and report tooth color outcomes using clinical shade guides, spectrophotometry, or digital color measurement. In vitro studies were included if they used clear aligners or aligner-like systems as bleaching delivery systems and reported quantitative or qualitative outcomes related to bleaching efficacy or material properties. Eligible studies investigated the mechanical and surface properties of aligner materials, as well as the integrity and potential clinical performance of orthodontic aligners when used as bleaching trays. No language restrictions were applied during the search process. In addition, grey literature was explored by screening Google Scholar and manually reviewing the reference lists of all included studies and relevant systematic reviews to identify additional eligible publications. Exclusion criteria

encompassed studies assessing bleaching with fixed appliances, non-vital tooth bleaching, internal bleaching, case reports, narrative or systematic reviews, letters to the editor, expert opinions, animal studies, or studies including participants with intrinsic discolorations, untreated caries, active periodontal disease, or extensive anterior restorations.

2.4. Study Selection and Data Extraction

Titles and abstracts identified through the electronic database search were independently screened for eligibility by two reviewers (R.B. and N.N.) in accordance with the predefined inclusion and exclusion criteria. When the information provided in the abstract was insufficient to determine eligibility, the full-text article was retrieved and assessed. Any disagreements during the selection process were resolved through discussion until consensus was reached (C.E.C.-S.).

For each eligible study, relevant data were systematically extracted, including the author(s), year of publication, study design, sample size, type of clear aligner system, bleaching agent and concentration, bleaching protocol and duration, evaluation methods, follow-up period, and main outcomes. All included studies incorporated a control condition. In clinical investigations, control groups consisted of either teeth bleached using conventional trays or teeth that did not receive any bleaching treatment. In in vitro studies, control groups were represented by aligner materials or dental specimens not exposed to bleaching agents or maintained under identical conditions without bleaching application.

2.5. Assessment of Methodological Quality

The methodological quality and risk of bias of the included studies were assessed separately for clinical and in vitro investigations.

Clinical studies were first classified as randomized controlled trials or non-randomized clinical studies according to the study design explicitly reported in the original publications. This classification determined the risk of bias assessment tool applied.

Randomized controlled trials were evaluated using the revised Cochrane Risk of Bias tool (RoB 2.0) [13], which assesses bias arising from the randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, selection of the reported result, and overall risk of bias judgment.

Non-randomized clinical studies were evaluated using the Risk Of Bias In Non-randomized Studies of Interventions (ROBINS-I) tool, which assesses bias due to confounding, selection of participants into the study, classification of interventions, deviations from intended interventions, missing data, measurement of outcomes, and selection of the reported result.

The risk of bias in in vitro studies was assessed using the Risk of Bias Tool for In Vitro Studies (QUIN) [28]. This tool evaluates four domains: planning and allocation (including control/reference groups, randomization, and sample size justification), specimen preparation (standardization of procedures and testing conditions), outcome assessment (measurement reliability and operator blinding), and data analysis and reporting (statistical appropriateness and transparency). Each criterion was rated as "sufficiently reported," "insufficiently reported," "not reported," or "not applicable."

All assessments were performed independently by two reviewers. Any discrepancies were resolved through discussion, and a third reviewer was consulted when consensus could not be reached. All studies, including those with incomplete methodological reporting, were assessed using the best available published information to ensure consistency and transparency in evaluation.

2.6. Data Synthesis

Due to heterogeneity in study designs, bleaching protocols, concentrations of bleaching agents, and evaluation methods, a qualitative synthesis was conducted. Clinical studies primarily focused on tooth color change, whereas in vitro studies also evaluated mechanical and physical properties of aligner or retainer materials. The findings were summarized and compared according to study design, bleaching protocol, and outcomes.

2.7. Assessment of Certainty of Evidence

The certainty of evidence for the main outcomes was assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach. The evidence was evaluated across the following domains: risk of bias, inconsistency, indirectness, imprecision, and publication bias. Given the inclusion of both clinical and in vitro studies, certainty of evidence was assessed separately for clinical outcomes (tooth color change) and material-related outcomes (mechanical and physicochemical properties). The overall certainty of evidence was categorized as high, moderate, low, or very low.

3. Results

A total of 186 articles were identified through electronic database searches and manual searches. After removing 64 duplicates, 122 records were screened based on titles and abstracts. Of these, 116 records were excluded due to ineligibility related to study design, population, or intervention. Ultimately, six studies were included in the qualitative synthesis, comprising three clinical studies [29–31] and three in vitro experimental studies [32–34]. All included studies contained appropriate control groups, allowing for comparison between bleaching using clear aligners, conventional bleaching trays, or non-bleached controls. The study selection process is summarized in Figure 1.

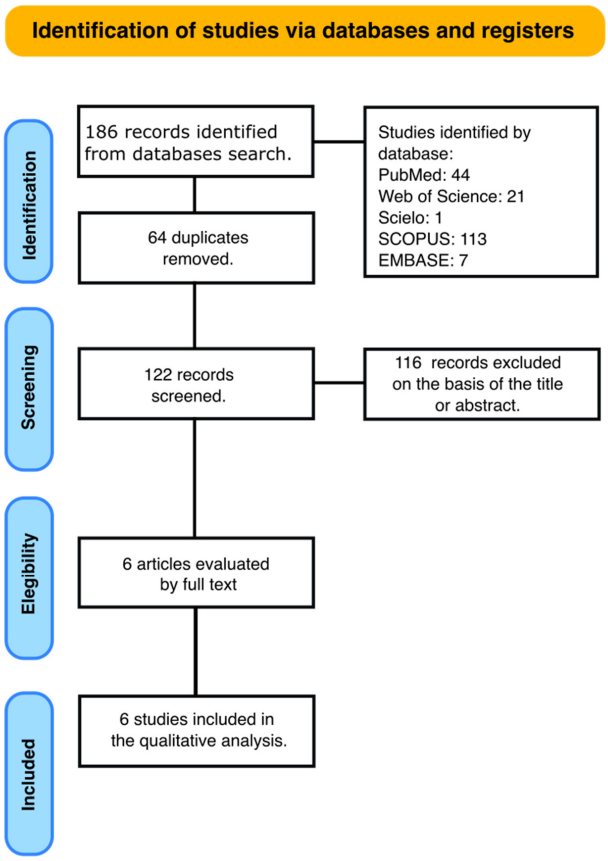

Figure 1. Flowchart according to PRISMA depicting the selection process.

3.1. Characteristics of Included Studies

The included studies evaluated the effectiveness of tooth bleaching using clear aligners, conventional bleaching trays, or experimental thermoforming films loaded with bleaching agents. Clinical studies involved 10 to 38 patients, while in vitro studies evaluated between 40 and 144 specimens or teeth. Clear aligner systems used included Invisalign and F22 aligners, while bleaching agents varied from 3% hydrogen peroxide to 16% carbamide peroxide, with application protocols ranging from 5 h per day for 14 days to continuous sustained-release systems for 40 days. Outcomes were measured using spectrophotometers, Vita Classical shade guides, CIE L*, a*, b* color parameters, and mechanical testing such as shear bonding strength, tensile strength, hardness, and compressive strength. One included study (Levrini et al., 2020) [31] was available only in abstract form; therefore, data extraction and risk-of-bias assessment were performed based on the information reported in the abstract and indexed bibliographic records.

3.2. Tooth Bleaching Efficacy

Clinical studies consistently reported effective tooth whitening when using clear aligners loaded with bleaching agents. Seleem et al. (2021) found that about half of the patients achieved a 3–6-shade improvement after 4 weeks of bleaching with 10% carbamide peroxide, while the remainder achieved 1–2 or more than 7 shades of improvement [29]. Oliverio et al. (2019) demonstrated that longer bleaching duration and higher carbamide peroxide concentrations enhanced whitening, with the greatest improvement observed in patients using 16% carbamide peroxide for 14 days [30]. Levrini et al. (2020) compared Invisalign aligners to conventional bleaching trays and found no significant difference in bleaching efficacy between the two approaches [31].

In vitro studies confirmed these findings. Cheng et al. (2023) showed that a thermoforming film loaded with 6% hydrogen peroxide resulted in significant increases in L* values and decreases in a* and b* values after 40 days, indicating effective whitening [33]. Khashashneh et al. (2023) demonstrated that 10% carbamide peroxide applied to Invisalign aligners for 14 days did not compromise tensile strength or translucency, although hardness decreased and surface roughness increased [32]. Ehteshami et al. (2025) reported that Polyethylene terephthalate glycol (PETG) thermoplastic retainers exposed to 15% carbamide peroxide for 14 days experienced reduced compressive strength, with bleaching alone causing the greatest decrease, while thermocycling did not further reduce strength [34]. A summary of the key study characteristics is presented in Table 2.

Table 2. Characteristics of the studies included in the review.

Author (Year)	Study Design	Sample Size	Clear Aligner System	Bleaching Agent (Concentration)	Bleaching Protocol & Duration	Evaluation Criteria	Follow-Up Period	Main Outcomes
Seleem et al., 2021 [29]	Clinical study (Non-randomized clinical study)	28 patients	Invisalign	10% carbamide peroxide (Opalescence, Ultradent Inc., South Jordan, UT, USA)	Two groups; control group where patients did not receive bleaching, study group where patients received bleaching using 10% carbamide peroxide for 8 h daily for 4 weeks	Vita Classical shade guide, middle third of maxillary and mandibular central and lateral incisors	At 2 and 4 weeks of dental bleaching and 2 weeks after bleaching termination (weeks 2, 4, and 6)	About half of the patients in the study group had a 3–6-shade improvement, while the remaining subjects showed an improvement of about 1–2 shades or more than 7 shades. Patients in the control group had a consistent shade average throughout the duration of the study
Oliverio et al., 2019 [30]	Clinical study (Randomized clinical study)	38 patients	F22 aligners (Sweden & Martina, Padua, Italy)	Group 1: Hydrogen peroxide (3%) Group 2: Carbamide peroxide (10%) Group 3: Carbamide peroxide (16%) Group 4: Carbamide peroxide (16%)	Bleaching performed 9 h/day during aligner wear Groups 1–3: days 7–14 (1 week) Group 4: days 1–14 (2 weeks)	Tooth color change assessed using a spectrophotometer and Vita Classical shade guide; three measurements per tooth (incisal, middle, cervical) on six maxillary anterior teeth	Re-evaluation at day 14 of aligner use	Group 4 demonstrated the greatest shade improvement. Only Group 1 exhibited sites with worsening tooth shade. Longer bleaching duration and higher carbamide peroxide concentration enhanced whitening efficacy
Levrini et al., 2020 [31]	Clinical study (Non-randomized clinical study)	10 patients	Invisalign	10% carbamide peroxide	8 h/day for 10 days; control teeth 41 and 32 bleached with conventional trays, study teeth 31 and 42 bleached using Invisalign aligners	Spectrophotometer	10 days	Both types of trays (conventional bleaching trays and Invisalign aligners) were effective for bleaching, with no significant differences between them

Table 2. *Cont.*

Author (Year)	Study Design	Sample Size	Clear Aligner System	Bleaching Agent (Concentration)	Bleaching Protocol & Duration	Evaluation Criteria	Follow-Up Period	Main Outcomes
Khashashneh et al., 2023 [32]	In vitro experimental study	22 unused aligners; 144 specimens	Invisalign (Align Technology, Santa Clara, CA, USA)	10% carbamide peroxide (Opalescence PF 10%, Ultradent Products, New York City, NY, USA)	Bleaching agent applied to internal aligner surfaces for 8 h/day at 37 °C for 14 days (total 112 h); specimens stored in distilled water for remaining 16 h/day	Tensile strength, Vickers hardness, surface roughness (internal and external), translucency	Immediate testing at baseline and after 2 weeks	No significant changes in tensile strength or translucency. Significant reduction in hardness and increase in internal and external surface roughness after bleaching. Invisalign maintained structural integrity without excessive material degradation
Cheng et al., 2023 [33]	In vitro experimental study	90 isolated human premolars	Experimental thermoforming film loaded with sodium alginate–dopamine/mesoporous silica nanoparticle gel	Hydrogen peroxide, 6 wt% (sustained-release system)	Thermoforming clear aligner film (Ailicen Medical Technology Co., LTD., Xi'an) loaded with hydrogen peroxide worn for 40 days; aligners replaced every 10 days	CIE L*, a*, b* color parameters measured every 10 days by Vita Easyshade V (VitaZahnfabrik, BadSackingen Germany) Shear bonding strength of attachments	40 days	Significant tooth whitening observed (↑L*, ↓a*, ↓b*); no significant effect on shear bond strength of orthodontic attachments compared with non-bleached controls
Ehteshami et al., 2025 [34]	In vitro experimental study	40 Polyethylene terephthalate glycol (PETG) specimens (10 per group)	PETG thermoplastic retainer (1 mm thickness)	Carbamide peroxide, 15% (Opalescence® PF 15%, Ultradent Products Inc., South Jordan, UT, USA)	5 h/day for 14 days	Compressive strength	After bleaching and/or thermocycling	All experimental groups showed significantly reduced compressive strength compared with control; bleaching alone caused the greatest reduction; no additional deleterious effect observed when bleaching was performed after thermocycling

3.3. Risk of Bias Assessment and Certainty of Evidence

A total of six studies were included in the risk-of-bias assessment, comprising three clinical studies (one randomized and two non-randomized) and three in vitro studies.

The randomized clinical trial (Oliverio et al., 2019) [30] was assessed using the RoB 2 tool and judged to be at high risk of bias, primarily due to limitations in the randomization process, lack of blinding, and potential confounding factors.

The two non-randomized clinical studies (Levrini et al., 2020 [31]; Seleem et al., 2021 [29]) were assessed using the ROBINS-I tool. Levrini et al. (2020) [31] was evaluated based on an abstract only; therefore, several key methodological details—particularly regarding allocation procedures and blinding of outcome assessment—were not available. Consequently, this study was judged as having "some concerns" due to incomplete reporting rather than confirmed methodological deficiencies. Seleem et al. (2021) [29] was consistently classified as a non-randomized clinical study and demonstrated an overall critical risk of bias, mainly due to confounding and limitations in outcome measurement.

The in vitro studies demonstrated generally low risk of bias according to the QUIN tool. However, common limitations included the absence of explicit operator blinding and incomplete reporting of certain methodological parameters. Overall, these studies provide relatively robust evidence regarding material behavior under bleaching conditions (Tables 3–5).

Table 3. Risk of Bias using the RoB-2 tool for randomized clinical trials.

Study	Domain					
	Selection Bias	Performance Bias	Attrition Bias	Detection Bias	Reporting Bias	Overall
Oliverio, 2019 [30]	High Risk	High Risk	Low Risk	Some Concerns	Some Concerns	High Risk

Table 4. Risk of Bias using the ROBINS-I tool for non-randomized clinical trials.

Study	Domain	Bias in Selection of Participants into the Study	Bias in Classification of Interventions	Bias Due to Deviations from Intended Interventions	Bias Due to Missing Data	Bias in Measurement of Outcomes	Bias in Selection of the Reported Result	Overall
	Bias Due to Confounding							
Seleem, 2021 [29]	Critical Risk	Moderate Risk	Low Risk	Moderate Risk	Low risk	Serious Risk	Moderate risk	Critical Risk
Levrini, 2020 [31]	Some concerns	Some concerns	Some concerns	Some concerns	Some concerns	Some concerns	Some concerns	Some concerns

Table 5. Risk of Bias using the QUIN tool for in vitro studies.

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Total Score	Result
Cheng, 2023 [33]	1	0.5	1	1	1	1	1	0	1	1	1	1	10.5	Low Risk of Bias
Khashashneh, 2023 [32]	1	1	1	1	1	1	1	0	1	1	1	1	11	Low Risk of Bias
Ehteshami, 2025 [34]	1	1	1	1	11	1	1	0.5	1	1	1	1	1.5	Low Risk of Bias

Overall, the certainty of evidence was rated as low for clinical outcomes due to serious risk of bias, inconsistency between study protocols, and imprecision related to small sample sizes. For in vitro outcomes, certainty ranged from low to moderate due to moderate risk of bias, heterogeneity in materials and testing methods, indirectness of laboratory conditions, and imprecision related to variability in outcome measures (Table 6).

Table 6. Summary of Findings and certainty of evidence assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach for clinical and in vitro outcomes related to bleaching during clear aligner therapy. The table presents the number of included studies, study designs, assessed domains (risk of bias, inconsistency, indirectness, imprecision, and publication bias), effect summaries, and overall certainty ratings for each outcome.

№	Outcome	Studies (n)	Study Design	Participants/Specimens	Risk of Bias	Inconsistency	Indirectness	Imprecision	Other Considerations	Effect (Narrative Summary)	Certainty
1	Tooth color change (whitening effectiveness)	3 (Oliverio et al., 2019 [30]; Seleem et al., 2021 [29]; Levrini et al., 2020 [31])	Randomized and non-randomized clinical studies	~76 patients	Serious	Moderate	Not serious	Serious	None	Aligner-based bleaching achieved clinically relevant whitening. Similar outcomes were observed between aligner systems, while higher peroxide concentration and longer application time improved whitening efficacy	Low (⊕○○○)
2	Mechanical properties (hardness, tensile strength, compressive strength)	3 (Cheng et al., 2023 [33]; Khashashneh et al., 2023 [32]; Ehteshami et al., 2025 [34])	In vitro studies	~276 specimens	Moderate	Moderate	Serious	Serious	None	Most aligner materials maintained structural integrity. Some reductions in hardness and compressive strength were observed following bleaching exposure	Low to Moderate (⊕⊕○○)
3	Optical properties (translucency; color parameters L*, a*, b*)	2 (Cheng et al., 2023 [33]; Khashashneh et al., 2023 [32])	In vitro studies	Subset of reported specimens	Moderate	Moderate	Serious	Serious	None	Whitening effect was confirmed, with increased L* and decreased a* and b* values. No major adverse effect on translucency was observed	Low to Moderate (⊕⊕○○)
4	Bond strength of orthodontic attachments	1 (Cheng et al., 2023 [33])	In vitro study	Subset of reported specimens	Moderate	Not serious	Serious	Serious	None	Bleaching showed no significant effect on the shear bond strength of orthodontic attachments	Low (⊕⊕○○)
5	Surface properties (roughness)	1 (Khashashneh et al., 2023 [32])	In vitro study	Subset of reported specimens	Moderate	Not serious	Serious	Serious	None	Surface roughness increased after bleaching, particularly on internal aligner surfaces	Low to Moderate (⊕⊕○○)

Downgrading decisions were based on: (i) serious risk of bias due to lack of blinding and methodological limitations in clinical studies; (ii) moderate heterogeneity in bleaching protocols and materials; (iii) indirectness for in vitro studies due to laboratory conditions not fully replicating the oral environment; and (iv) imprecision due to small sample sizes and lack of pooled effect estimates.

4. Discussion

Dental bleaching during orthodontic treatment has gained significant attention due to increasing patient demand for aesthetic outcomes [29–34]. Clear aligners offer a unique opportunity to combine tooth movement and cosmetic whitening in a single appliance, potentially improving patient compliance and satisfaction [13]. This systematic review analyzed both clinical and in vitro studies investigating the efficacy, safety, and mechanical implications of bleaching with clear aligners.

4.1. Clinical Effectiveness of Bleaching During Clear Aligner

The clinical studies included in this review demonstrated that clear aligners are effective in delivering peroxide-based bleaching agents. Seleem et al. (2021) reported that about half of the patients experienced a 3–6-shade improvement using 10% carbamide peroxide over four weeks, while other patients had minor or more pronounced whitening effects, indicating variability in individual response [29]. Oliverio et al. (2019) showed that higher concentrations of carbamide peroxide and longer treatment duration resulted in greater shade improvement, with the group treated for two weeks with 16% carbamide peroxide achieving the most significant whitening [30]. Levrini et al. (2020) confirmed that Invisalign aligners produced comparable bleaching outcomes to conventional trays, highlighting that clear aligners can serve as an effective alternative without compromising patient comfort [31].

As discussed by the authors [29], the effectiveness of 10% carbamide peroxide is strongly influenced by both the duration of exposure and the consistency of contact between the bleaching agent and the tooth surface [11,35,36]. In the present study, an overnight wear time of approximately eight hours was selected based on the prolonged reactive half-life of carbamide peroxide, which allows a sustained release of hydrogen peroxide and urea over extended contact periods [35,36]. However, individual variations in aligner fit, salivary flow, enamel permeability, and baseline tooth shade likely influenced the extent of whitening achieved, contributing to heterogeneous clinical outcomes [29].

Furthermore, carbamide peroxide dissociates into hydrogen peroxide and urea, with urea subsequently increasing oral pH through its breakdown into ammonia and carbon dioxide [18,37]. This transient alkalinization enhances bleaching efficacy by stabilizing peroxide radicals and facilitating their diffusion through enamel and dentin, while also exerting antimicrobial effects that reduce plaque accumulation and alter plaque microflora [37–39]. The diffusion of peroxide may be influenced by aligner thickness, fit, and design [29–34].

After confirming that liquid bleaching agents could be uniformly distributed within the limited space between the F22 aligner and the tooth surface [30], the authors demonstrated that increasing carbamide peroxide concentration and prolonging daily contact time significantly enhanced shade improvement [40,41]. The most pronounced whitening effect was observed in the group treated with 16% carbamide peroxide for nine hours per day over a 14-day period, underscoring the cumulative effect of higher peroxide availability and extended exposure [30].

The findings further support the suitability of at-home bleaching protocols during aligner treatment, as low-to-moderate peroxide concentrations applied over longer periods were associated with effective whitening and minimal adverse effects [42,43]. Importantly,

scanning electron microscopy analysis revealed no clinically relevant alterations in the surface morphology of the F22 aligner material following exposure to either hydrogen peroxide or carbamide peroxide, indicating that bleaching did not compromise aligner integrity or transparency [44,45]. Spectrophotometric evaluation confirmed that aligner translucency remained above 80% after 14 days of use, establishing them as an alternative to conventional fixed orthodontic appliances [45].

From a clinical perspective, patient satisfaction was high, largely due to the simultaneous achievement of tooth alignment and whitening without additional chair time, which is known to enhance compliance and overall treatment acceptance [16,46,47]. Although the aligner does not provide a dedicated reservoir for bleaching agents, no intolerable side effects were reported, supporting the safety of this combined approach [30]. Nevertheless, the authors acknowledged methodological limitations, including a relatively small and heterogeneous sample size and the absence of a clearly defined randomization protocol. Additionally, the requirement to avoid labial attachments on anterior teeth during bleaching represents a practical limitation, which may necessitate postponing whitening to the final aligner phase in certain orthodontic treatment plans. Collectively, these findings indicate that higher carbamide peroxide concentrations and longer treatment durations can optimize whitening outcomes during clear aligner therapy, provided that material integrity, patient comfort, and orthodontic biomechanics are carefully considered [48,49].

Using finite element analysis, the authors showed that adequate gel distribution can be achieved through the intimate fit of aligners, even in the absence of reservoirs, provided that an optimal gel volume is applied to the vestibular tooth surface. Clinical spectrophotometric evaluation confirmed no significant differences in color change between teeth bleached with aligners and those treated with conventional trays. These findings suggest that the close adaptation of clear aligners to enamel surfaces allows sufficient and stable contact with the bleaching agent, ensuring effective whitening while maintaining patient comfort and satisfaction. The integration of bleaching into orthodontic treatment was also highlighted as a time-efficient and cost-effective approach, supporting the clinical use of clear aligners as an alternative to conventional bleaching trays [18,31,50].

These findings suggest that bleaching during clear aligner is particularly effective when a sufficient concentration of peroxide and adequate exposure time are used. The split-mouth design used in some studies, where different teeth were bleached using conventional trays and clear aligners in the same patient, reduces inter-patient variability and supports the reliability of the results. The studies consistently demonstrated clinically meaningful whitening effects with no adverse effects reported, indicating a favorable safety profile [29–31]. These suggest that clear aligners may serve as a delivery system for peroxide-based bleaching agents during orthodontic treatment; however, their clinical application should be supported primarily by clinical evidence, with in vitro findings providing complementary material-level insight.

4.2. Material and Mechanical Considerations: Evidence from In Vitro Studies

While clinical outcomes focus on shade improvement, in vitro studies provide essential insights into the mechanical and structural integrity of the aligners and retainer materials under bleaching conditions. Khashashneh et al. (2023) demonstrated that 10% carbamide peroxide applied to Invisalign aligners did not significantly affect tensile strength or translucency but caused measurable increases in surface roughness and reductions in hardness. These surface changes could influence long-term appliance wear, plaque accumulation, and patient comfort if aligners are reused over extended periods [32].

In vitro studies reported reductions in hardness and increases in surface roughness following exposure to peroxide agents, while optical properties were less affected in the short term [32–34].

Cheng et al. (2023) explored a novel sustained-release hydrogen peroxide system incorporated into thermoforming films. This system provided continuous whitening over 40 days without affecting the shear bond strength of attachments, suggesting that carefully designed drug-delivery systems in aligners can achieve effective bleaching without compromising orthodontic mechanics [33]. Ehteshami et al. (2025) evaluated polyethylene terephthalate glycol (PETG) retainers exposed to 15% carbamide peroxide and thermocycling. Bleaching alone caused the greatest reduction in compressive strength, whereas thermocycling before bleaching did not exacerbate material degradation. This finding indicates that bleaching may transiently weaken some thermoplastic materials, but proper appliance selection and treatment timing can mitigate mechanical risks [34]. Collectively, in vitro studies emphasize that while aligners can safely deliver bleaching agents, clinicians must consider the type of thermoplastic material, thickness, and exposure duration to prevent undesirable effects on appliance integrity [32–34].

The findings of Khashashneh et al. (2023) [32] are consistent with previous observations that low-concentration carbamide peroxide produces limited adverse effects on enamel and aligner surfaces while still achieving effective bleaching outcomes [51–53]. The increase in surface roughness observed after bleaching could potentially enhance plaque retention, emphasizing the importance of reinforcing oral hygiene practices during combined orthodontic and bleaching treatments. Additionally, the use of newer aligner materials, such as Smart Track LD30, provides improved elasticity and mechanical stability, likely contributing to the preservation of tensile strength and translucency despite chemical exposure. These results suggest that 10% carbamide peroxide may be used with Invisalign aligners without significant short-term compromise of key mechanical properties; however, the observed reductions in hardness indicate that repeated or prolonged exposure should be considered with caution.

A sustained-release peroxide system has been proposed to improve whitening efficiency while maintaining aligner integrity [33].

Bleaching alone induced the greatest reduction in compressive strength, likely due to oxidative polymer degradation, whereas prior thermocycling did not further worsen material properties. These findings indicate that bleaching may transiently weaken thermoplastic retainers but performing it after an initial intraoral adaptation period may reduce mechanical risk. These supports avoiding early use of thermoplastic retainers as bleaching trays during retention, while later application appears safer. This aligns with evidence that mechanical changes observed in thermoplastic materials are likely related to chemical exposure and environmental aging conditions [54–56].

It is important to emphasize that these mechanistic interpretations are derived from in vitro evidence and should not be directly extrapolated to clinical performance, which is primarily determined by clinical studies.

4.3. Mechanisms and Clinical Implications

Peroxide-based bleaching agents act by oxidizing organic chromophores in dental tissues. The diffusion of peroxide through the aligner material can be influenced by the thickness, fit, and design of the appliance [29–34]. Sustained-release systems, such as those tested by Cheng et al., may optimize peroxide delivery by maintaining a consistent concentration at the tooth surface, potentially reducing the need for high concentrations and minimizing adverse effects [33].

Clinically, integrating bleaching with aligner therapy offers logistical advantages, as patients can perform both treatments simultaneously without additional appliances. Split-mouth designs in clinical studies confirm that whitening efficacy is not compromised by concurrent orthodontic treatment. However, patient-specific factors such as baseline tooth color, enamel thickness, and compliance with wear schedules can influence outcomes, highlighting the need for individualized treatment planning [29–31].

Although in vitro studies reported changes in surface roughness, hardness, and compressive strength after exposure to peroxide-based bleaching agents, the clinical relevance of these findings should be interpreted cautiously. Increased surface roughness may theoretically enhance plaque accumulation and staining over time, potentially affecting oral hygiene and aesthetics. However, the magnitude of these changes remains below clinically critical thresholds in most studies and does not appear to compromise short-term aligner function or orthodontic force delivery. Reductions in hardness and mechanical strength may be more relevant in long-term use or repeated bleaching cycles, particularly for thermoplastic retainers used during retention phases. Therefore, while material alterations are measurable, their direct clinical impact remains uncertain and likely depends on treatment duration, aligner material type, and patient compliance.

4.4. Risk of Bias and Study Limitations

The clinical studies were generally at high risk of bias due to small sample sizes, lack of blinding, and unclear allocation procedures. Seleem et al. (2021) did not blind outcome assessors, which may introduce subjective bias in shade measurement using visual shade guides [29]. Oliverio et al. (2019) randomized patients but did not specify concealment or blinding procedures [30]. Levrini et al. (2020) used a split-mouth design, which mitigates inter-patient variability but cannot fully blind participants or operators [31]. It should be noted that the study by Levrini et al. (2020) [31] was available only in abstract form and was included in the synthesis and risk-of-bias assessment based on limited reported information. Consequently, important methodological details, such as allocation procedures, blinding, and full outcome reporting, could not be fully evaluated. This represents a limitation of the present review, as it restricts the reliability of the assessment and may affect the interpretation of the findings. Therefore, the results of this study should be interpreted with caution and are considered to contribute limited weight to the overall conclusions.

In vitro studies were generally at low to moderate risk of bias, with standardized preparation and objective measurements [32–34]. Limitations include small sample sizes, short experimental durations, and use of simplified laboratory conditions that may not fully replicate intraoral environmental factors, such as salivary flow, masticatory forces, and temperature fluctuations.

Heterogeneity in bleaching protocols, peroxide concentrations, exposure durations, and outcome measures further limits direct quantitative comparison. Differences in aligner materials (e.g., PETG versus polyurethane-based systems) also contribute to variability in mechanical outcomes. Furthermore, one important limitation of this review is that the search strategy was primarily focused on bleaching-related terms and did not include an extensive range of keywords specifically targeting physicomechanical properties of aligner materials. As a result, the evidence regarding material degradation and mechanical behavior may not be exhaustive. Another limitation of this review is that one included study provided limited methodological details, which constrained full risk-of-bias evaluation and may have influenced the certainty of the evidence. In addition to risk-of-bias assessment, the overall certainty of evidence is limited due to the small number of clinical studies, high or critical risk of bias in randomized trials, and heterogeneity in study designs, which collectively reduce the strength of clinical recommendations.

4.5. Future Directions

Future research should include well-designed randomized controlled trials with larger sample sizes and standardized protocols to clarify optimal peroxide concentrations and treatment durations for clear aligners. Long-term follow-up is required to assess the durability of whitening, relapse rates, and appliance integrity over extended wear periods. Investigations into novel sustained-release systems, biocompatible coatings, and combined orthodontic-bleaching materials may provide additional clinical advantages. Moreover, standardized reporting of mechanical properties and patient-reported outcomes will improve the quality of evidence and facilitate meta-analyses.

Previous investigations evaluating the use of clear aligners as adjunctive bleaching trays have primarily focused on the effects of carbamide peroxide on the physicomechanical properties of aligner materials [29–34]. From an industrial and clinical innovation perspective, it is noteworthy that limited manufacturers have actively explored the integration of orthodontic aligner therapy with simultaneous bleaching protocols. Among them, SDI company has specifically addressed this combined approach, proposing peroxide-based whitening systems (Pola for aligners, SDI Limited, Bayswater, Victoria, Australia), designed for use in conjunction with clear aligner therapy. This reflects a growing interest in multifunctional orthodontic platforms capable of delivering aesthetic enhancement without interrupting treatment progression. The convergence of aligner therapy and bleaching protocols represents a shift toward integrated digital-aesthetic workflows. However, despite promising preliminary findings, further independent randomized clinical trials and long-term material studies remain necessary to validate safety, material stability, and treatment efficiency when bleaching agents are used concurrently with orthodontic aligners. Overall, clinical studies support the effectiveness of bleaching during clear aligner therapy, while in vitro studies provide complementary information on material behavior. However, heterogeneity across studies limits direct comparison.

While most studies report comparable bleaching efficacy between clear aligners and conventional trays, some discrepancies exist regarding the extent of whitening achieved and the impact on material properties, highlighting the need for standardized evaluation protocols. It is important to note that many findings related to material properties are derived from in vitro studies, which may not fully replicate intraoral conditions. Overall, the evidence indicates that clinical studies support the effectiveness of bleaching during clear aligner in terms of tooth color improvement, while in vitro studies provide mechanistic understanding of material behavior under chemical exposure. These two evidence levels should be interpreted independently to avoid overgeneralization of findings.

5. Conclusions

Within the limitations of this systematic review, dental bleaching using clear aligners appears to be a promising approach, with some studies suggesting outcomes comparable to conventional bleaching trays. However, the available evidence is limited and characterized by methodological heterogeneity and potential risk of bias.

Higher concentrations and longer exposure durations may enhance shade improvement, although these findings must be interpreted with caution. Clear aligners and related thermoplastic appliances seem to demonstrate acceptable mechanical stability under bleaching conditions, despite some reported alterations in material properties.

Overall, clear aligners may represent a potential modality for delivering peroxide-based bleaching agents during orthodontic treatment; however, further well-designed randomized controlled trials are required to confirm their clinical effectiveness and safety. These conclusions should be interpreted considering the distinction between clinical efficacy and in vitro material behavior.

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