AVALIAÇÃO DA INFLUÊNCIA DO TIPO DE RESINA COMPOSTA NA CONFEÇÃO DE ATTACHMENTS ORTODÔNTICOS

UMA REVISÃO SISTEMÁTICA

Dissertação apresentada à Universidade Católica Portuguesa
para obtenção do grau de Mestre em Medicina Dentária

Por:
Lara Bastos Frias

Viseu, 2026

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Orientador: Professor Doutor Pedro Lopes
Coorientador: Professora Doutora Rita Pereira

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RESUMO

O tratamento com alinhadores transparentes tornou-se cada vez mais procurado na ortodontia contemporânea, recorrendo a attachments em resina composta para melhorar a transmissão de forças e aumentar a previsibilidade do movimento dentário. As propriedades físico-químicas e mecânicas destes biomateriais desempenham um papel crucial na durabilidade dos attachments, na estabilidade dimensional e no desempenho estético durante o tratamento. Esta revisão sistemática teve como objetivo avaliar de que forma diferentes tipos de resina composta influenciam o desempenho mecânico, ótico e funcional dos attachments ortodônticos utilizados na terapia com alinhadores transparentes.

Foi realizada uma revisão sistemática da literatura nas bases de dados PubMed, Scopus e Cochrane, para estudos publicados entre 2015 e 2025, seguindo as diretrizes PRISMA. Foram incluídos estudos *in vitro* e ensaios clínicos que avaliaram resinas compostas utilizadas na confeção de attachments. Quinze estudos cumpriram os critérios de elegibilidade, incluindo onze investigações laboratoriais e quatro estudos clínicos. Os desfechos avaliados incluíram resistência ao cisalhamento, resistência ao desgaste, rugosidade superficial, microdureza, estabilidade de cor e precisão da reprodução dos attachments.

De forma geral, todas as resinas compostas avaliadas apresentaram valores de resistência ao cisalhamento dentro de intervalos clinicamente aceitáveis. No entanto, observaram-se diferenças significativas no desempenho dos materiais em função da composição e viscosidade. As resinas compostas nanohíbridas e de alta viscosidade apresentaram, de modo geral, maior resistência mecânica, menor desgaste e maior estabilidade dimensional. Em contraste, as resinas compostas fluidas demonstraram melhor manuseamento e adaptação aos moldes dos attachments, mas maior suscetibilidade à degradação superficial e à descoloração.

Os resultados sugerem que a composição e as propriedades das resinas compostas influenciam significativamente o comportamento mecânico e ótico dos attachments ortodônticos. A otimização da seleção de materiais de acordo com as exigências biomecânicas e os requisitos estéticos pode melhorar a longevidade dos attachments e a previsibilidade do tratamento com alinhadores transparentes. Os clínicos devem privilegiar resinas compostas nanohíbridas ou de alta viscosidade para attachments sujeitos a cargas elevadas, e utilizar resinas compostas fluidas quando a adaptação e a estética são fatores críticos.

Palavras-chave: alinhadores transparentes; attachments ortodônticos; resinas compostas; propriedades mecânicas; resistência ao desgaste

ABSTRACT

Clear aligner therapy has become increasingly widespread in contemporary orthodontics, relying on composite resin attachments to enhance force transmission and improve the predictability of tooth movement. The physicochemical and mechanical properties of these biomaterials play a crucial role in attachment durability, dimensional stability, and esthetic performance during treatment. This systematic review aimed to evaluate how different composite resin types influence the mechanical, optical, and functional performance of orthodontic attachments used in clear aligner therapy.

A systematic literature search was conducted in PubMed, Scopus, and Cochrane databases for studies published between 2015 and 2025, following PRISMA guidelines. *In vitro* studies and clinical trials evaluating composite resins used for attachment fabrication were included. Fifteen studies met the eligibility criteria, including eleven laboratory investigations and four clinical studies. The evaluated outcomes comprised shear bond strength, wear resistance, surface roughness, microhardness, color stability, and accuracy of attachment reproduction.

Overall, all evaluated composite resins demonstrated shear bond strength values within clinically acceptable ranges. However, significant differences were observed in material performance depending on resin composition and viscosity. Nanohybrid and high-viscosity composite resins generally exhibited superior mechanical resistance, reduced wear, and greater dimensional stability. In contrast, flowable composite resins showed improved handling and adaptation to attachment molds but presented higher susceptibility to surface degradation and discoloration.

The findings suggest that the composition and properties of composite resins significantly influence the mechanical and optical behavior of orthodontic attachments. Optimizing material selection according to biomechanical demands and esthetic requirements may improve attachment longevity and treatment predictability in clear aligner therapy. clinicians should prioritize nanohybrid or high-viscosity composite resins for high-load attachments and use flowable composite resins materials when adaptation and esthetics are critical.

Keywords: clear aligners; orthodontic attachments; composite resins; mechanical properties; wear resistance

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INDEX OF ABBREVIATIONS AND ACRONYMS

3D- Three-Dimensional

BPA- Bisphenol A

Bis-EMA- Bisphenol A Ethoxylated Dimethacrylate

Bis-GMA- Bisphenol A Glycidyl Methacrylate

CAD- Computer-Aided Design

CAM- Computer-Aided Manufacturing

CI- Confidence Interval

ΔE- Color Difference

ΔE00- CIEDE2000 Color Difference

GC- GC Corporation (Dental Materials Manufacturer)

HCl- Hydrochloric Acid

LED- Light-Emitting Diode

PET-G- Glycol-Modified Polyethylene Terephthalate

PICO- Population, Intervention, Comparison, Outcome

PRISMA- Preferred Reporting Items for Systematic Reviews and Meta-Analyses

Ra- Surface Roughness Average

RMS- Root Mean Square

RoB- Risk of Bias

RoB 2.0- Revised Cochrane Risk of Bias Tool for Randomized Trials

SD- Standard Deviation

SEM- Scanning Electron Microscopy

SBS- Shear Bond Strength

TEGDMA- Triethylene Glycol Dimethacrylate

UDMA- Urethane Dimethacrylate

VHN- Vickers Hardness Number

INTRODUCTION

1. INTRODUCTION

Orthodontics is the specialty of dental medicine dedicated to the study, diagnosis, prevention, and treatment of dental malocclusions and the improper positioning of teeth and maxillofacial bone structures (1). It is a field with a significant impact on oral health and has a direct influence on patients' quality of life. Orthodontics enable the reestablishment of both aesthetic and functional harmony, thereby enhancing masticatory efficiency, supporting periodontal integrity, and contributing to optimal occlusal relationships (2).

Currently, orthodontic therapy can be performed through two systems: conventional fixed appliances and transparent removable aligners (2). Conventional appliances consist of metallic or ceramic brackets, connected by orthodontic archwires. They present high efficacy and predictability, offering three-dimensional control of tooth movements, and are widely used in the correction of complex malocclusions. The increasing emphasis on aesthetics has substantially increased the demand for aesthetic treatment modalities, thereby promoting the widespread adoption of discreet orthodontic appliances such as aligners. This therapeutic approach is enabled through the integration of digital planning technologies with advanced thermoplastic materials (3,4,5).

Clear aligners which are removable appliances used for the correction of dental malocclusions emerged as alternative to the fixed appliances (5). The defining feature of this therapeutic system is its capacity to remain essentially imperceptible; a property conferred to the use of trays composed of advanced thermoplastic polymers such as polyurethane and glycol-modified polyethylene terephthalate (PET-G). Selected for their mechanical strength, elastic behavior, and favorable biocompatibility profile, these polymers maintain dimensional stability and optical clarity over the entire course of treatment (6,7). The thermoplastic nature of polyurethane facilitates molding during the manufacturing process, especially in vacuum-formed procedures, ensuring well-fitted aligners. This material demonstrates resistance to fractures and tears, essential attributes for maintaining the force applied to teeth and ensuring aligner durability. Studies indicate that polyurethane aligners can exert consistent forces throughout the usage period, without significant degradation in performance (3,8,9). Glycol-modified polyethylene terephthalate (PET G) is recognized for its rigidity and high optical transparency. These properties provide a favorable aesthetic effect to the aligners, in addition to contributing to the maintenance of shape. PET G exhibits greater resistance to staining and discoloration compared to other plastics, which is advantageous for patients using the aligner for prolonged periods (10).

Additionally, the hydrophobic characteristic of PET G reduces bacterial adhesion, decreasing the risk of biofilm formation on the aligner surface (10,11). In many cases, these materials are modified or combined to improve aligner performance. Some manufacturers develop multilayer aligners, which combine more flexible inner layers with more rigid outer layers, balancing comfort and effective application of orthodontic forces (11,12).

The fabrication of clear aligners involves the integration of advanced digital technologies, computer-aided design (CAD), and thermoforming processes, with the objective of producing precise and personalized appliances. The workflow begins with high-resolution digital scans, which allow the creation of detailed three-dimensional models of the dental arches. These models serve as the basis for rigorous treatment planning, including the mapping of the gradual tooth movements required over time (13). With the digital model defined, CAD software is used to develop a sequence of aligners, each designed with subtle alterations that apply controlled forces, progressively guiding the teeth toward the desired alignment (4,14). Once planning is complete, the aligners are produced through thermoforming, using 3D-printed molds corresponding to each stage of the treatment (14). Quality assurance is fundamental at all stages of production, ensuring that each aligner strictly meets dimensional criteria and material properties, preventing any irregularities that could compromise treatment efficacy. The incorporation of 3D printing technologies has optimized this process, allowing faster production and greater cost efficiency (15,16). Careful evaluations of biocompatibility and resistance to deformation are also performed, as even small variations in physical characteristics can significantly affect the precision of sequential tooth alignment (16). Despite the evident benefits, it is essential to consider the potential degradation of materials over time and their possible implications for health. The deterioration of the thermoplastic can lead to the release of compounds that exhibit toxicity, potentially causing everything from mild local irritation to more significant systemic effects, making this a crucial factor in evaluating the long-term safety and efficacy of aligners (16,17).

Although most aligners are produced with polyurethane or PET G, concerns have arisen regarding the possible release of bisphenol A (BPA) and other chemical compounds, especially under conditions of high temperature or acidity present in the oral cavity. BPA, recognized as an endocrine disruptor, has been identified in certain polycarbonate plastics, raising questions about the safety of some dental materials (10). Currently, many manufacturers use BPA-free plastics, and polyurethane and PET G are considered safer alternatives due to the lower risk of releasing harmful substances. Nonetheless, research continues to investigate the long-term effects of these materials in the oral cavity (13,14).

1.1. Impact of Orthodontic Systems on Oral Environment

Fixed appliances are composed of stainless steel or nickel-chromium-based alloys, which, due to mechanical friction and the action of saliva, tend to release metallic ions, potentially enhancing toxic effects on oral tissues. Consequently, during treatment, there is a higher predisposition for the development of dental caries lesions and gingival inflammation. Studies indicate that, although clear aligners present a reduced risk of toxicity compared to fixed appliances, it is essential that patients maintain rigorous oral hygiene and follow the orthodontist's instructions to minimize potential adverse effects (18).

For an appropriate clinical approach in selecting the therapeutic option, the impact on the oral microbiome, as well as its chemical composition and the resulting effects, must be considered. Oral hygiene during orthodontic treatment differs substantially between patients of conventional fixed appliances and clear aligners. In fixed appliances, there are multiple retentive surfaces, making effective brushing and flossing difficult. This limitation promotes the accumulation of dental biofilm and food debris (19). Larger retention areas and the inability to remove the appliance favor the growth of acidogenic and periodontopathogenic bacteria in fixed appliance users. Microorganisms associated with enamel demineralization and the development of dental caries, such as *Streptococcus mutans* and *Lactobacillus* spp., and gram-negative anaerobic bacteria related to periodontal disease and gingival inflammatory processes, such as *Porphyromonas gingivalis*, *Prevotella intermedia*, and *Tannerella forsythia*, are more prevalent (19). On the other hand, clear aligners can be taken out during meals and oral hygiene practices, allowing patients to maintain oral hygiene routines very similar to those of individuals without appliances. It has been observed that there is no significant increase in levels of *Streptococcus mutans* and *Lactobacillus spp*. throughout treatment. Additionally, there is lower colonization by periodontopathogenic species, resulting in reduced indices of gingival inflammation and bleeding (19).

However, some authors associate the continuous and incorrect use of aligners with an increase in oral temperature and a decrease in the mechanical action of saliva, which may favor the proliferation of fungi such as Candida albicans (20). Proper cleaning of aligners is essential, as inadequate use can turn the device into a reservoir for microorganisms, negating its benefits (18,19).

1.2. Orthodontic attachments

In addition to aligners, this system is also composed of attachments that are composite resin elements applied to the buccal surface of teeth during orthodontic treatment with aligners. They act as support and retention points, allowing more controlled and complex tooth movements, improving the efficiency of force transmission. In the context of treatment planning, the morphological characteristics, dimensional parameters, and constituent materials of the attachments must be rigorously assessed to ensure predictable outcomes, optimal stability, and overall clinical success (13). Clinical application of clear aligners involves a complex interaction between different materials, creating friction between attachments and the more flexible aligner polymer. This environment, combined with adverse oral cavity conditions, can influence material aging and wear (14). Given the large enamel area involved in bonding, particles and debris from the attachment-aligner system are released during treatment. Moreover, the removal or wear process of composite resins is labor-intensive and generates potentially hazardous aerosols, limiting the use of multiple attachments to the minimum necessary (10,13).

Loss of attachment retention is a relatively common adverse event during treatment with transparent aligners, occurring more frequently on molars. Factors such as the type of composite resins used, aligner wear, duration of use, chewing habits, and tooth position influence attachment retention. In particular, unilateral chewing habits may increase the risk of detachment. Most of these risk factors are related to patient behavior and can be minimized through proper guidance and education on care during treatment (17).

To minimize these adverse effects, specific clinical protocols are followed. Initially, attachments are installed using a 0.3–0.5 mm acetate tray stamped over the patient's initial model (13). Subsequently, prophylaxis is performed on the selected tooth surfaces, which are washed, dried, and relatively isolated before composite resin application (13,14).

Attachments are available in different types, shapes, and functions, playing an essential role in the transmission of specific and controlled dental forces. For these movements to be executed accurately, it is imperative that attachments are fabricated using composite resins with high durability and mechanical performance. The careful selection of the appropriate material for each type of attachment, considering its position and clinical function, is crucial for efficacy, allowing for a reduction in the total treatment duration for the patient and optimizing clinical intervention time. Correct adaptation of composite resin to dental morphology, combined with standardized application techniques, is critical to minimize failures and optimize aligner performance. Other relevant factors include the chemical and thermal resistance of the material in the oral environment, biocompatibility, the capacity for complete polymerization, and dimensional stability over time, all of which directly impact the longevity of the attachment and the maintenance of applied forces (4,6).

The attachment size has a direct influence on aesthetics and functionality. Smaller attachments provide greater discretion but reduce the capacity to generate predictable forces due to a smaller contact surface. For this reason, reducing the size of attachments should be done with caution. The geometry and shape of attachments is also important. Regarding shape, attachments can be classified in conventional attachments or optimized attachments (1,9). Conventional attachments are frequently ellipsoid, recommended for teeth with a limited surface area, providing adequate retention and anchorage. Rectangular attachments are positioned vertically or horizontally, generally in the central region of the tooth crown. To favor specific tooth movements beveled rectangular attachments: can be applied on the occlusal, gingival, mesial, or distal surfaces, promote more precise movements, adapting to tooth dimensions, longitudinal axis, and contours. Proper placement ensures effective force application while minimizing interferences. Examples include rotation, extrusion, multiplanar movements in the anterior and posterior regions, root control, and anchorage (3).

1.2.1. Chemical Composition of Composite Resins

Orthodontic attachments can be manufactured from different types of composite resins. Selection should consider not only aesthetics but, more importantly, the mechanical and functional properties necessary to withstand the forces applied by aligners (14,16).

Restorative materials should exhibit wear behavior like natural enamel, avoiding damage to both treated teeth and antagonists. Composite resins consist of an organic matrix, composed of crosslink monomers such as Bisfenol A-glycidyl dimethacrylate (Bis-GMA), Ethoxylated bisphenol A dimethacrylate (Bis-EMA), Urethane dimethacrylate (UDMA), and Triethylene glycol dimethacrylate (TEGDMA), a photoinititator system, and silanated inorganic particles, frequently comprised of colloidal silica, barium silicate, zinc oxide, and zirconia (14,16)

Bis-GMA: The most commonly used monomer in resin composites, characterized by high strength and low polymerization shrinkage, although it presents high viscosity and a relatively lower degree of conversion (16).

Bis-EMA: Low viscosity monomer with reduced polymerization shrinkage (16).

TEGDMA: Low viscosity monomer, acts as a diluent in the organic matrix. When combined with Bis-GMA, it promotes composite resins with improved mechanical properties due to bonds formed during polymerization (16).

UDMA: Exhibits intermediate viscosity between Bis-GMA and TEGDMA/Bis-EMA. Often used as a partial or total substitute for Bis-GMA, presenting a higher monomer conversion rate (16).

1.2.2. Classification of Composite Resins by Particle Size

<u>Macrofilled</u>: Resin composites with quartz as filler. Due to low radiopacity, replaced by barium and strontium glasses, improving radiographic visibility. Particles range from 10 to 50 µm, providing high strength but low surface smoothness and difficult polishing, gradually falling out of use (16).

<u>Microfilled</u>: Developed to overcome aesthetic limitations of macrofilled resin composites, with particles around 0.04 µm (colloidal silica), providing better polish and gloss. Lower mechanical strength, indicated for flat areas with low functional stress (16).

<u>Hybrid and Microhybrid</u>: Combine silica microparticles and heavy glass macroparticles, with filler content around 80% by weight. Hybrids have medium-sized particles slightly larger than 1 µm, combined with 40 nm silica, while microhybrids have a higher proportion of small particles, optimizing polishing, aesthetics, and mechanical strength. Considered universal composite resin due to versatility and durability (16).

<u>Nanofilled and Nanohybrid</u>: Incorporate nanometric particles (1–100 nm), providing improved polishing, aesthetics, fracture resistance, and flexibility. Nanocomposites can be exclusively nanofilled or mixed (nanohybrid), combining nano- and micrometric particles to further enhance mechanical properties and tissue adhesion (16).

To allow thick restorative increments of 4-5mm bulk-fill composite resins were developed to simplify clinical practice, with more reactive photo-initiators and greater translucency, allow deeper polymerization and monomer conversion. Contain monomer modulators that reduce shrinkage and stress at the adhesive interface, ensuring good longevity and mechanical performance (14).

1.3. Study Objective

Can the use of different types of composite resins in fabrication of attachments influence the outcomes of orthodontic treatment with aligners? Correct adaptation of composite resin to dental morphology, combined with standardized application techniques, is critical to minimize failures and optimize aligner performance. Other relevant factors include the chemical and thermal resistance of the material in the oral environment, biocompatibility, the capacity for complete polymerization, and dimensional stability over time, all of which directly impact the longevity of the attachment and the maintenance of applied forces.

The present study aims, through a systematic literature review, to evaluate the impact of different types of resin composites used in the fabrication of attachments on outcomes associated to clear aligners efficacy. Key parameters to be analyzed include accurate reproduction of shape, fit, shear strength, and wear experienced throughout the treatment.

MATERIALS AND METHODS

2. MATERIALS AND METHODS

2.1. Search Strategy

A comprehensive and systematic literature search was conducted in September 2025, at the electronic databases PubMed, Scopus, and Cochrane to identify relevant studies on the use of different types of composite resins in the fabrication of attachments. This systematic review was carried out in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. Previous systematic reviews and the review protocol was registered in the OSF database under the Registration DOI: https://doi.org/10.17605/OSF.IO/EHKRB .

The research question was formulated according to the PICO strategy, defined as follows:

P (Population): Patients undergoing orthodontic treatment with transparent aligners.

I (Intervention): Use of different types of composite resins in the fabrication of attachments.

C (Comparison): Distinct composite resin materials.

O (Outcome): Impact on the efficacy of clear aligners, considering parameters such as:

- accuracy of shape and fit reproduction,
- shear strength,
- wear over time,
- durability and dimensional stability,
- color stability,
- influence on treatment efficiency and duration.

Below is the defined PICO question:

In patients undergoing orthodontic treatment with clear aligners, does the use of different types of composite resins for attachment fabrication, compared with other composite materials, influence the effectiveness of orthodontic treatment?

The search strategy was initially constructed for the PubMed database and subsequently adapted for each of the other databases consulted. The results obtained were cross-checked to identify and remove duplicates.

The search equation used was: (orthodontic attachment OR attachment) AND (composite resins OR composite) AND (clear aligner OR aligner OR Invisalign).

Period: articles published within the last 10 years (2015–2025);
Search date: September 14, 2025.

In total, the search identified 215 articles in PubMed, 54 in Scopus, and 30 in Cochrane.

Inclusion criteria:

- Clinical trials;
- *In vitro* studies;
- Published between 2015 and 2025;
- Studies addressing the comparison of different types of composite resins in fabrication of attachments;
- Full-text availability.

Exclusion criteria:

- Systematic reviews;
- Critical or narrative reviews;
- Letters to the editor, editorials, or clinical guidelines.

2.2. Study Selection and Data Extraction

The study selection process was performed in three stages:

1. *Initial screening:* two independent reviewers (PL and LF) examined the titles and abstracts of the identified articles, applying the predefined eligibility criteria. Any discrepancies between reviewers were resolved through discussion with a third author (RFP). Cohen's Kappa test was performed to assess inter-reviewer agreement. The Rayyan Intelligent Systematic Review Platform was used to assist in the systematic review process (21).

2. *Abstract reading*: non-excluded articles were assessed in full based on their abstracts, considering compliance with the inclusion criteria.

3. *Full evaluation*: potentially eligible articles were read in full and analyzed for their relevance to the review objective.

Included studies were assigned specific codes for organization and analysis.

During data extraction, the following information was collected and organized in a table: article title, year of publication, authors, methodological design, sample characteristics, type of orthodontic treatment, duration of clinical follow-up, and evaluated outcomes.

2.3. Methodological Quality Assessment

The methodological quality of the included studies was evaluated using the Revised Cochrane Risk of Bias Tool for Randomized Trials (RoB 2.0). This tool comprises five main domains:

D1: Bias arising from the randomization process;

D2: Bias due to deviations from the intended interventions;

D3: Bias due to missing outcome data;

D4: Bias in the measurement of outcomes;

D5: Bias in the selection of the reported results.

Each study was individually assessed with respect to these domains, and one of the following judgments was assigned: *low risk of bias*, *some concerns*, or *high risk of bias*.

The final classification of each study was determined based on the predominant judgment across the five domains, thus reflecting the overall risk of bias assigned.

RESULTS

3. RESULTS

The initial search identified a total of 299 articles, of which 215 were retrieved from PubMed, 54 from Scopus, and 30from the Cochrane Library. After the removal of 49 duplicates, 250 articles remained for screening.

In the first evaluation stage, based on titles and abstracts, 233 articles were excluded for the following reasons: (1) Systematic review, (2) Animal study, (3) Wrong study design, (4) Wrong outcome and (5) Results not related.

Thus, 17 articles were selected for full-text reading. Of these, 2 studies were subsequently excluded because they were only study registrations that had not yet been completed and had no published results, Figure 1.

At the end of the selection process, 15 studies meet all the eligibility criteria and were included in the review, Table 1, 2.

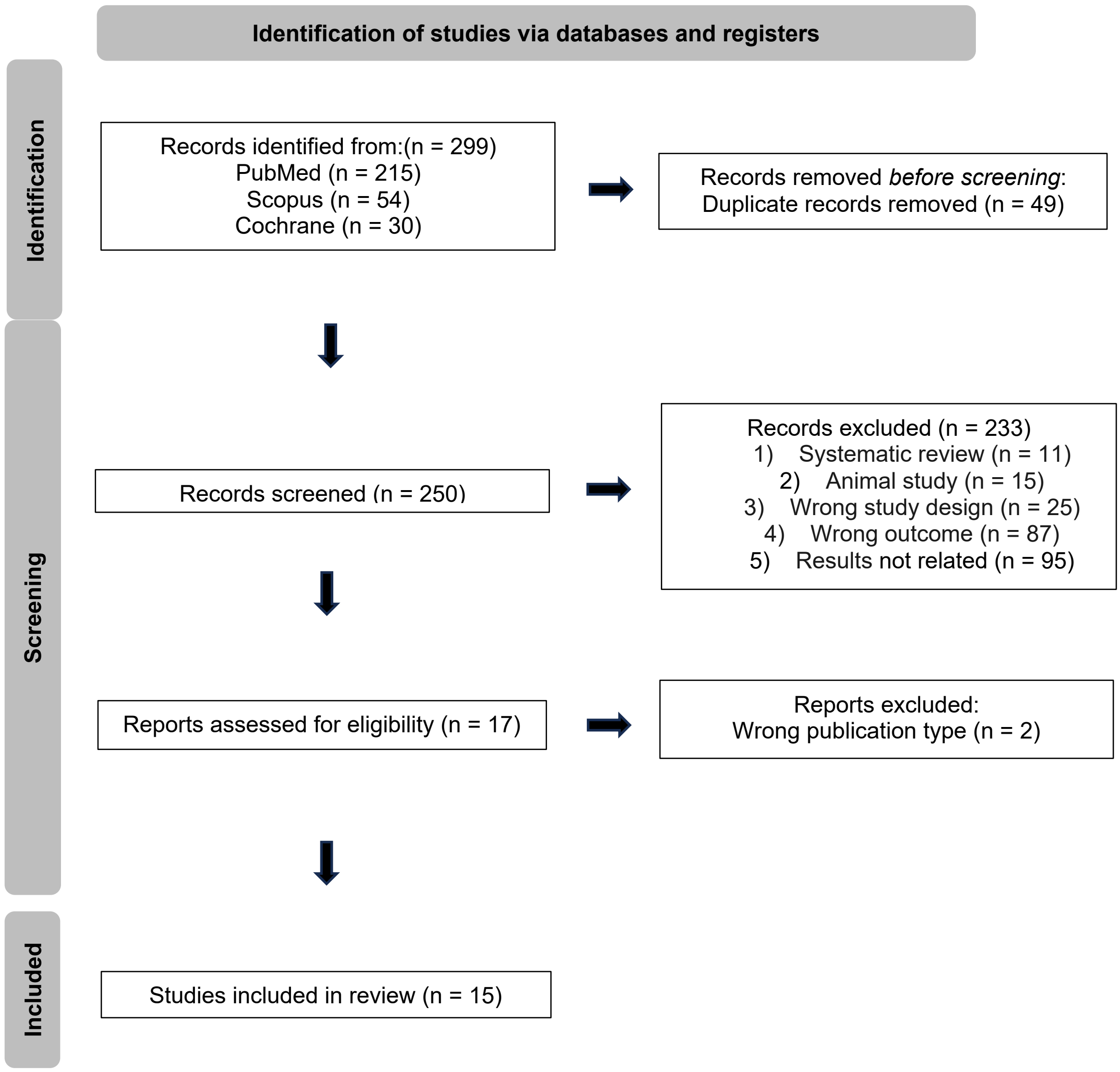


Figure 1. Study selection process is illustrated in the PRISMA flow diagram

Table 1. *Characteristics of the studies in vitro included in this systematic Review*

Author (Year)	Composite resins (chemical composition)	Fillers	Evaluated parameters	Conclusions
Guan et al. (2025)	Z250 XT, 3M: Bis-GMA, BIS-EMA, UDMA, TEGDMA Z350 XT,3M: Bis-GMA, BIS-EMA, UDMA, PEGDMA, TEGDMA P60: Bis-GMA, UDMA, Bis-EMA	Z250 XT, 3M: 0.01-3.5 µm zirconia/ silica;82 wt% Z350 XT,3M: 5–20 nm silica nanofillers and 0.6–1.4 µm zirconia/Silica nanoclusters (78.5 wt%) P60: 0.01–3.5 µm zirconia/Silica (83 wt%)	Color stability, SBS, wear	P60 best balance
Erbas & Atik (2025)	GC Aligner, GC: Octahydro-4,7-methano-1H-(indenediyl) bis(methylene) bismethacrylate, 1,3,5-triazine-2,4,6-triamine, polymer with formaldehyde, 2,2'-ethylene-dioxydiethyl dimethacrylate, 2-(H-benzotriazol-2-yl)-p-cresol, UDMA Ortho Connect: ND Z350XT Flowable, 3M: Bis-GMA, TEGDMA, procrylat resin Z350XT Universal,3M: Bis-GMA, UDMA, Bis-EMA	GC Aligner, GC: ND Ortho Connect: ND Z350XT Flowable, 3M: Ytterbium trifluoride, silica, zirconium oxide (65 wt%) Z350XT Universal: Silica, zirconia nanoparticles (20 µm) (72.5 wt%)	Adhesion, SBS	Z350 Universal best SBS
Bellocchio (2023)	Enaflow, Micerium: UDMA, HEMA Enamel Plus HRI, Micerium: tetramethylene dimethacrylate	Enaflow, Micerium: silicon dioxide Enamel Plus HRI, Micerium: 0.7-0.04 µm Glass filler, silicone dioxide 77 wt%	Accuracy	High viscosity more stable
Alshammari (2025)	Tetric PowerFlow, Ivoclar: Bis-GMA, Bis-EMA, UDMA,	Tetric PowerFlow, Ivoclar: Barium aluminium silicate	Microhardness, SBS	Clearfil Majesty Flow, Kuraray best hardness

	DCP Tetric PowerFill, Ivoclar: Bis-GMA; Bis-EMA, UDMA, PBPA,DCP, β-allyl sulfone Filtek™ Supreme Flowable Restorative, 3M: Procrylat, BisGMA, and TEG-DMA resins Filtek™ Supreme XTE Universal, 3M: Bis-GMA (5–10 wt%), UDMA, TEGDMA,Bis-EMA6, PEGDMA) Clearfil Majesty Flow, Kuraray: TEGDMA, Hydrophobic aromatic dimeth-acrylate dl-Camphorquinone · Accel era-tors · Pigments · Others Estelite Sigma Quick, Tokuyama: Bis-GMA, TEGDMA	glass, an Iso-filler copolymer mix, ytterbium fluoride (71 wt %) Tetric PowerFill, Ivoclar: Barium aluminium silicate glass, an Iso-filler copolymer mix, ytterbium fluoride and a spherical mixed oxide (79 wt%) Filtek™ Supreme Flowable Restorative, 3M: Non-agglomerated/non-aggregated surface modified 20 nm silica filler, a non-agglomer-ated/non-aggregated surface modified 75 nm silica filler, a surface modified aggregated zirconia/silica cluster filler (comprised of 20 nm silica and 4 to 11 nm zirconia particles) and ytterbium trifluoride filler with a range of particle sizes from 0.1 to 5.0 µm The aggregate has an average cluster particle size of 0.6 to 10 µm (78.5 wt%) Clearfil Majesty Flow, Kuraray: Silanated barium glass filler (average: 3 µm). Silanated colloidal silica (average: 20 nm) (81 wt%) Estelite Sigma Quick, Tokuyama: SiO_2, ZrO_2, PFSC (200 nm) 82 wt%		

Ocak (2025)	Flow Tain, Reliance: Bis-GMA, TEGDMA Transbond XT Light Cure Adhesive, 3M: Bis-GMA, TEGDMA G-aenial Universal Flo, GC: DMA, Bis-MPEPP Filtek Z350 XT Flowable Restorative, 3M: Bis-GMA, UDMA, TEGDMA, Bis-EMA	Flow Tain, Reliance: Silica, Barium Glass, Fumed Silica (60wt%) Transbond XT Light Cure Adhesive, 3M: Silica, Quartz (70- wt%) G-aenial Universal Flo: Silica, Strontium glass, Fluoroaluminosilicate glass (69 wt%) Filtek Z350 XT Flowable Restorative, 3M: Zirconia/Silica (65 wt%)	Wear	G-aenial Universal Flo best
Chen (2021)	Z350XT,3M: Bis-GMA, UDMA, Bis-EMA Z350 Flow, 3M: Bis-GMA, UDMA, TEGDMA, Bis-EMA SonicFill, Kerr: Bis-GMA, Bis-EMA, EBPADMA, TEGDMA	Z350XT,3M: Silica, zirconia nanoparticles (20 μm) (72.5 wt%) Z350 Flow, 3M: : Ytterbium trifluoride, silica, zirconium oxide (65 wt%) SonicFill, Kerr: Silicon dioxide modified dimethacrylate aminoformate (81.3 wt%)	SBS, wear	SonicFill best
Chavanavesh (2025)	Tetric N-Flow, Ivoclar: Bis-GMA, Bis-EMA, UDMA, Bis-PMA, DCP, D3MA Beautifil, Shofu: Bis-GMA, TEGDMA Z350XT,3M: Bis-GMA, UDMA, Bis-EMA	Tetric N-Flow, Ivoclar: barium glass, Ytterbium, Trifuoride, Copolymer, Mixed oxide (SiO2/ZrO2) (79 wt%) Beautifil, Shofu: Multifunctional glass filler, Surface prereacted glass-ionomer filler based on aluminofluoro-borosilicate glass (83.3 wt%) Z350XT,3M: Silica, zirconia nanoparticles (20 μm) (72.5 wt%)	Wear	Z350 highest wear
Kircelli (2023)	Tetric Evoceram, Ivoclar: Dimethacrylates Tetric N-Ceram, Ivoclar: Dimethacrylates Tetric N-Flow, Ivoclar: Bis-GMA, Bis-EMA,	Tetric Evoceram, Ivoclar: barium glass, ytterbium trifluoride, mixed oxide and copolymers (82 wt%) Tetric N-Ceram, Ivoclar: barium glass, ytterbium	SBS	All acceptable

	UDMA, Bis-PMA, DCP, D3MA G-aenial Universal Injectable, GC: Bis EMA, UDMA Aligner Connect, GC: Octahydro-4,7-methano-1H-(indenediyl) bis (methylene) bismethacrylate, 1,3,5-Triazine-2,4,6-triamine, polymer with formaldehyde, 2,2'-ethylenedioxydiethyl dimethacrylate, 2-(2H-benzotriazol-2-yl)-p-cresol, UDMA... (Not all content is shared)	trifluoride, mixed oxide and copolymers (80–81 wt. %) Tetric N-Flow, Ivoclar: Ba-Al- Silicate Glass, Copolymer, Mixed Oxide, Ytterbium Trifluoride, Silicone Dioxide (40 wt%) G-aenial Universal Injectable, GC: Silica, Barium Glass, Ultra Fine (150 nm) (69 wt% Aligner Connect, GC: ND		
Erçin (2023)	Omnichroma, Tokuyama: UDMA, TEGDMA Aligner Connect, GC: Octahydro-4,7-methano-1H-(indenediyl) bis (methylene) bismethacrylate, 1,3,5-Triazine-2,4,6-triamine, polymer with formaldehyde, 2,2'-ethylenedioxydiethyl dimethacrylate, 2-(2H-benzotriazol-2-yl)-p-cresol, UDMA... (Not all content is shared) Tetric Power Flow: Bis-GMA, Bis-EMA, UDMA, Bis-PMA, DCP, D3MA	Omnichroma, Tokuyama: nano spherical fillers (260 nm spherical SiO2-ZrO2) (79 wt%) Aligner Connect, GC: N.D Tetric Power Flow: Barium glass, Ytterbium, Trifluoride, Copolymer, Mixed oxide (SiO2/ZrO2) (79wt%)	Color	Omnichroma best
Erbas (2024)	Aligner Connect, GC: Octahydro-4,7-methano-1H-(indenediyl) bis(methylene) bismethacrylate, 1,3,5-triazine-2,4,6-triamine, polymer with formaldehyde, 2,2’-ethylene-	GC Aligner Connect:ND Z350 Flowable: Ytterbium trifluoride, silica, zirconium oxide (65 wt%) Z350 XT universal, 3M: Silica, zirconia nanoparticles (20 µm) (72.5 wt%)	Accuracy, roughness	Z350 smoother

	dioxydiethyl dimethacrylate, 2-(H-benzotriazol-2-yl)-p-cresol, UDMA Ortho Connect: ND Z350 Flowable. 3M: Bis-GMA, TEGDMA, procrylat resin Z350 XT universal, 3M: Bis-GMA, UDMA, Bis-EMA	Ortho Connect: ND		
Sfondrini (2019)	Enamel Hri, Micerium Tricyclodecane dimethanol dimethacrylate, UDMA Bracepaste, American Orthodontics: Methacrylic acid ester, activator, Ethoxylated Bisphenol A, Dimethacrylate, Tetramethylene Dimethacrylate, Diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide	Enamel Hri, Micerium: (0.005 μm–0.05 μm silicon dioxide fillers), (0.2–3.0 μm glass fillers) (74. Wt%) Bracepaste, American Orthodontics: N.D	Shape	Similar fidelity

Table 2. *Characteristics of the studies in humans included in this systematic Review*

Author (Year)	Composite resins (chemical composition)	Fillers	Evaluated parameters	Conclusions
Barreda (2023)	Z350 XT,3M: Bis-GMA, UDMA, Bis-EMA Amelogen Plus, Ultradent: Bis-GMA	Z350 XT universal, 3M: Silica, zirconia nanoparticles (20 μm) (72.5 wt%) Amelogen Plus, Ultradent: 76 wt%	Wear	Amelogen higher wear
Yildiz (2024)	G-aenial Universal Injectable, GC: Bis EMA, UDMA Tetric EvoFlow, Ivoclar: Bis GMA, UDMA,	G-aenial Universal Injectable, GC: Silica, Barium Glass, Ultra Fine (150 nm) (69 wt%)	Color	G-aenial best

	D3MA GC Aligner Connect, GC: Tetric Prime, Ivoclar: Bis GMA, UDMA, Bis- EMA	Tetric EvoFlow, Ivoclar: Ba- Al- Silicate Glass, Copolymer, Mixed Oxide, Ytterbium Trifluoride, Silicone Dioxide (40 wt%) Tetric Prime, Ivoclar: Ba- Al- Silicate Glass, Copolymer, Mixed Oxide, Ytterbium Trifluoride		
Jardim (2023)	Not specified	Not specified	Wear/failure	More failures
Nieto-Sánchez (2024)	Transbond XT, 3M: Bis-GMA, TEGDMA Tetric EvoCeram, Ivoclar: Dimethacrylates	Transbond XT, 3M: Silica, Quartz 70- wt% Tetric Evoceram, Ivoclar: barium glass, ytterbium trifluoride, mixed oxide and copolymers (82 wt%)	Aesthetics	Transbond worse

Table 1 and table 2 briefly presents the main characteristics of the studies included in this systematic review.

A total of 15 articles published between 2019 and 2025 were included, analyzing different composite resins used in the fabrication of attachments for clear aligners. Of this total, 11 corresponded to *in vitro* studies and 4 to clinical trials conducted on patients.

In vitro studies mainly focused on shear bond strength (SBS), surface wear, color stability, surface roughness, microhardness, and reproduction accuracy of the attachments. The clinical trials primarily evaluated color change in the oral cavity, wear over time, and aesthetic perception by the patients.

Among the composites composite resin studied, Filtek™ Z350 XT (3M ESPE) was the most frequently evaluated, in its different formulations (flowable, universal, nanoparticulate composite resins). Other recurrent materials included GC Aligner Connect, Tetric range composites (Ivoclar/GC) in different viscosities, Amelogen Plus (Ultradent), Omnichroma (Tokuyama), and G-ænial Universal Injectable (GC).

Overall, all studies reported adhesive strength values considered clinically acceptable for use in attachments. Most investigations showed that flowable composite resins offer greater ease and speed of handling, while high-viscosity composite resins (packable/nanohybrid) demonstrated greater wear resistance and smoother surfaces.

Regarding color stability, significant changes were observed after exposure to staining agents, with coffee and red wine causing the most discoloration.

Concerning the accuracy of attachment reproduction, laboratory studies showed differences between materials and polymerization techniques, with variation in the presence of excess composite resin and in the fidelity of digitally planned shape.

3.1. Risk of Bias Analysis

Risk of bias analysis was carried out for all included studies, with the purpose of assessing the methodological quality and the reliability of the findings.

For clinical trials, the Cochrane RoB 2 tool was used, while for *in vitro* studies, an adaptation of the criteria proposed by Faggion (2012) was applied, which consider aspects such as randomization, blinding, standardization of the experimental protocol, and adequacy of statistical analysis, Table 3.

Table 3. *Risk of bias analysis according to the RoB tool (Cochrane Library)*

D1: Bias arising from the randomization process, D2: Bias due to deviations from intended interventions, D3: Bias due to missing outcome data, D4: Bias in measurement of the outcome, D5: Bias in selection of the reported result. Judgment: high, moderate, and low.

Autores (Ano)	**D1**	**D2**	**D3**	**D4**	**D5**
Guan *et al*. (2025)	low	moderate	low	moderate	low
Erbas & Atik (2025)	low	low	low	low	low
Bellocchio *et al*. (2023)	low	low	low	low	low
Alshammari *et al*. (2025)	moderate	low	low	low	low
Ocak *et al*. (2025)	low	low	low	low	low
Chen *et al*. (2021)	low	moderate	low	low	low
Chavanavesh *et al*. (2025)	low	low	low	low	low
Kircelli *et al.* (2023)	low	low	low	low	low
Erçin, Kurnaz & Kopuz (2023)	low	low	low	low	low
Erbaş & Atik (2024)	low	low	low	low	low

Sfondrini *et al*. (2019)	moderate	low	low	low	low
Barreda *et al*. (2023)	low	low	low	low	low
Yildiz *et al.* (2024)	low	low	low	low	low
Jardim *et al*. (2023)	low	moderate	moderate	low	low
Nieto-Sánchez *et al*. (2024)	low	low	low	moderate	low

Most of the studies included presented a low risk of bias, reflecting consistent methodologies, well-defined criteria, and appropriate outcome measurement. Studies such as those by Erbas & Atik (2025), Bellocchio *et al*. (2023), Ocak *et al*. (2025), Kircelli *et al*. (2023), Erçin *et al*. (2023), Erbaş & Atik (2024), Barreda *et al*. (2023), and Yildiz *et al*. (2024) were classified as having low risk in all domains, demonstrating methodological robustness and transparency in experimental conduct.

Some studies, such as Guan *et al*. (2025), Chen *et al*. (2021), Sfondrini *et al*. (2019), Jardim *et al*. (2023), and Nieto-Sánchez *et al*. (2024), presented "some concerns," mainly due to the absence of detailed information on the randomization process, possible influence of deviations from the original intervention, or outcome measurement without blinding. Nevertheless, the potential biases identified do not substantially compromise the validity of the presented results.

Overall, the evaluated studies show good methodological quality, with a low overall risk of bias, supporting the reliability of the conclusions of the systematic review.

4. DISCUSSION

The results of this systematic review demonstrate that the mechanical properties of composite resins influence the durability of orthodontic attachments. In the specific context of orthodontic attachments, filler size and shape, monomer composition, resin matrix viscosity and polymerization conditions should not be regarded as generic material descriptors. Rather, these parameters directly influence attachment shape fidelity, aligner seating, wear resistance during repeated aligner insertion and removal, and the stability of force transmission throughout treatment (22,23,24).

Regarding SBS, most studies maintained identical adhesive systems and polymerization conditions across the tested composite resins, allowing intra-study comparison of material performance. For example, Guan *et al*. standardized both the adhesive protocol and curing conditions, reporting SBS values between 10–20 MPa, with Filtek™ P60 exhibiting the highest values. Similarly, Kircelli *et al*. applied a consistent adhesive strategy and light-curing protocol, with Tetric N-Ceram showing the highest SBS values (21 ± 4 MPa). Nevertheless, substantial variability in adhesive systems and bonding protocols was observed between studies. Therefore, although higher SBS values were frequently associated with nanohybrid and high-viscosity composite resins, these findings should be interpreted cautiously, since bond strength may also be influenced by adhesive strategy, enamel conditioning, curing parameters, and testing methodology. The higher SBS values may be partly associated with increased inorganic filler content, reduced organic matrix proportion, and lower polymerization shrinkage stress, resulting in a stronger stability of orthodontic attachments, indeed Filtek™ P60 (3M) is composed of 83 wt%, inorganic filler particles of zirconia and silica ranging 0.01-3.5 µm, Tetric N-Ceram (Ivoclar) with a filler load of approximately 81 wt% Filtek™ P60 (3M). Also, Tetric N-Ceram (Ivoclar) and Filtek™ P60 (3M), share the same monomers within the organic matrix UDMA, BiS-EMA and Bis-GMA which can also increase the inherent rigidity and decrease polymerization shrinkage. (25,26). Nano and micro-scale particles are combined in the composite resins´ microstructure to promote a mechanical reinforcement under chewing loading (25). On the other hand, flowable composites resins, such as Filtek Z350 XT Flow and GC Aligner Connect, showed greater ease of handling and adaptation to the molds, but presented lower mechanical resistance and higher surface roughness (25,26). This difference can be explained by the higher amount of TEGDMA and Bis-EMA within the organic matrix, responsible for reducing viscosity and increasing flowability. In orthodontic attachments, this balance becomes clinically critical, as excessive flowability may lead to distortion or excess material during template placement, compromising attachment shape accuracy and aligner fit. Conversely, higher-viscosity materials contribute to better shape retention and more predictable force application throughout treatment (14,16).

The dimensional reliability of attachments depends on multiple factors, including the viscosity of the composite resin, the mold material, and the photopolymerization conditions (12). The study by Bellocchio *et al*. (2023) demonstrated that PET-G molds presented greater dimensional stability and precision in reproducing shapes compared to polyethylene molds. This result is consistent with the physical properties of PET-G, which features high rigidity and lower thermal deformation (24).

Regarding viscosity, it was observed that Filtek Z350 Universal with 72.5 wt% of inorganic filler particles composite resin exhibited higher shape fidelity with less overflow, while flowable composite resin Z350 XT, with 65 wt% of inorganic particles showed a tendency toward excess volume formation, especially under reduced irradiance time of 10s (24). Erbaş & Atik (2024) found that Filtek Z350 XT Universal (3M) presented smoother surfaces and lower roughness, while GC Aligner Connect™ showed greater roughness under high irradiance of 3200 mw/cm^2 for 3 s. The time of light exposure depends on the light irradiance as well as type and thickness of the restorative materials to reach the energy required for the polymerization of composite resins. Higher irradiance energy increases the degree of conversion and surface hardness but may also induce thermal stresses and microcracks (25,26). Previous studies have shown that adequate polymerization of composite resins depends on both the irradiance of the light-curing unit and the exposure time. An irradiance close to 1000 mW/cm^2, combined with sufficient curing time, is generally recommended to achieve appropriate radiant exposure and clinical accepted values of degree of conversion between 52 up to 75 % immediately post-polymerization (25,26). In the context of attachment fabrication, inadequate polymerization may result not only in reduced mechanical performance but also in subtle dimensional inaccuracies, which can compromise aligner seating and the efficiency of force transmission (25,26). Thus, standardizing the curing protocol with adequate light irradiation and exposure time, visible light irradiance and wavelength, correct distance between LCU tip are essential to avoid variations in attachment accuracy.

The color stability of composite resins is a fundamental parameter in material selection, especially for aesthetic areas. In general, studies indicate that coffee and red wine are the most aggressive staining agents, inducing color changes beyond clinically perceptible thresholds (20,23,27). In clinical trials, Yildiz *et al*. (2024) confirmed that G-ænial

Universal Injectable showed less color change after exposure to staining substances, a result attributed to its high inorganic filler density, filler distribution, particle shape and size and low content of aromatic monomers. These findings reinforce that chemical composition and surface finishing are determining factors for aesthetic performance, with the use of nanoparticulate composite resins being recommended in anterior regions (24,27). The study by Erçin, Kurnaz & Kopuz (2023) demonstrated that Omnichroma (Tokuyama) showed the best performance in terms of color stability, followed by GC Aligner Connect, while Tetric PowerFlow exhibited the highest color change after immersion in coffee. These results corroborate previous findings by Feinberg *et al*. (27), who identified a direct influence of the matrix composition and the amount of nanometric particles on stain resistance.

Wear resistance is another crucial factor for the longevity of attachments. Continuous friction between the composite resin and the aligner can compromise the shape and force transmission. Ocak *et al*. (2025) observed that G-ænial Universal Flo exhibited the lowest volumetric wear, while Flow Tain showed the greatest volume loss. These results were corroborated by Chen *et al*. (2021), who found lower wear and higher SBS for SonicFill compared to the Z350XT and Z350XT Flow composites (14,26). Clinically, progressive wear of attachments may lead to loss of their designed morphology, reducing the effectiveness of aligner engagement and ultimately compromising the predictability of tooth movement (14). The superior wear resistance of hybrid and nanoparticulate composite resins is mainly attributed to their higher filler content and more homogeneous distribution of smaller filler particles, which enhance resistance to wear and long-term stability (25,26,28). Meanwhile, composite resins with a high proportion of organic matrix are more susceptible to hydrolytic degradation and microabrasion (17). Thus, materials such as Filtek P60 and Tetric EvoCeram demonstrated more stable performance, especially in posterior attachments subjected to higher loads (22).

The adhesive strength values observed in the included studies ranged from 6 to 14 MPa, values considered clinically acceptable for use in orthodontic attachments (22).

Kircelli *et al*. (2023) reported that all tested composite resins exceeded the recommended minimum value, with Tetric N-Ceram showing the highest SBS and Aligner Connect the lowest. Adhesive and cohesive failures were frequently reported, being related to tooth morphology, type of resin, and masticatory habits (28). Jardim *et al*. (2023) observed that conventional attachments had a higher incidence of adhesive failures, while optimized attachments showed a higher prevalence of cohesive failures, reflecting the internal structural behavior of the material. This is directly related to attachment loss, which is more common in posterior teeth and can be minimized through proper isolation during application and selection of composite resins with a higher elastic modulus (29).

Although this review focused on the intrinsic properties of composite resins used for orthodontic attachment fabrication, adhesion to enamel is not determined by the composite resin alone (12). Bonding agents represent the true adhesive interface between enamel and the composite attachment and may substantially influence shear bond strength, debonding behavior, and the clinical risk of attachment loss (12). Therefore, differences in adhesive systems, enamel conditioning protocols, curing procedures, and isolation conditions across studies may act as confounding factors when comparing the performance of different composite resins. For this reason, the SBS results reported in this review should be interpreted as reflecting the performance of the complete bonding protocol rather than the composite resin in isolation. Future studies should standardize, or at least comprehensively report, etching strategy, primer/adhesive application, light-curing protocol, and debonding assessment to allow more reliable comparison between composite materials.

The surface integrity of composite resins has a direct impact on biocompatibility and oral hygiene. Rough surfaces promote bacterial retention and staining, while well-polished composite resins exhibit lower microbial adhesion (10). Despite the potential release of residual monomers, such as Bis-GMA and TEGDMA, there is no clinical evidence of significant toxicity associated with the composite resins used in attachments (14).

Attachments play an essential role in the three-dimensional control of tooth movements (11,12). The choice of composite resin must consider the biomechanical function and anatomical region, prioritizing high-strength materials for posterior areas and greater color stability for anterior regions (11). Additionally, proper hygiene instruction and regular monitoring by the orthodontist are essential to reduce biofilm accumulation and the risk of adhesive or inflammatory failures (11,17).

The comparative analysis between the results obtained in vitro and in vivo studies demonstrates a general agreement in the observed trends, despite differences in the magnitude of the effects. In the in vitro tests, it was found that conventional nanohybrid composite resins showed higher shear bond strength values, lower wear, and better shape fidelity (17,19). The same was observed in most in vivo studies, in which these materials demonstrated greater dimensional stability and a lower incidence of adhesive failures during clinical use (30). While bonding agents are essential to adhesion, this systematic review investigated associations between intrinsic composite resin properties and attachment performance rather than isolating the independent effect of each material variable. Reliable inter-study comparability requires careful standardization of adhesion protocols and testing methodologies; otherwise, variability in shear bond strength and debonding behavior remains confounded. Such standardization ensures that observed differences are attributable to the composites' physicochemical characteristics-namely monomer composition, filler architecture, and rheological properties-rather than to heterogeneity in the adhesive systems employed.

A significant limitation across the included clinical studies was the absence of clearly defined sample sizes and follow-up periods. These factors are critical for interpreting the clinical relevance and durability of the reported outcomes. The lack of standardized reporting hampers direct comparison between studies and weakens the overall level of evidence.

Future research should prioritize methodological consistency, including well-defined sample sizes and longitudinal follow-up, to allow for more reliable and clinically meaningful comparisons. Moreover, because adhesive systems and bonding protocols varied substantially across the included studies, the independent contribution of composite resin composition to SBS outcomes cannot be fully isolated.

Furthermore, while laboratory tests revealed significant differences in microhardness and surface roughness between flowable and conventional composite resins (31,32), clinical trials indicated that these discrepancies tend to diminish in the oral environment (10). The color stability observed in vitro was corroborated in vivo, although the degree of discoloration was slightly higher in the clinical context (23,26). This emphasizes the high experimental heterogeneity among the studies included in this review.

Laboratory studies are essential tools for predicting the intrinsic behavior of materials but do not replace in vivo evaluation, where interaction with the biological environment, functional wear, and individual patient variations can significantly modify the clinical performance of the attachments (13,32).

The main limitation of this review lies in the heterogeneity of methodologies specifically related to attachment fabrication, including differences in mold materials, photopolymerization protocols, and testing methods for wear and dimensional accuracy (14,26). Additionally, most clinical studies evaluate attachment performance only during the early stages of treatment, which prevents assessment of long-term degradation under continuous aligner-induced friction (13). This limitation is particularly relevant for orthodontic attachments, as their functional performance depends on maintaining shape integrity throughout the entire treatment duration. In general, nanohybrid and high-viscosity composite resins demonstrate better mechanical performance and lower wear, while flowable composite resins offer greater ease of handling and precision of adaptation. Customization of the material according to clinical needs, combined with standardized photopolymerization protocols and controlled application techniques, is essential to maximize the durability, effectiveness, and predictability of orthodontic treatments with clear aligners.

From a clinical perspective, understanding the mechanical and aesthetic performance of different composite resins is essential for optimizing attachment longevity and improving treatment predictability in clear aligner therapy.

Regarding long-term performance, most available clinical studies present relatively short follow-up periods, which limits definitive conclusions about attachment longevity (13,33,34). Nevertheless, based on the analyzed evidence, composite resins with a higher organic matrix content, such as flowable composite resins, are more susceptible to long-term wear and degradation due to their increased proportion of diluent monomers (29). Therefore, in prolonged orthodontic treatments, the selection of materials with higher inorganic filler content, such as nanohybrid composite resins, is critical to maintain attachment shape fidelity and ensure effective force transmission throughout treatment (27,28,29).

From a clinical translation perspective, the findings of this review support structured recommendations for practitioners. In areas subjected to higher masticatory loads (posterior teeth), nanohybrid or high-viscosity composite resins should be prioritized due to their superior wear resistance and dimensional stability (14,16). In contrast, in esthetic zones (anterior teeth), materials with high filler content and lower aromatic monomer content, such as G-ænial® Universal Injectable composite resin, should be preferred due to their improved color stability when exposed to staining agents such as coffee and red wine (23,26). Additionally, standardization of the photopolymerization protocol, particularly using an irradiance close to 1000 mW/cm² for 20s, represents a critical clinical step to ensure that laboratory-derived mechanical properties are effectively translated into clinical success and reduced incidence of adhesive failures (24,25).

CONCLUSION

5. CONCLUSION

This systematic review evaluated the influence of composite resin type on the performance of orthodontic attachments used in clear aligner therapy. The available evidence indicates that the physicochemical and mechanical properties of composite resins play a significant role in determining attachment stability, durability, and functional performance. Overall, nanohybrid and high-viscosity composite resins demonstrated superior mechanical properties, including higher shear bond strength, improved wear resistance, and greater dimensional stability. In contrast, flowable composite resins showed advantages in handling and adaptation to attachment molds but were generally associated with increased surface degradation and discoloration over time. The findings highlight the importance of material composition, filler content, and polymerization protocols in optimizing the mechanical and optical behavior of orthodontic attachments. From a clinical perspective, appropriate selection of composite resin according to biomechanical demands and esthetic requirements may contribute to improved treatment predictability and attachment longevity. Nevertheless, the current evidence is limited by methodological heterogeneity and the relatively small number of clinical studies. Future well-designed clinical trials with standardized evaluation protocols are needed to further clarify the long-term performance of composite resins used for orthodontic attachments.

BIBLIOGRAPHY

6. BIBLIOGRAPHY

1. Sousa HAF, Nascimento JJPNF, Sousa MAF, Gerani B, Souza AO, Degrazia FW. Invisible orthodontic aligners: A review. Res Soc Dev. 2021;10:e5510111259.
2. Naqbi SRA, Pratsinis H, Kletsas D, Eliades T, Athanasiou AE. In vitro assessment of cytotoxicity and estrogenicity of. Vivera® retainers. J Contemp Dent Pract. 2018;19:1163-1168.
3. Vlaskalic V, Boyd R. Orthodontic treatment of a mildly crowded malocclusion using the Invisalign system. Aust Orthod J. 2001;17:41-46.
4. Dinu S. In vitro biocompatibility and in ovo irritant potential screening of two clear aligners with orthodontic applications. Farmacia. 2024;72:513-520.
5. Boyd RL. Esthetic orthodontic treatment using the Invisalign appliance for moderate to complex malocclusions. J Dent Educ. 2008;72:948-967.
6. Milovanović A, Sedmak A, Golubović Z, Mihajlović KZ, Žurkić A, Trajković I, et al. The effect of time on mechanical properties of biocompatible photopolymer resins used for fabrication of clear dental aligners. J Mech Behav Biomed Mater. 2021;119:104494.
7. Ziuchkovski JP, Fields HW, Johnston WM, Lindsey DT. Assessment of perceived orthodontic appliance attractiveness. Am J Orthod Dentofacial Orthop. 2008;133(Suppl):S68-S78.
8. Yan C, Kleiner C, Tabigue A, Shah V, Sacks G, Shah D, et al. PETG: Applications in modern medicine. Eng Regen. 2024;5:45-55.
9. Iliadi A, Koletsi D, Papageorgiou SN, Eliades T. Safety considerations for thermoplastic-type appliances used as orthodontic aligners or retainers: A systematic review and meta-analysis. Materials (Basel). 2020;13:1843.
10. Campobasso A, Lo Muzio E, Battista G, Ciavarella D, Crincoli V, Lo Muzio L. Taxonomic analysis of oral microbiome during orthodontic treatment. Int J Dent. 2021;2021:8275181.
11. Papadimitriou A, Mousoulea S, Gkantidis N, Kloukos D. Clinical effectiveness of Invisalign orthodontic treatment: A systematic review. Prog Orthod. 2018;19:37.
12. Gomes DC. Descrição dos attachments utilizados no tratamento com alinhadores ortodônticos [master's thesis]. Belo Horizonte: Universidade Federal de Minas Gerais; 2022.
13. Eliades T, Papageorgiou SN, Ireland AJ. The use of attachments in aligner treatment. Am J Orthod Dentofacial Orthop. 2020;158:166-174.

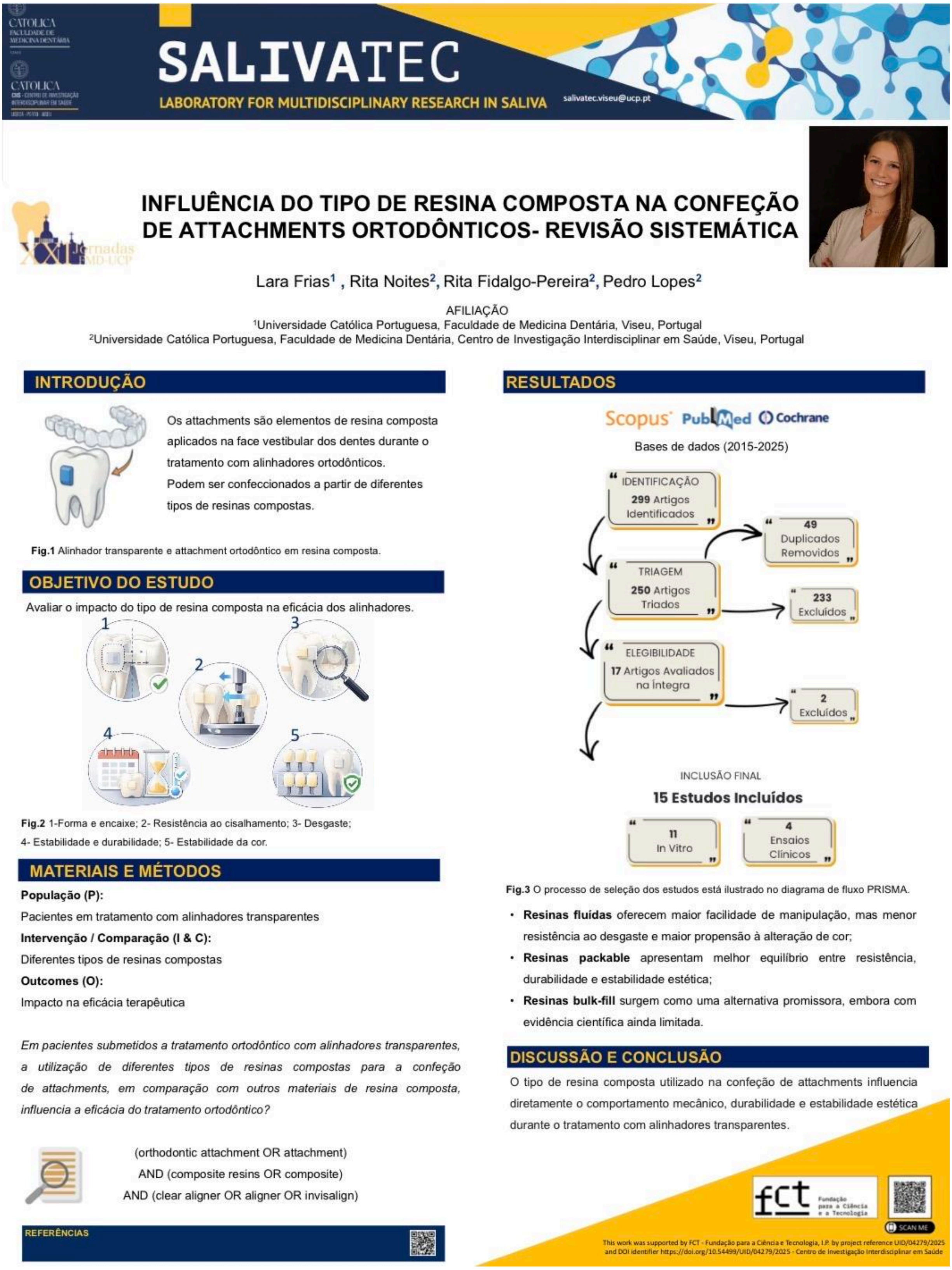
14. Chen W, Qian L, Qian Y, Zhang Z, Wen X. Comparative study of three composite materials in bonding attachments for clear aligners. Orthod Craniofac Res. 2021;24:250-257.
15. D'Antò V, Muraglie S, Candida E, Martina R, Valletta R. Shear bond strength of different composites for orthodontic attachments: An in vitro study. Prog Orthod. 2016;17:35.
16. Erbaş S, Atik E. A comparative in vitro study of different composite materials in terms of aligner attachment accuracy and surface roughness using different curing irradiances. Int Orthod. 2024;23:100961.
17. Yaosen C, Mohamed AM, Jinbo W, Ziwei Z, Al-Balaa M, Yan Y. Risk factors of composite attachment loss in orthodontic patients during clear aligner therapy. Biomed Res Int. 2021;2021:6620377.
18. Ferreira M, Costa H, Veiga N, Correia MJ, Gomes ATPC, Lopes PC. Do clear aligners release toxic chemicals?—A systematic review. J Funct Biomater. 2025;16(5):173. doi:10.3390/jfb16050173.
19. Campobasso A, Lo Muzio E, Battista G, Ciavarella D, Crincoli V, Lo Muzio L. Taxonomic analysis of oral microbiome during orthodontic treatment. Int J Dent. 2021;2021:8275181. doi:10.1155/2021/8275181.
20. Chandra S, Jha AK, Asiri SN, Naik A, Sharma S, Nair A, et al. Effect of fixed orthodontic appliances on oral microbial changes and dental caries risk in children: A 6-month prospective study. J Pharm Bioallied Sci. 2024;16(Suppl 3):S2353-S2355.
21. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan—A web and mobile app for systematic reviews. Syst Rev. 2016;5:210.
22. Guan Y, Xu J, Qiu J, Cai H, Xia W, Ye Z, et al. Multiparametric performance comparison of dental composites for clear aligner attachments. BMC Oral Health. 2025;25:1206.
23. Erbas S, Atik E. In vitro comparison of different composite resins for aligner attachment production: Amount of adhesive flash, flash removal time, and shear bond strength. J Orofac Orthop. 2025.
24. Bellocchio AM, Portelli M, Ciraolo L, Ciancio E, Militi A, Peditto M, et al. Evaluation of the clinical variables affecting attachment reproduction accuracy during clear aligner therapy. Materials (Basel). 2023;16:6811.

25. Alshammari RR, Alshihah N, Aldweesh A. Quantitative evaluation of surface roughness and mass loss for different types of composite resins used for clear aligner attachments: An in vitro study. Front Mater. 2025;12:1614811.
26. Ocak I, Gorucu-Coskuner H, Aksu M. Wear resistance of orthodontic attachments: A comparative analysis of different composite resins in clear aligner therapy. Clin Oral Investig. 2025;29:242.
27. Roatkanjanaporn N, Chavanavesh J, Teekavanich C. Wear volumes of flowable and sculptable resin composite attachments and their correlation with retentive force of clear aligners: A laboratory study. BMC Oral Health. 2025;25:483.
28. Hancıoğlu Kircelli B, Kilinc DD, Karaman A, Sadry S, Gonul EY, Gögen H. Comparison of the bond strength of five different composites used in the production of clear aligner attachments. J Stomatol Oral Maxillofac Surg. 2023;124:101481.
29. Sirichamratsakul T, Khemaleelakul W, Sirabanchongkran S. Shear bond strength and enamel effects of bioactive composite attachments for clear aligners. J Clin Exp Dent. 2025;17:e1305-e1313.
30. Barreda GJ, Dzierewianko EA, Muñoz KA, Piccoli GI. Surface wear of resin composites used for Invisalign® attachments. Acta Odontol Latinoam. 2017;30:90-95.
31. Yildiz H, Dedeoglu M, Aydemir M, Oktay H. Evaluation of long-term colour resistance of composite materials used in aligner treatments: A comparative study. Orthod Craniofac Res. 2024;27:758-766.
32. Jardim A, da Veiga F, Curado de Freitas J, Estrela C. Surface wear and adhesive failure of resin attachments used in clear aligner orthodontic treatment. J Orofac Orthop. 2023.
33. Hassanaly T, Rabal-Solans A, Mediero-Pérez MC, Nieto-Sánchez I. A comparison of the upper anterior teeth movements with optimized and conventional attachment. J Clin Exp Dent. 2024;16:e480-e484.
34. Faggion CM Jr. Guidelines for reporting pre-clinical in vitro studies on dental materials. J Evid Based Dent Pract. 2012;12:182-189.

ATTACHMENTS

7. ATTACHMENTS

7.1. Scientific poster presented at the XXI Jornadas of Dentistry at FMD-UCP



CERTIFICADO

XXI

Certifica-se que Lara Bastos Frias, Rita Noites, Rita Fidalgo-Pereira, Pedro Campos Lopes participaram nas comunicações orais, apresentando o trabalho intitulado "**Influência do Tipo de Resina Composta na Confeção de Attachments - Revisão Sistemática**" nas XXI Jornadas de Medicina Dentária de Viseu que se realizaram na Faculdade de Medicina Dentária da Universidade Católica Portuguesa nos dias 19 e 20 de Março de 2026.

Professor Pedro Campos Lopes
Presidente das XXI Jornadas FMD-UCP

7.2. Article published

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Systematic Review

Material Properties of Composite Resins Used for Orthodontic Attachments in Clear Aligner Therapy: A Systematic Review

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Abstract

Clear aligner therapy has become increasingly widespread in contemporary orthodontics, relying on composite resin attachments to enhance force transmission and improve the predictability of tooth movement. The physicochemical and mechanical properties of these biomaterials play a crucial role in attachment durability, dimensional stability, and esthetic performance during treatment. This systematic review aimed to evaluate how different composite resin types influence the mechanical, optical, and functional performances of orthodontic attachments used in clear aligner therapy. A systematic literature search was conducted in the PubMed, Scopus, and Cochrane databases for studies published between 2015 and 2025, following PRISMA guidelines. In vitro studies and clinical trials evaluating composite resins used for attachment fabrication were included. Fifteen studies met the eligibility criteria, including eleven laboratory investigations and four clinical studies. The evaluated outcomes comprised shear bond strength, wear resistance, surface roughness, microhardness, color stability, and accuracy of attachment reproduction. Overall, all evaluated composite resins demonstrated shear bond strength values within clinically acceptable ranges. However, significant differences were observed in the material performances depending on the resin composition and viscosity. Nanohybrid and high-viscosity composite resins were generally associated with improved mechanical resistance, reduced wear, and greater dimensional stability, although SBS outcomes should be interpreted in light of the bonding protocols used. In contrast, flowable composite resins showed improved handling and adaptation to attachment molds but presented higher susceptibility to surface degradation and discoloration. The findings suggest that the composition and properties of composite resins significantly influence the mechanical and optical behavior of orthodontic attachments. Optimizing material selection according to biomechanical demands and esthetic requirements may improve attachment longevity and treatment predictability in clear aligner therapy. Clinicians should prioritize nanohybrid or high-viscosity composite resins for high-load attachments and use flowable composite resins materials when adaptation and esthetics are critical.

Keywords: clear aligners; orthodontic attachments; composite resins; biomaterials; mechanical properties; wear resistance

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