Open Access Library Journal
2026, Volume 13, e14791
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Shape, Position, Dimension of Attachments in Clear Aligners: A Systematic Review

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How to cite this paper: Sair, S., Chkhayess, D., El Quars, F. and El Mabrak, A. (2026) Shape, Position, Dimension of Attachments in Clear Aligners: A Systematic Review. *Open Access Library Journal*, **13**: e14791.
https://doi.org/10.4236/oalib.1114791

Received: December 21, 2025
Accepted: January 10, 2026
Published: January 13, 2026

Abstract

Background: Clear aligner therapy (CAT) has become an increasingly popular alternative to fixed appliances, yet its effectiveness in achieving complex orthodontic tooth movements remains limited. Composite attachments are routinely incorporated to enhance biomechanical control, but the optimal attachment shape, position, and dimension for maximizing movement efficiency are still unclear. **Objective:** To evaluate how the shape, position, and dimensions of composite attachments influence the efficacy and predictability of orthodontic tooth movements in clear aligner therapy. **Methods:** This systematic review followed PRISMA guidelines and was registered in INPLASY (INPLASY 202570109). Electronic databases including PubMed, Scopus, Cochrane Library, and ScienceDirect were searched for studies published between January 2014 and January 2025. Eligible studies included human research evaluating attachment design variables. Exclusion criteria were finite element simulations, case reports, reviews, and non-English/French publications. Nine studies met inclusion criteria. Risk of bias was assessed using MINORS for non-randomized studies and the Cochrane tool for randomized clinical trials. **Results:** Nine clinical studies were included. Overall, attachment design significantly influenced tooth movement predictability, although effects varied by movement type. Ellipsoid and cylindrical shapes showed favorable force distribution for extrusion, intrusion, and anterior retraction, while rectangular attachments improved torque and mesio-distal angulation. Optimized attachments enhanced rotational performance in some studies, though evidence remained inconsistent. Attachment position played a critical role: lingual placement consistently provided better torque control and reduced unwanted rotations compared with buccal placement. Larger and more prominent attachments improved force transmission but increased wear and the risk of open gingival embrasures; similarly, a greater number of attachments enhanced anchorage yet did not reliably improve rotational movements. **Conclusion:** Composite attachments are essential auxiliaries for enhancing the biomechanical performance of clear align-

ers. However, their effectiveness is movement-specific. Ellipsoid/cylindrical shapes favor vertical movements, rectangular attachments optimize torque, and lingual positioning offers superior control for complex biomechanics. Evidence remains heterogeneous, highlighting the need for standardized clinical trials to determine optimal attachment configurations.

Subject Areas

Dentistry

Keywords

Clear Aligners, Composite Attachments, Orthodontic Tooth Movement, Biomechanics, Attachment Shape, Attachment Position, Attachment Dimensions

1. Introduction

The field of orthodontics has witnessed a profound evolution in recent decades, primarily driven by a significant and growing demand from patients for more aesthetic and comfortable treatment alternatives to conventional fixed appliances, especially among adults [1] [2]. This trend has propelled clear aligner therapy (CAT) to global prominence, a treatment modality widely appreciated for its discreet appearance, patient comfort, removability, and the perceived ease of maintaining oral hygiene, often considered superior for periodontal health compared to traditional braces [3]. Continuous advancements in materials science and digital technologies have consistently refined aligner systems, expanding their indications to an ever-broader spectrum of orthodontic cases [4].

However, despite the increasing prevalence and continuous improvements in aligner technology, the exclusive reliance on clear aligners inherently presents limitations, particularly when attempting to achieve complex orthodontic tooth movements (OTM) with predictable outcomes [5]. Clinical observations and studies frequently report that the meticulously planned tooth movements visualized in proprietary digital planning software, such as ClinCheck®, do not always translate fully or accurately into actual clinical results [6]. A recent prospective clinical trial, for example, highlighted that the mean accuracy of movements predicted by these software platforms was approximately 50%, a modest improvement from the 41% accuracy reported a decade earlier, underscoring the persistent gap between digital prediction and clinical reality. This discrepancy emphasizes the inherent biomechanical challenges that aligners face when confronted with demanding tooth movements [7] [8].

To overcome these inherent limitations and to enhance the efficacy of OTM within CAT, auxiliary elements are frequently incorporated into treatment protocols [4]. Among these, attachments represent a cornerstone auxiliary device. Attachments are precisely defined as small protrusions of composite resin material

that are bonded onto specific tooth surfaces. Their fundamental role is multi-faceted: they serve as crucial force transducers, designed to significantly improve aligner retention on the teeth, thereby enhancing the critical contact area between the aligner and the tooth surface, and enabling a more efficient and effective application of the biomechanical forces required for desired OTM [9]. In essence, attachments are engineered to precisely control the direction, magnitude, and point of application of orthodontic forces, thereby facilitating tooth movements previously considered challenging or even unachievable with aligners alone. The intentional predetermined mismatch created between the aligner and these bonded attachments is central to their biomechanical function, allowing for the generation of specific force systems [10].

Given the considerable heterogeneity, occasional contradictions, and often inconclusive nature of the existing scientific literature, there is a clear and urgent need for a comprehensive systematic review that synthesizes the current understanding of attachments in clear aligner therapy.

While previous systematic reviews have broadly addressed the clinical effectiveness of clear aligners, often acknowledging the general role of auxiliaries like attachments, a focused and in-depth examination specifically on the shape, precise position, and various dimensions of composite attachments, and their multifaceted impact on diverse orthodontic tooth movements, associated clinical outcomes, and potential adverse effects such as OGE, is conspicuously lacking [11]. Such a targeted review is indispensable for consolidating fragmented knowledge, addressing existing gaps, and ultimately providing clinicians with clearer, evidence-based guidelines for the selection, design, and strategic integration of attachments into their clear aligner treatment plans. This will facilitate improved predictability, enhanced efficiency, and superior overall patient outcomes in clear aligner orthodontics.

The overarching goal of this systematic review is to comprehensively synthesize the current evidence regarding the optimal shape, position, and dimension of composite attachments used in clear aligner therapy to enhance orthodontic tooth movement and minimize potential adverse effects. Specifically, this review aims to evaluate the influence of different attachment shapes, sizes, and positions on the efficacy and predictability of various tooth movements, identify attachment configurations that demonstrate superior performance for specific types of complex orthodontic movements; and investigate the relationship between attachment design (number and distribution) and the incidence of adverse outcomes in adult patients undergoing clear aligner treatment.

It should also be noted that, given the inherent diversity of study designs in the existing literature, ranging from retrospective analyses to randomized controlled trials, heterogeneity and potential methodological variability were anticipated. These factors, together with the limited number of randomized studies available, represent expected limitations that were critically considered throughout the present review.

2. Materials and Methods

2.1. Focus Question

"How do the shape, position, and dimension of attachments influence the efficiency and predictability of orthodontic tooth movements with clear aligner therapy?"

2.2. Research Strategy

The methodology applied in this systematic analysis was based on the PRISMA guidelines (Preferred Reporting Items for Systematic Review and Meta-Analysis).

A search protocol was specified in advance and registered at INPLASY REGISTER (International Platform of Registered Systematic Review and Meta-analysis Protocols) under the following registration number: INPLASY 202570109.

The literature for this paper was identified and selected by performing a thorough search in electronic databases like Pubmed, Scopus, Cochrane Library, Science direct published over the past decade (January 2014-January 2025) by using of certain keywords such as:

1) Orthodontic appliances, removable
2) Orthodontic tooth movement
3) Designs, orthodontic appliance
4) Composite resins
5) Denture precision attachments
6) Dental bonding
7) Orthodontics

A comprehensive literature search was carried out using Medical Subject Headings (MeSH) terms combined with free-text keywords through Boolean operators ("AND").

"Orthodontic Appliances, Removable" [Mesh] AND attachments

"Orthodontic Appliances, Removable" [Mesh] AND composite attachments

("Orthodontic Appliances, Removable" [Mesh]) AND "Composite Resins" [Mesh]

("Denture Precision Attachment" [Mesh]) AND "Orthodontic Appliances, Removable" [Mesh]

This search was based on the PICO elements (problem/patient/population, intervention/indicator, comparison, and outcome) (See Table 1).

Table 1. Description of the PICO elements.

PICOS	DESCRIPTION
Population	Orthodontic patients treated with clear aligners therapy.
Intervention	Use of specific attachment designs (shape, position, and/or dimension).
Comparison	Different shapes (conventional, optimized), position (vertical, horizontal, buccal, lingual)...
Outcome	Effectiveness and predictability of tooth movements
Study Design	Retrospective studies, randomized control studies, cohort study.

The search strategy resulted in the collection of 1315 articles, duplicates were removed and filters were used (date, type of article), the remaining articles were then left at the number of 326, then reviewed the titles and abstracts of potentially relevant studies to exclude off-topic articles that did not meet the inclusion criteria. In cases of doubt, studies were included, and full texts were assessed for eligibility.

2.3. Criteria for Study Selection

Inclusion criteria:

- Human studies, English and French language,
- Articles published from January 2014 to January 2025,
- Studies that examine the shape, the size, the position of the attachments

Exclusion criteria:

- Finite element studies, case reports, systematic reviews and meta-analysis, letters, commentaries, editorials
- Articles not meeting the objectives of our work based on abstract reading and critical reading of the full text.
- Articles in languages other than English and French.

After applying these criteria, the number of articles was further reduced to 9, representing a database for the systematic analysis. These articles were critically assessed after referring the guidelines of Cochrane risk of bias tool for randomized clinical trials, minors' risk of bias assessment: a tool for assessing risk of bias in non-randomized studies.

2.4. Risk of Bias of Included Studies

Methodological quality of eligible articles was assessed using the MINORS (Methodological index for non-randomized studies) based on the following scores: 0—when unreported item, 1—when reported inappropriately, and 2—when reported properly.

The articles were classified based on their methodological quality: low (>17), medium (≥10, ≤17), and high risk of bias (<10).

We used also the Cochrane risk of bias tool for randomized clinical trials.

On the basis of the MINORS quality assessment, all studies had a medium risk of Bias, except one had a low risk of biais (See Table 2 and Table 3).

Table 2. Score of each article selected with the inclusion criteria according to the items of MINORS.

MINORS SCORE	Hassanaly *et al.* (2024)	Fan-Fan Dai *et al.* (2019)	Karras *et al.* (2021)	Simon *et al.* (2014)	Smith *et al.* (2022)	Zhang *et al.* (2023)	Burashed *et al.* (2023)
A clearly stated aim	2	2	2	2	2	2	2
Inclusion of consecutive patients	2	2	2	1	2	2	2
Prospective data collection	0	0	0	0	0	0	0
End points appropriate to the aim of the study	2	2	2	2	2	2	2

Continued

Unbiased assessment of the study end point	1	2	2	0	0	0	0
Follow-up period appropriate to the aim of the study	0	0	0	2	2	2	0
Loss of follow-up lower than 5%	0	0	0	1	0	0	0
Prospective calculation of the study size	2	2	2	0	2	2	0
Adequate control group	0	0	0	0	2	0	2
Contemporary groups	0	0	0	2	2	2	2
Baseline equivalence of groups	2	0	0	2	2	2	2
Adequate statistical analyses	2	2	2	2	2	2	2
Total score	13	12	12	14	18	16	14
Risk of Bias	Medium	Medium	Medium	Medium	Low	Medium	Medium

Table 3. Quality assessment of randomized clinical trial using Cochrane risk of bias tool.

Study	Randomization	Intervention Bias	Missing Data	Outcome Measurement	Reporting Bias	Overall Risk of Bias
Effectiveness of Composite Attachments in Controlling Upper Molar Movement with Aligners	Low	Low	Low	Low	Low	Low
Effect of clear aligner attachment design on extrusion of maxillary lateral incisors: A multicenter, single-blind randomized clinical trial	Low	Low	Low	Low	Low	Low

3. Results

13 research articles were included and analyzed for quantitative data (**Figure 1**).

All of these articles were analyzed with a data extraction as presented in **Table 4**.

4. Discussion

Clear aligner therapy (CAT) has gained significant popularity as an aesthetic and comfortable alternative to traditional fixed orthodontic appliances [20]. However, the efficacy of aligners in achieving complex tooth movements remains a primary concern for orthodontists. Composite attachments, bonded to the tooth surface, are designed to enhance aligner retention, facilitate the transmission of forces, and improve the predictability of these challenging movements [19]. This systematic review aimed to synthesize the current evidence regarding the influence of attachment shape, position, and dimension on the effectiveness of CAT.

4.1. General Efficacy of Attachments

The literature broadly supports the role of attachments in improving the biomechanics of clear aligners. Attachments serve as force transducers, creating specific undercuts and increasing contact areas to apply more effective force systems.

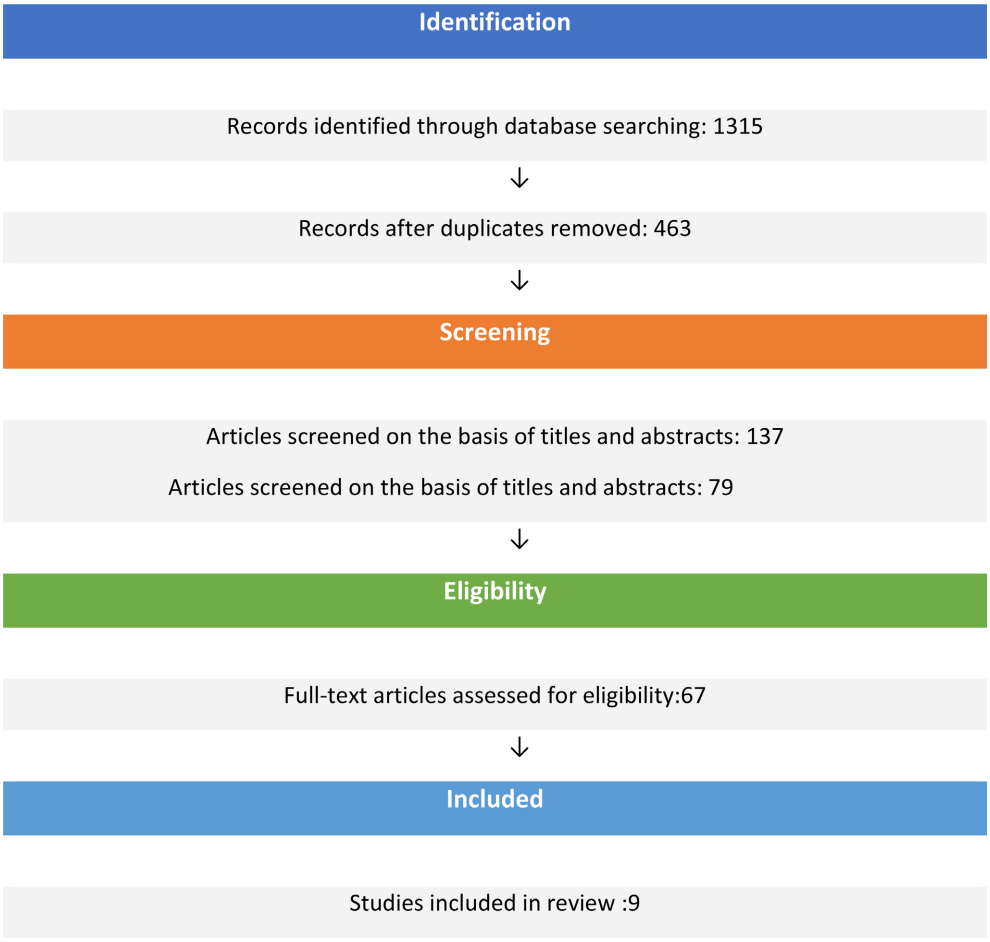

Figure 1. Flow chart for article selection.

Table 4. The general characteristics of selected studies.

Title	Author/Year	Type of study	Sample	Type of attachments (Intervention)	Statistical analysis strategy	Duration of treatment	Conclusion (Outcome)
A comparison of the upper anterior teeth movements with optimized and conventional attachment [12]	Hassanaly *et al.* (2024)	Retrospective study	95 (40 males and 55 females)	147 upper incisors divided into two groups: 87 with rectangular attachment and 60 with optimized attachment.	SPSS software, Kolmogorov-Smirnov test, Mann-Whitney U test, Kruskal-Wallis test, and Pearson and Spearman correlation coefficients	Between 2018 and 2022	-Optimized attachments rotate better lateral incisors -Conventional vertical attachments are more efficient to improve mesio-distal angulation - Horizontal attachments serve best for torque movements.
Comparison of achieved and predicted tooth movement of maxillary first molars and central incisors: First premolar extraction	Fan-Fan Dai *et al.* (2019)	Retrospective study	30 patients (4 males, 26 females) who underwent extraction of two maxillary first premolars	3-mm vertical, 3-mm horizontal, 5-mm horizontal, G6-optimized	IBM SPSS Statistics for Windows, Pearson's correlation coefficients and Bland-Altman analyses.	from January 2014 to December 2016	In first premolar extraction cases treated with Invisalign, first molar anchorage control and central incisor retraction were not fully achieved as predicted. Age, attachment type, and initial crowding affected the differences

treatment with Invisalign [13]							between predicted and achieved tooth movement. Auxiliary anchorage devices, power ridges and attachment designs, and overcorrection should be considered to help achieve predicted changes.
Effectiveness of Composite Attachments in Controlling Upper Molar Movement with Aligners [14]	Garino *et al.*, (2016)	Randomized clinical trial	30 non-growing patients (12 males, 18 females) treated with invisalign®	Rectangular composite attachments	R version 3.0.1†† statistical package. Fisher's exact test for qualitative variables and the unpaired t-test for quantitative variables.	24.3 months	The upper first and second molars were each distalized about 2 mm, accompanied by intrusion of about 1 mm, when vertical rectangular attachments were placed on all five distalized teeth. This approach appears to be effective in minimizing distal crown tipping and preventing molar extrusion, anterior anchorage loss, and undesirable changes in lower facial height.
Efficacy of Invisalign attachments: A retrospective study [15]	Karras *et al.*, (2021)	Retrospective study	382 teeth from digital dental models of 100 orthodontic patients treated with invisalign®	163 optimized rotation (43%), 72 conventional rotation (19%), 81 optimized extrusion (21%), and 66 conventional extrusion (17%)	Statistical Analysis Software (SAS version 9.4, SAS Institute, Cary, NC).	Between January 2016 and August 2018	Clear aligner therapy achieved an overall mean accuracy of 57.2% for rotation and extrusion combined. Rotations of canines and premolars (63.2%) were more predictable than extrusion of incisors and canines (47.6%), with maxillary central incisor extrusion being the most accurate (73.9%) and mandibular canine extrusion the least (16.1%). No significant differences were found between optimized and conventional attachments, indicating comparable effectiveness. Clinicians should anticipate mid-course corrections and apply overcorrection, particularly for anterior tooth extrusion, to enhance treatment predictability.
Treatment outcome and efficacy of an aligner technique – regarding incisor torque, premolar derotation and molar distalization. [6]	Simon *et al.* (2014)	Retrospective study	30 patients treated with Invisalign®	Horizontal ellipsoid: upper medial incisor torque optimized rotation: premolar derotation horizontal bevelled gingival:	Statistical Package for Social Sciences, version 20.0 (SPSS Inc., Chicago, Illinois, USA)	1 year	The torque of upper central incisors and premolar derotation show similar effectiveness whether supported with attachments or not. However, upper molar distalization is generally the most effective movement regardless of

				molar distalization			attachment use. The accuracy of certain dental movements decreases as the predicted rotations or staging increase.
Predictability of lower incisor tip using clear aligner therapy [16]	Smith and al (2022)	Retrospective study	42 patients treated Invisalign	Vertical rectangular	SPSS software (version 20.0, IBM Corporation, Chicago, Illinois, USA)	2 years	Vertical rectangular attachments are recommended when large amounts of root movement are planned, and their presence improves the ability to translate the root apex.
IPR treatment and attachments design in clear aligner therapy and risk of open gingival embrasures in adults [17]	Zhang and al (2023)	Retrospective study	226 patients	lingual	IBM SPSS version 22.0 (IBM Corp, Armonk, New York, USA	3 years	The number of attachments in the anterior teeth or central incisors was significantly related to the incidence of OGE ($P < 0.05$) but was not associated with severity.
Effect of clear aligner attachment design on extrusion of maxillary lateral incisors: A multicenter, single-blind randomized clinical trial [18]	Groody *et al.* (2023)	Randomized control trial	40 patients	horizontal nonbeveled horizontal incisally beveled horizontal gingivally beveled optimized	SAS Enterprise Guide (version 8.2; SAS Institute, Cary, NC)	11 months	Horizontal attachments (H, HIB, or HGB) were significantly more effective at achieving prescribed maxillary incisor extrusion compared with O attachments in patients with mild malocclusion undergoing Invisalign treatment. The 3 horizontal attachment types performed similarly to achieve prescribed extrusion.
Clinical expression of programmed mandibular canine rotation using various attachment protocols and 1- vs 2-week wear protocols with Invisalign SmartTrack aligners: A retrospective cohort study [19]	Stephens and al (2022)	Cohort study	75 patients	Optimized Conventional nonbeveled rectangular	R (version 4.0.2; R Core Team, Vienna, Austria)	**NR**	none of the Invisalign SmartTrack aligner attachment configurations display clinical accuracy in their predicted rotation

[11] They are considered essential for complex movements such as translation, rotation, and torque, which are often difficult to execute with aligners alone [21]. Despite their benefits, achieving ideal tooth movement with aligners, even with attachments, frequently falls short of predictions. Several studies highlight that predicted tooth movements, particularly for rotations and extrusions, are often "underexpressed," leading to a common need for refinement stages or overcorrection in digital treatment plans [19].

4.2. Influence of Attachment Shape

The design of composite attachments significantly impacts the force distribution and efficacy of tooth movement.

4.2.1. Ellipsoid and Cylinder Shapes

Finite element analysis (FEA) studies frequently highlight the benefits of ellipsoid or cylinder-shaped attachments. For anterior retraction, ellipsoid attachments were found to generate substantial and evenly distributed forces [20]. This finding aligns with other FEA investigations suggesting that ellipsoid or cylinder forms exhibit superior mechanical performance and achieve desired stress distribution patterns for various tooth movements, including extrusion and intrusion [21]. Specifically, a cylinder shape was deemed optimal for extrusion and intrusion due to a favorable stress distribution and reduced risk of attachment fracture [22]. While effective for upper central incisor extrusion, the initial displacement achieved with ellipsoid attachments showed only minimal, non-clinically significant differences compared to other conventional shapes [23]. Historically, however, some conventional ellipsoid attachments were considered less effective due to their smaller size and lack of a well-defined active surface [15].

4.2.2. Rectangular Shapes

Rectangular attachments are another common conventional design. For anterior retraction, rectangular attachments demonstrated evenly distributed force patterns [20]. In the context of molar anchorage, horizontal rectangular attachments were found to be more effective in counteracting mesial tipping than vertical rectangular attachments [13]. Hassanaly *et al.* [12] specifically noted that conventional vertical attachments were more efficient for mesio-distal angulation, while conventional horizontal attachments were superior for vestibulo-lingual inclination (torque) in upper lateral incisors. For upper central incisor extrusion, horizontal rectangular attachments produced the greatest initial displacement, although the differences from ellipsoid and rectangular beveled attachments were not clinically significant [23].

4.2.3. Optimized Attachments

Optimized attachments, proprietary to Invisalign, are designed with customized geometries for specific tooth movements. For mandibular canine rotation, optimized rotation attachments demonstrated higher median efficiencies (81.5% and 76.5%) compared to conventional rectangular attachments (63.1%). [19] However, this study did not support the manufacturer's claim of a drastic increase in predictability with optimized designs. [19] In contrast, other studies, including a retrospective analysis by Karras *et al.* [15], found no statistically or clinically significant difference in accuracy between optimized and conventional attachments for either rotation or extrusion. Moreover, Groody and al [18], in a randomized clinical trial showed that conventional horizontal attachments were significantly more effective for maxillary lateral incisor extrusion (76% achieved predicted ex-

trusion) compared to optimized attachments (62%). Long-term studies on wear also indicate that optimized attachments experience greater wear volume and a higher ratio of wear volume, particularly on surface ridges, which could potentially affect their sustained efficacy in force transmission [24].

4.2.4. Pyramidal Attachments

While less commonly studied in detail for their mechanical function, pyramidal attachments were noted in one Finite element study to exert the highest maximum pressure force compared to rectangular and ellipsoid shapes during anterior retraction [20].

4.3. Influence of Attachment Position

The precise placement of attachments on the tooth surface is critical for directing forces and controlling specific movements.

4.3.1. Buccal vs. Lingual Placement

Kim *et al.*, [22] suggest that positioning attachments on the lingual side of the tooth, rather than the buccal side, is more effective for controlling torque and achieving planned tooth movements, particularly for canines. Lingual placement was found to nearly eliminate unintended rotation during extrusion, intrusion, and torque applications. [22] This aligns with our results emphasizing the dominant role of attachment position over design for achieving desired movements like upper central incisor extrusion (e.g., palatal placement) [12].

4.3.2. Specific Locations on the Tooth Surface

For specific movements, various optimal positions have been identified. For extrusion, the lower (incisal) region of the buccal side of the tooth showed the highest displacement, though with an increased risk of unintended rotation if placed solely buccally. [22] For intrusion, the central region of the buccal side demonstrated maximum displacement. [22] For torque, the upper region of the buccal side was associated with the highest movement. However, for all these movements, the studies consistently highlighted that lingual placement offered better control over unintended rotations. One study on upper central incisor extrusion, using attachments placed on the labial surface (with the incisal margin 3.5 mm gingivally to the incisal edge), observed unintended palatal crown tipping. This was attributed to the extrusive force being applied anterior to the tooth's center of resistance, creating an undesirable tipping moment [23].

4.4. Influence of Attachment Dimensions (Size, Prominence, Number)

The physical dimensions of attachments, including their size, prominence, and number, play a crucial role in their biomechanical performance.

4.4.1. Size and Prominence

Studies indicate that larger attachments with sharper edges may be more effective

for derotation movements [11].

Cai *et al.* noted that attachment thickness is typically around 1 mm, emphasizing that excessively large attachments could complicate aligner application. [25] Conversely, conventional ellipsoid attachments were historically considered less effective partly due to their smaller size and lack of a defined active surface. [15] While optimized attachments are generally smaller than conventional horizontal attachments, their efficacy relative to size remains debated. [18] Although optimized attachments are generally smaller, they demonstrated a greater wear volume and a higher ratio of wear volume, particularly on surface ridges, compared to 3-mm rectangular attachments after four months of treatment, which could impact their sustained efficacy. [24] The initial volume of an attachment has been shown to positively correlate with its wear volume over time, suggesting that larger attachments, by virtue of their greater surface area, may experience more substantial wear. This underscores the importance of monitoring attachment integrity during treatment.

For anterior retraction, finite element studies [20] [22] [23] comparing rectangular, ellipsoid, and pyramidal attachments of similar dimensions (3 mm × 4 mm width × height, 1.5 mm prominence) found ellipsoid attachments to be the most effective due to their substantial and evenly distributed force. Different dimensions were specifically designed for various movements.

4.4.2. Number of Attachments

The quantity of attachments utilized can also influence treatment outcomes. In Class II patients requiring molar distalization, the placement of vertical rectangular attachments on a greater number of teeth (five per quadrant, from canine to second molar) significantly improved distal movement of the first molar and central incisor retraction, and provided more accurate control of incisor bodily movement. [14] This protocol also enhanced posterior anchorage during anterior retraction, compared to using fewer attachments (three per quadrant) [14].

Conversely, evidence regarding rotation suggests that using two attachments may not necessarily improve the magnitude of rotation and, in some cases, could even be less effective than using no attachments at all.

Furthermore, a higher number of attachments in the anterior teeth or central incisors has been positively correlated with the incidence of Open Gingival Embrasure (OGE), with more than two attachments in the anterior teeth or two in the central incisors identified as independent risk factors [17].

4.5. Comparative Efficacy for Specific Tooth Movements

The performance of attachments varies depending on the type of tooth movement. Rotation, particularly of rounded teeth such as canines and premolars, remains one of the least predictable movements with aligners. [20] Early studies reported only modest improvements with vertical-ellipsoid designs, [15] while more recent trials suggest that optimized rotation attachments yield better accuracy than conventional vertical rectangular ones. [19] Nevertheless, no configuration

has consistently achieved clinically reliable rotational outcomes.

Differences in sample specificity and data aggregation seem to be the main causes of disparities between clinical findings for extrusion. traditional horizontal attachments produced about 22% higher extrusion efficiency than optimized designs, according to Groody *et al.*'s investigation, which was limited to maxillary lateral incisors. This is probably because traditional horizontal attachments offer a wider and more stable push surface for small anterior crowns. [18] On the other hand, Karras *et al.* merged several tooth types, such as canines and incisors, into a single outcome measure [15]. This methodological approach may have hindered the identification of geometry-dependent advantages and diluted tooth-specific biomechanical effects. Regarding torque and angulation, horizontal rectangular attachments appear more effective for vestibulo-lingual inclination [12], while vertical designs contribute to anchorage and bodily movement control during molar distalization. [14] These findings suggest that no single attachment type is universally effective, and selection must be tailored to the biomechanics required.

4.6. Aligner Thickness

Although aligner thickness is not a geometric property of attachments, it acts as a secondary biomechanical determinant by modulating the magnitude and distribution of forces transmitted through attachment geometry. In this regard, thickness indirectly influences attachment efficacy by conditioning the mechanical environment in which attachments operate. Finite element analyses consistently show that increasing aligner thickness elevates von Mises stress at the attachment–tooth interface, enhances residual stress within the aligner, and increases the risk of attachment debonding. Optimal mechanical performance for complex movements such as anterior retraction is achieved with aligner thicknesses of approximately 0.75 - 0.85 mm, beyond which excessive thickness results in force systems that are less controlled and potentially detrimental to periodontal integrity and attachment stability. Therefore, aligner thickness indirectly governs attachment efficiency by modifying force transmission, mechanical precision, and overall clinical reliability [20].

4.7. Overall Synthesis

Taken together, current evidence indicates that attachments significantly influence the predictability of clear aligner therapy, but their effectiveness is movement-specific. Horizontal rectangular attachments are advantageous for extrusion and torque, optimized designs for rotation, and vertical attachments for anchorage support, though none is universally superior. The persistence of variability across studies highlights the need for individualized attachment planning, considering biomechanical demands, patient compliance, and side effects such as wear and OGE. Future research should focus on high-quality clinical trials and biomechanical modeling to refine attachment design and placement for optimal outcomes.

5. Conclusions

The current body of evidence demonstrates that composite attachments are vital auxiliaries in clear aligner therapy, significantly impacting the control and predictability of tooth movements. While there is a growing consensus that ellipsoid or cylinder shapes often provide more desirable and evenly distributed forces for movements like anterior retraction, extrusion, and intrusion, rectangular attachments prove efficient for specific angulations and torque. The position of attachments, especially their placement on the lingual aspect of teeth, appears to be paramount for achieving effective movement and torque control while minimizing unintended rotations. The number of attachments can enhance anchorage and bodily movement, but a higher number is not always beneficial for all types of movement, such as rotation. Furthermore, attachment design must consider wear characteristics, as optimized attachments may exhibit greater relative wear over time.

However, the literature also reveals areas of contradiction, particularly regarding the comparative efficacy of optimized versus conventional attachments for rotation and extrusion. These discrepancies underscore the complexity of biomechanical interactions in CAT (clear aligner therapy) and highlight the need for further rigorous clinical trials and FEA (finite element analysis) studies. Future research should aim to clarify optimal attachment configurations (shape, position, and dimension) for a wider range of tooth movements, addressing current limitations such as small sample sizes and the challenge of isolating specific movement types. Ultimately, clinicians should thoughtfully consider the interplay of attachment design and aligner properties, potentially incorporating overcorrection, to maximize treatment outcomes with clear aligners.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Momtaz, P. (2016) The Effect of Attachment Placement and Location on Rotational Control of Conical Teeth Using Clear Aligner Therapy. https://digitalscholarship.unlv.edu/thesesdissertations/2712/

[2] Comba, B., Parrini, S., Rossini, G., Castroflorio, T. and Deregibus, A. (2017) A Three-Dimensional Finite Element Analysis of Upper-Canine Distalization with Clear Aligners, Composite Attachments, and Class II Elastics. *Journal of Clinical Orthodontics*, **51**, 24-28.

[3] Jiang, Q., Li, J., Mei, L., Du, J., Levrini, L., Abbate, G.M., *et al.* (2018) Periodontal Health during Orthodontic Treatment with Clear Aligners and Fixed Appliances: A Meta-Analysis. *The Journal of the American Dental Association*, **149**, 712-720.e12. https://doi.org/10.1016/j.adaj.2018.04.010

[4] Rossini, G., Parrini, S., Castroflorio, T., Deregibus, A. and Debernardi, C.L. (2014) Periodontal Health during Clear Aligners Treatment: A Systematic Review. *The European Journal of Orthodontics*, **37**, 539-543. https://doi.org/10.1093/ejo/cju083

[5] Papadimitriou, A., Kakali, L., Pazera, P., Doulis, I. and Kloukos, D. (2019) Social Media and Orthodontic Treatment from the Patient's Perspective: A Systematic Review. *European Journal of Orthodontics*, **42**, 231-241. https://doi.org/10.1093/ejo/cjz029

[6] Simon, M., Keilig, L., Schwarze, J., Jung, B.A. and Bourauel, C. (2014) Treatment Outcome and Efficacy of an Aligner Technique—Regarding Incisor Torque, Premolar Derotation and Molar Distalization. *BMC Oral Health*, **14**, Article No. 68. https://doi.org/10.1186/1472-6831-14-68

[7] Haouili, N., Kravitz, N.D., Vaid, N.R., Ferguson, D.J. and Makki, L. (2020) Has Invisalign Improved? A Prospective Follow-Up Study on the Efficacy of Tooth Movement with Invisalign. *American Journal of Orthodontics and Dentofacial Orthopedics*, **158**, 420-425. https://doi.org/10.1016/j.ajodo.2019.12.015

[8] Kravitz, N.D. (2017) Remote Retainer Fabrication Using Teledentistry. *Journal of Clinical Orthodontics*, **51**, 706.

[9] Gomez, J.P., Peña, F.M., Martínez, V., Giraldo, D.C. and Cardona, C.I. (2015) Initial Force Systems during Bodily Tooth Movement with Plastic Aligners and Composite Attachments: A Three-Dimensional Finite Element Analysis. *The Angle Orthodontist*, **85**, 454-460. https://doi.org/10.2319/050714-330.1

[10] Skaik, A., Wei, X.L., Abusamak, I. and Iddi, I. (2019) Effects of Time and Clear Aligner Removal Frequency on the Force Delivered by Different Polyethylene Terephthalate Glycol-Modified Materials Determined with Thin-Film Pressure Sensors. *American Journal of Orthodontics and Dentofacial Orthopedics*, **155**, 98-107. https://doi.org/10.1016/j.ajodo.2018.03.017

[11] Nucera, R., Dolci, C., Bellocchio, A.M., Costa, S., Barbera, S., Rustico, L., *et al.* (2022) Effects of Composite Attachments on Orthodontic Clear Aligners Therapy: A Systematic Review. *Materials*, **15**, Article No. 533. https://doi.org/10.3390/ma15020533

[12] Hassanaly, T., Rabal-Solans, A., Mediero-Pérez, M. and Nieto-Sánchez, I. (2024) A Comparison of the Upper Anterior Teeth Movements with Optimized and Conventional Attachment. *Journal of Clinical and Experimental Dentistry*, **16**, e480-e484. https://doi.org/10.4317/jced.61466

[13] Dai, F., Xu, T. and Shu, G. (2019) Comparison of Achieved and Predicted Tooth Movement of Maxillary First Molars and Central Incisors: First Premolar Extraction Treatment with Invisalign. *The Angle Orthodontist*, **89**, 679-687. https://doi.org/10.2319/090418-646.1

[14] Garino, F., Castroflorio, T., Daher, S., Ravera, S., Rossini, G., Cugliari, G., *et al.* (2016) Effectiveness of Composite Attachments in Controlling Upper-Molar Movement with Aligners. *Journal of Clinical Orthodontics*, **50**, 341-347.

[15] Karras, T., Singh, M., Karkazis, E., Liu, D., Nimeri, G. and Ahuja, B. (2021) Efficacy of Invisalign Attachments: A Retrospective Study. *American Journal of Orthodontics and Dentofacial Orthopedics*, **160**, 250-258. https://doi.org/10.1016/j.ajodo.2020.04.028

[16] Smith, J.M., Weir, T., Kaang, A. and Farella, M. (2022) Predictability of Lower Incisor Tip Using Clear Aligner Therapy. *Progress in Orthodontics*, **23**, Article No. 37. https://doi.org/10.1186/s40510-022-00433-4

[17] Zhang, Y., Wang, X., Wang, J., Gao, J., Liu, X., Jin, Z., *et al.* (2023) IPR Treatment and Attachments Design in Clear Aligner Therapy and Risk of Open Gingival Embrasures in Adults. *Progress in Orthodontics*, **24**, Article No. 1. https://doi.org/10.1186/s40510-022-00452-1

[18] Groody, J.T., Lindauer, S.J., Kravitz, N.D., Carrico, C.K., Madurantakam, P., Shroff, B., *et al.* (2023) Effect of Clear Aligner Attachment Design on Extrusion of Maxillary

Lateral Incisors: A Multicenter, Single-Blind Randomized Clinical Trial. *American Journal of Orthodontics and Dentofacial Orthopedics*, **164**, 618-627. https://doi.org/10.1016/j.ajodo.2023.07.011

[19] Stephens, C., Weir, T., Llewellyn, S., Freer, E. and Kerr, B. (2022) Clinical Expression of Programmed Mandibular Canine Rotation Using Various Attachment Protocols and 1- vs 2-Week Wear Protocols with Invisalign SmartTrack Aligners: A Retrospective Cohort Study. *American Journal of Orthodontics and Dentofacial Orthopedics*, **162**, e103-e115. https://doi.org/10.1016/j.ajodo.2022.06.015

[20] Alhasyimi, A.A., Ayub, A. and Farmasyanti, C.A. (2023) Effectiveness of the Attachment Design and Thickness of Clear Aligners during Orthodontic Anterior Retraction: Finite Element Analysis. *European Journal of Dentistry*, **18**, 174-181. https://doi.org/10.1055/s-0043-1761452

[21] Hong, K., Kim, W., Eghan-Acquah, E., Lee, J., Lee, B. and Kim, B. (2021) Efficient Design of a Clear Aligner Attachment to Induce Bodily Tooth Movement in Orthodontic Treatment Using Finite Element Analysis. *Materials*, **14**, Article No. 4926. https://doi.org/10.3390/ma14174926

[22] Kim, W., Hong, K., Lim, D., Lee, J., Jung, Y. and Kim, B. (2020) Optimal Position of Attachment for Removable Thermoplastic Aligner on the Lower Canine Using Finite Element Analysis. *Materials*, **13**, Article No. 3369. https://doi.org/10.3390/ma13153369

[23] Laohachaiaroon, P., Samruajbenjakun, B. and Chaichanasiri, E. (2022) Initial Displacement and Stress Distribution of Upper Central Incisor Extrusion with Clear Aligners and Various Shapes of Composite Attachments Using the Finite Element Method. *Dentistry Journal*, **10**, Article No. 114. https://doi.org/10.3390/dj10060114

[24] Li, Q. and Yang, K. (2024) Surface Wear of Attachments in Patients during Clear Aligner Therapy: A Prospective Clinical Study. *Progress in Orthodontics*, **25**, Article No. 7. https://doi.org/10.1186/s40510-023-00506-y

[25] Cai, Y., He, B., Yang, X. and Yao, J. (2015) Optimization of Configuration of Attachment in Tooth Translation with Transparent Tooth Correction by Appropriate Moment-to-Force Ratios: Biomechanical Analysis. *Bio-Medical Materials and Engineering*, **26**, S507-S517. https://doi.org/10.3233/bme-151340