

Understanding the effectiveness of attachments in clear aligner therapy: navigating design, placement, material selection and biomechanics

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Background: Clear aligner treatments have gained popularity due to their aesthetic advantages over traditional metal brackets. Attachments play a crucial role in enhancing the efficacy of treatment by addressing challenges posed by the flexibility of aligner materials. This comprehensive review aims to clarify the significance of attachments used during clear aligner therapy and explore the nuances of their design, placement, and material selection.

Methods: A systematic search of literature databases including Web of Science, PubMed, Scopus, Google Scholar, and Cochrane was conducted. Twelve sets of keywords related to clear aligner therapy and attachments were applied for the search.

Results: A total of 24 studies that met the inclusion criteria and focused on the biomechanics of attachments, attachment shape, attachment placement and materials used in attachment production were included in the analysis.

Conclusion: Within the limits of the review, the use of attachments in clear aligner therapy can enhance the efficacy of treatment by facilitating complex tooth movements. The selection of materials, as well as the design and positioning strategies of attachments, should be customised for each patient to optimise treatment success. By the use of clinical studies, future research should focus on the long-term performance of attachments to confirm their effectiveness in achieving planned tooth movements, particularly regarding design, positioning, and the materials used.

(Aust Orthod J 2024; 40: 63 - 74. DOI: 10.2478/aoj-2024-0021)

Received for publication: April, 2024

accepted: August, 2024.

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Introduction

In recent years, aesthetic concerns and the desire for comfort have significantly increased the popularity of innovative orthodontic treatment methods in the form of clear aligners and aesthetic brackets, especially for adult patients. Alternatives made from plastic, polycarbonate, vinyl, ceramic brackets, and teflon-coated wires have attempted to replace metal brackets but have not fully met patients' expectations. This situation has heightened interest for more innovative solutions, by way of lingual appliances and clear aligners. Due to their technical ease and cost advantages, clear aligner therapy has been widely adopted by a broad patient base. The aligners, introduced by Align Technology (San Jose,

CA, USA) in the late 1990s, are preferred not only for their aesthetic and comfort advantages but also for their support of oral hygiene and periodontal health. Advancements in materials and developments in 3D printing technology have made planned tooth movements more predictable throughout aligner treatment.^{1,2} However, challenges remain in achieving certain complex tooth movements as the flexibility of the clear aligner material can result in limitations affecting force application. The material flexibility may decrease the accuracy of the applied force and cause the aligners to poorly fit the teeth, leading to incomplete planned tooth movements. To address this issue, auxiliary elements in clear aligner biomechanics have been developed. Auxiliary

attachments are directly applied to the tooth surface using composite materials, which allow the aligners to exert greater effective forces.^{2,3} In the current literature, the effectiveness of attachments in achieving planned orthodontic movements has been evaluated and assessed from various perspectives. Since their integration into clear aligner therapies, these auxiliary components have been subjected to continuous development with the objective of further enhancing outcomes.

The aim of the present review is to provide a detailed evaluation of applied attachments, which play a critical role in the biomechanical processes of clear aligner treatment. The study plans to examine how the dimensions, configuration and positioning of attachments affect tooth movements and how optimisation of the treatment process is achieved. Furthermore, the properties of the composite attachment materials will be assessed. The review aims to highlight the effectiveness and importance of attachments in clear aligner treatment, and thereby assist informed decision-making in orthodontic practice.

Methods

Search strategy

A comprehensive literature search was conducted using several reputable databases: Medline (PubMed), Web of Science, Scopus, Google Scholar, and the Cochrane database. The search was restricted to articles published during the past 10 years, with the last search conducted in March 2024. The search was limited in Google Scholar to the first 100 relevant articles. A preliminary search was undertaken to identify the most effective search terms. Keywords and a Boolean query were generated based on the study's objectives using the prompt designed by Demir et al. for systematic reviews and with the assistance of a large language model.⁴ The keywords and Boolean query were then reviewed and adjusted to ensure accuracy and relevance and included combinations related to attachments used during clear aligner therapy: "attachment placement," "attachment shapes," "attachment efficacy," "attachment materials," "attachment biomechanics," "customised attachments," "conventional attachments," "optimised attachments," "attachment design," and "attachment optimisation". The Boolean search was performed according to:

1. Clear aligner appliances
2. Clear aligner attachments

3. Biomechanics
4. 1 OR 3
5. 1 OR 2 OR 3
6. Attachment placement
7. Attachment shapes
8. Attachment efficacy
9. Attachment materials
10. Customised attachments
11. Conventional attachments
12. Optimised attachments
13. Attachment design
14. Attachment optimisation
15. 5 OR 6 OR 7 OR 8 OR 9 OR 10
OR 11 OR 12 OR 13 OR 14
16. 5 AND 15

Criteria for eligibility and data extraction

The following inclusion criteria were employed:

- Meta-analyses
- Systematic reviews
- Randomised clinical trials (RCTs)
- Cohort studies
- Case-control studies
- In vitro studies
- Finite element method (FEM) studies
- Articles published within the last 10 years
- Articles published in English

The following exclusion criteria were applied:

- Case reports
- Abstracts, author debates, or editorials
- Articles not related to attachments used in clear aligner therapy.

The identified articles were initially screened to remove duplicates. The titles and abstracts were selected according to the pre-established inclusion criteria. Subsequently, the full text of each identified article was subjected to a rigorous analysis to confirm its eligibility for inclusion. The year of publication, the authorship, type of each eligible study, and the relevance of the study to attachments in clear aligner therapy were verified and extracted.

Results

Articles that did not meet the review's inclusion criteria or were not pertinent were excluded. The remaining studies were subjected to a rigorous

examination to evaluate the role of attachments in clear aligner therapy, with a particular focus on aspects related to attachment placement, attachment design, materials used in attachment production, and the biomechanical impact on tooth movement. Consequently, a final total of 24 studies were included in the analysis.

Discussion

The analysis of the included studies provides insight into various factors that influence the effectiveness of clear aligner therapy. The discussion is organised into key themes identified during the review and which highlight important aspects and the potential impact on treatment outcomes. Each section examines the relevant studies and explores how these elements might contribute to the efficacy of clear aligner therapy.

Biomechanics of clear aligners and attachments

During clear aligner treatment, the primary method of applying force to move teeth is a shape moulding effect, which facilitates the targeted tooth movements by the aligners. The close contact between the aligner and the tooth surface generates push forces, while appliance gaps allow for tooth movement and define movement limits. Predetermined discrepancies between the shape of the aligners and the geometry of the tooth crown create a distribution of three-dimensional force systems on the contact surfaces. The ability of clear aligners to interact simultaneously with the occlusal, buccal, and lingual surfaces of the teeth grants them the capacity to apply pushing forces in all directions in a phenomenon known as the “watermelon seed effect”. Due to the asymmetric structure of tooth crowns, the distribution of forces often becomes uneven, frequently creating a moment. If this moment can be anticipated, modifications known as “pressure areas” may be added to the aligners. However, executing specific and complex tooth movements, such as rotation, extrusion, and root movements, can present challenges.^{1,5} To overcome these difficulties and increase the predictability of tooth movement, auxiliary elements such as attachments and power ridges are used. These elements enable the clear aligners to adhere more effectively to the tooth surface, thereby moving the teeth more accurately and efficiently. The design and positioning of the attachments, customised according to the direction, amount, and type of tooth movement, are critical to

the success of the treatment. By correctly directing the forces applied by the aligner, the attachments extend the range of treatment and allow more complex tooth movements to be performed efficiently. This increases the effectiveness of clear aligner treatment and broadens the range of treatment options.^{1,2,5}

Shapes and sizes of attachments used in clear aligner therapies

The attachment's shape and size vary depending on the treatment method and the targeted tooth movements. An attachment's geometry, including length, width, and depth dimensions, is designed to best support the planned tooth movement during the treatment process. In order to achieve complex orthodontic movements, it is possible to increase the dimensions of the tooth. The attachment's position should be adjusted with care to avoid any interference with the insertion and removal of the clear aligner. The design and size of attachments may be optimised in order to ensure the correct application of force, which can result in a reduction of treatment time and an improvement in outcomes, particularly in cases involving complex tooth movements. Therefore, to maximise the success of a treatment plan, the design of each attachment may be customised to meet treatment needs, both aesthetically and functionally. The classifications of the frequently used attachments in clear aligner therapy based on their configuration and dimensions are illustrated in Table I. Attachments can be classified into three main categories based on their design: conventional, customised, and optimised^{6,7} (Figure 1).

Conventional attachments

Conventional attachments are available in ellipsoidal, rectangular, and bevelled shapes and are the preferred choice for space closure and aligner retention. The dimensions and configuration of conventional attachments may be tailored to align with the specific orthodontic force requirements and the intended tooth movement.^{2,7}

Ellipsoid attachments

Ellipsoid attachments, typically sized 3mm high, 2mm wide and 1 mm protruding, are used to provide retention or anchorage. Vertical ellipsoid

Table 1. Classification of frequently used attachments in clear aligner therapy based on their configuration and dimensions

Classification	Configuration	Mesial-distal dimension	Occlusal-lingual dimension	Buccal-lingual dimension
Conventional	Elipsoid	2 mm	3 mm	1
	Rectangular	2 mm–5 mm	2 mm–5 mm	0.5 mm– 1 mm
	Bevelled	2 mm–5 mm	2 mm–5 mm	0.25 mm (bevelled side) 1 mm–1.25 (opposite side)
Optimised	Clear aligner provider-determined based on planned tooth movement	Predetermined fixed dimensions by the clear aligner provider	Predetermined fixed dimensions by the clear aligner provider	Predetermined fixed dimensions by the clear aligner provider.
Customised	Clinician-designed based on individual tooth movement and treatment needs	Variable depending on the clinician	Variable depending on the clinician	Variable depending on the clinician

attachments may size up to 2.5 mm wide, 4 mm high and 2mm protruding. The ellipsoid shape is currently considered to be the least effective attachment due to its lack of a distinct active surface. However, they may be utilised in limited areas of the tooth surface, such as wedge-shaped lateral incisors or the lingual surface of lingually-inclined mandibular second molars.^{6,7} Dasy et al.⁷ evaluated the effects of different attachment shapes and materials on aligner adhesion. It was reported that ellipsoidal attachments did not produce a significant change in the force required to remove the aligner and therefore supported the retention of the aligner.

Rectangular attachments

Rectangular attachments may be vertically or horizontally placed and are typically attached in the centre of the tooth crowns. However, they may be moved to any position according to the planned tooth movement. Horizontal rectangular attachments serve multiple purposes as they can control root position, particularly for buccal root torque of molars, and enhance the retention of aligners on short crowns. These attachments are commonly used in growth modification treatments related to mandibular advancement. Additionally, in cases of a unilateral crossbite, horizontal rectangular attachments are utilised on the non-crossbite side to provide anchorage for posterior crossbite correction. Vertical rectangular attachments are employed for root control of the

mandibular incisors when optimised root control attachments cannot be placed by the software, often in cases of lower incisor extraction. The dimensions, prominence, bevelling of the edges, and position on the tooth of conventional rectangular attachments can be modified according to clinical preference.⁷ Elshazly et al. conducted a finite element study of the maxillary central incisor to investigate the impact of different attachment configurations and cutting-line designs on the biomechanical performance of orthodontic aligners. The study found that horizontal rectangular attachments were effective in distalisation and tooth extrusive movements. The combination of a straight extended trim line and horizontal rectangular attachments was found to be particularly effective in achieving the planned tooth movement.⁸ A study investigating the effects of using rectangular attachments for arch distalisation reported that the placement of a vertical rectangular attachment reduced the tendency for mesiodistal tooth tipping during movement. The study also revealed that vertical rectangular attachments exhibited the greatest side effects related to tipping, torque, and intrusive force. However, optimal performance was demonstrated in the derotation of a premolar tooth due to their flat active surfaces.⁹ In an alternative study, 12 different attachment configurations were examined to evaluate their effectiveness on the forces and moments generated during the derotation of upper second premolars. Of the configurations, the rectangular attachment was found to achieve superior

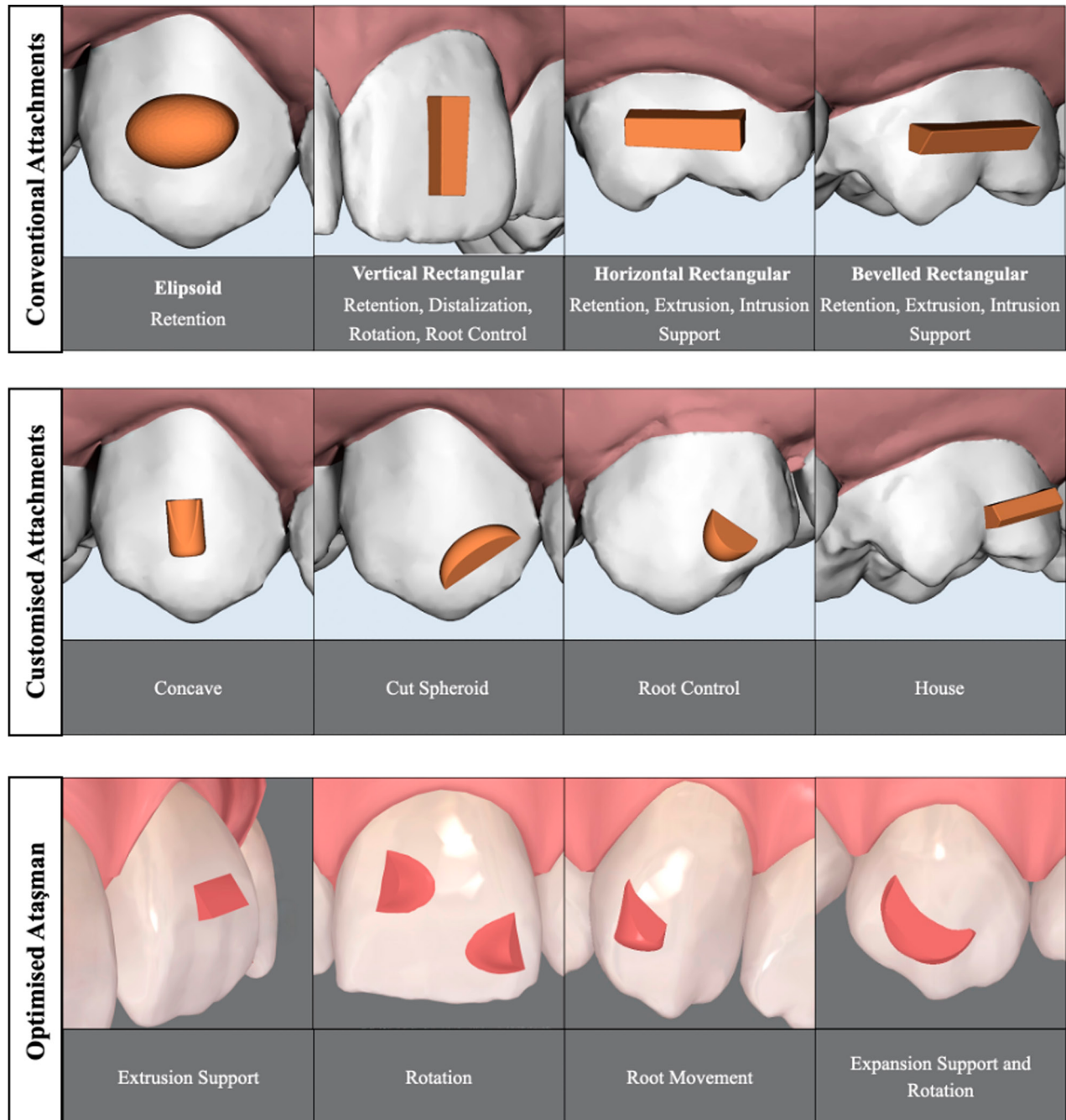


Figure 1. Attachment classifications and examples with various configurations in clear aligner therapy.

derotation compared to the others, although it also produced the greatest side effects, related to tipping, torque, and intrusive force.¹⁰ A study using a finite element analysis was conducted to determine the effects of different attachment shapes on movement efficiency and stress distribution during the extrusion of upper central incisors. Four models were assessed which involved no attachment, a bevelled rectangular

attachment, an ellipsoidal attachment, and a horizontal rectangular attachment. The model with the horizontal rectangular attachment showed the highest extrusive movement, but the differences were very small and considered not clinically significant.¹¹ Savignano et al. conducted a finite element analysis to investigate the effects of attachments on tooth movement efficiency and stress distribution during

the extrusion of upper central incisors. The study reported that extrusion could not be performed without an attachment. Additionally, the study found no significant difference between the rectangular and ellipsoid attachments in their effectiveness.¹² In a finite element analysis which investigated the effectiveness of attachment positioning for the rotation of molars, the combination of a 1.2 mm aligner activation and a 3 mm vertical rectangular attachment was found to be effective in achieving correction.¹³

Bevelled attachments

Rectangular attachments may be bevelled both horizontally and vertically to enhance aligner retention. For extrusive movements, a horizontal attachment inclined towards the gingiva is recommended, while for intrusion, a horizontal attachment bevelled occlusally may be preferred. Bevelled vertical attachments are effective for rotational movements. In cases in which the clear aligner treatment planning software does not provide optimised rotational attachments, an oblique mesial or distal attachment may be used. The flat surface of the bevel provides a stable platform for aligner force application, ensuring the planned tooth movement is achieved efficiently.^{2,7} In an in vitro study investigating the effect of different attachment shapes on aligner retention, three attachment groups were tested: ellipsoid (3 mm height, 2 mm width, 1 mm depth), rectangular (2 mm height, 3 mm width, 0.25 mm incisal depth, and 1.25 mm gingival depth), against a control group with no attachments. The results indicated that the bevelled rectangular attachment significantly enhanced aligner retention.⁷ Costa et al. evaluated the forces generated by three different attachment designs across the three planes (X, Y, and Z) during the extrusion of maxillary central incisors. The study concluded that the bevelled attachment design produced the greatest extrusive force while also minimising angular deviation in the direction of extrusion.¹⁴

Customised attachments

The effectiveness and predictability of attachments used in clear aligner therapies depend largely on their geometric design. Clinicians may use advanced 3D modelling software such as Maestro (AGE Solutions®, Pontedera, Italy) and Autodesk Meshmixer (Open source, www.meshmixer.com, Autodesk Inc., San Francisco, CA, USA) to design customised

attachments with different geometries tailored to each patient's unique dental structure and treatment needs. The software tools can be applied to precisely adjust the size, shape, and position of the attachments based on the planned tooth movement. A study was conducted to evaluate the intensity and direction of forces produced by attachments of three different geometries, and significant differences were observed. It was noted that specially-designed attachments without edges, which were less protrusive, and with a vestibular length of 3.32 mm, produced sufficient extrusive force while minimising the side effects of torque and tipping.¹⁴

Optimised attachments

Optimised attachments are uniquely designed with specific characteristics to apply appropriate force and enable more predictable tooth movements. Align Technology (San Jose, CA, USA) has developed optimised attachments that are automatically placed by the ClinCheck software when a specific amount and type of movement is planned. These attachments are available exclusively in the Invisalign system and are specifically designed to match the width, long axis, and shape of each tooth when precisely positioned to transmit forces in the most effective way.^{6,15}

Optimised attachments enable more complex tooth movements to be performed in a required direction and according to a planned timetable. Align Technology reports that the specific movements of rotation, extrusion, or intrusion, can be directed more efficiently and consistently by using the correct positioning and design of the optimised attachments. Karras et al. conducted a retrospective cross-sectional study to investigate the effect of attachment type (optimised or conventional) on movement efficiency. The study concluded that optimised attachments are more effective in rotation movements, while conventional attachments are more successful in extrusive movements.⁶ A randomised controlled clinical trial evaluated the effects of attachment shape and position on tooth movement during premolar extraction space closure. The study utilised four different attachments, including a G6-optimised molar attachment. The results indicated that G6-optimised attachments provided control of molar angulation similar to that of horizontal rectangular attachments.¹⁶ A study using finite element analysis

investigated the effect of attachments on stress distribution during the distalisation of canines. The study compared two optimised ellipsoid attachment models against a model without attachments. The findings revealed that, in the models with attachments, the canine exhibited nearly parallel movement. In contrast, models without attachments showed uncontrolled tipping movement, with almost no movement of the apical region of the tooth.¹⁷

Attachment placement

As aligners cover all surfaces of the teeth, unintended movements in addition to planned movements may be observed. Therefore, the positioning of attachments is essential to ensure that the planned movements are carried out with maximum efficiency and minimal unwanted side effects. To minimise unintended movements, it is crucial to carefully consider the nature of the planned movement and the force required, taking into account the tooth's centre of resistance.^{1,2} Attachment positioning should be based on the balance between the centre of resistance and the magnitude and direction of the applied force. If the planned movement requires the tooth to move along multiple axes, the direction of these movements must be considered, and the attachment positioning should be adjusted accordingly. This process may involve customisations, such as creating bevelled surfaces on the attachment to allow the force to be applied more effectively.

The application of a force to a tooth with the intention of achieving movement may result in the unintended movement of adjacent teeth due to the single-piece structure of the aligners. Depending on the nature of the planned orthodontic movement, it may be necessary to place attachments on adjacent teeth to provide anchorage or to prevent unwanted effects. The proper placement of the attachments can enhance the effectiveness of the intended tooth movements while reducing the risk of unintended movement of adjacent teeth.^{1-3,18}

Clear aligner materials produced by the thermoforming method are thicker in the incisal and occlusal areas and thinner near the gingival margin due to the nature of the production process. These characteristics play a significant role in the positioning of attachments as the thicker areas of the aligner can more effectively transmit an applied force, and in effect, act like robust

arch wires. When performing challenging orthodontic movements, placing attachments in these thicker regions can optimise force transmission and enhance treatment effectiveness.^{1,5}

In planning the attachment position for clear aligner treatment, it is important to consider aligner design. Research has shown that aligners extending 1 to 2 mm beyond the gingival margin are more effective in transmitting force. This is because a longer aligner wraps around the anatomical structure of the tooth more effectively and results in more accurate force application. The distance between the attachment and the trim line should be carefully adjusted to ensure treatment efficiency. If attachments are placed too close to the gingival margin, leaving too short a distance to the trim line, the aligner in this area may be weaker and may stretch under occlusal forces and result in incomplete contact with the tooth. Therefore, when positioning the attachment, the distance between the endpoint of the attachment and the trim line needs to be sufficient.^{3,19}

A finite element study evaluated the effectiveness of attachment positioning in intrusive and retrusive movements and its impact on stress distribution. The study found that palatal attachments were the most effective for tooth retraction. Additionally, the authors suggested that placing attachments on the labial surface may help prevent uncontrolled tipping.²⁰ An additional study was conducted to investigate the movement efficiency of attachment positioning on molar intrusion using a finite element analysis. Four different models were evaluated and involved no attachment, a buccal attachment only, a palatal attachment only, and both buccal and palatal attachments. The results showed that the combined use of both buccal and palatal attachments effectively prevented buccal and palatal tipping and demonstrated the highest efficiency in intruding the molars.²¹

Rossini et al. conducted a study investigating the effects of attachments on movement efficiency and stress distribution during the distalisation of the maxillary second molar using a finite element analysis. The study evaluated three models: one without attachments, one with vertical 3 mm attachments from the canine to the first molar, and one with vertical 3 mm attachments from the canine to the second molar. The findings indicated that attachments were necessary to control the

parallel movement of the second molar. It has been further suggested that attachments can be used to reinforce anchorage support and act as active units on consecutively distalised molars. The attachment configuration from the canine to the second molar has been identified as the most promising model for maxillary molar distalisation in the correction of Class II malocclusions.¹⁸ A further study examined the effects of attachment shape and placement on the efficiency of movement during diastema closure using a finite element analysis. Two different models were evaluated: one without attachments and one with double opposing attachments placed on the labial surface of central incisors. While the attachments did not affect the tooth's initial movement, significant differences were observed during the ongoing time simulation. The research findings demonstrated that using attachments restricts unintended root movement and tipping, thereby enhancing the efficiency of diastema closure.²²

Materials used in attachment production

The positioning and configuration of attachments directly affect the applied force system. The accurate transfer of the planned attachments to the tooth surfaces is crucial for achieving the intended tooth movements and ensuring the proper fit of the aligners. It is also essential for clinical effectiveness that attachments maintain their shape and integrity throughout the treatment period.^{1,2}

Composite materials, commonly used in restorative dentistry, are employed in the production of aligner attachments. The composite materials typically consist of two phases: an organic resin matrix and an inorganic/organic filler. The matrix of composite resin is composed of methacrylate-based compounds, such as bisphenol A-glycidyl methacrylate (Bis-GMA), urethane dimethacrylate (UDMA), triethylene glycol dimethacrylate (TEGDMA), or bisphenol A-ethoxylate dimethacrylate (Bis-EMA). Fillers, which may be inorganic or organic particles, are added to enhance the composite material's mechanical properties, wear resistance, aesthetic appearance, and manipulation. Fillers are made from various inorganic materials, including silica, quartz, zirconia, and glass ionomers.^{23,24}

The physical and mechanical properties of composites are largely dependent on the filler content, specifically

the filler ratio and particle size. The filler ratio represents the amount of filler as a percentage of the composite's total volume. An increase in filler ratio generally results in higher material viscosity, which can directly affect the clinical applicability of the composite. High-viscosity composites typically exhibit better wear resistance, while low-viscosity composites may be preferred for thin restoration layers and "hard-to-reach" areas due to their superior flowability.²⁵

Dentists prefer composite materials with varying viscosities and filler ratios based on the restorative needs. The choice is made to maximise the benefits of a specific restoration. Aligner attachments are considered a type of restoration. It is crucial to select the composite material that offers the most suitable advantages for attachment configuration and geometry.

Conventional composites and packable composites

Conventional composites and packable composites are frequently preferred materials for orthodontic attachments due to their high viscosity and high filler content. The structure of conventional composites makes them ideal for applications that require predetermined shapes and contours. Packable composites, in contrast, are harder and less sticky compared to conventional composites, making them easier for clinicians to shape. The chemical composition of these composites enhances their wear resistance, while the high filler ratio improves their mechanical properties. The high filler ratio and enhanced wear resistance of these composites helps to minimise shape distortion of the attachments during treatment. In clear aligner therapy, it is important that the attachments maintain their shape to transmit the optimal forces required for the planned tooth movements and to ensure that the aligners fit precisely to the teeth.^{24,25}

Clear aligner therapy is the preferred treatment method when the patient's aesthetic concerns are significant. Anterior composites, which fall under the traditional composite category, are often used for attachment production due to their superior colour matching and aesthetic qualities. These composites are further noted for their colour stability and translucency, offering long-term aesthetic solutions due to their ability to blend with the natural tooth colour and resist colour change over time.⁷

Anterior composites present certain challenges in attachment production as careful manipulation is required and, due to their high viscosities, particularly in small and complex attachment areas, extra effort may be needed to ensure the material fully spreads into and penetrates the attachment reservoirs. This can be especially challenging in cases requiring multiple attachments, thereby potentially extending the overall session time of the treatment visit. This situation can negatively impact on time management and patient comfort in clinical practice.

Flowable composites

In comparison to conventional composites, flowable composites are characterised by a reduction in the filler content from 50-70% to 37-53%. This reduced viscosity enables flowable composites to easily penetrate small cracks or corners of cavities using an injection syringe, thereby simplifying the procedure and shortening operation time. However, flowable composites exhibit higher shrinkage compared to conventional non-flowable composites. Due to their decreased filler ratio and wear resistance, flowable composites are recommended for use in areas of low stress. Based on evaluations of flexibility, wear and other mechanical properties, studies have shown that flowable composites have lower mechanical strength compared to conventional resin composites. To compensate for this, flowable composites with a higher filler content have been developed to improve their mechanical properties of increased mechanical resistance and lower polymerisation shrinkage. High filler ratio flowable composites therefore provide advantages related to greater wear resistance and strength while retaining the functionality of standard flowable composites. However, as the filler ratio increases, the viscosity of flowable composites also increases.^{2,24,25}

Flowable composites are preferred in the production of attachments due to their practicability and minimal manipulation needs. Their high penetrating ability makes them suitable for producing complex shaped attachments. However, their flowable nature also presents potential disadvantages related to the formation of air bubbles and the spread of excess material on the tooth surface. To ensure precise movement transmission and the proper fit of an aligner, the excess material may need to be removed which potentially increases clinical time. Prolonged

removal of excess composite further increases the risk of damaging the tooth structure. Therefore, careful application is required when using flowable composites. D'Antò et al.²⁶ conducted an in vitro study to evaluate three composite materials of different viscosities for the production of attachments. It was found that there were significant differences in the amount of overflow between the composites and it was concluded that the viscosity of the composite affected the amount of overflow during application.

Bulk fill composites

Bulk-fill composites were developed to address the time-consuming nature of conventional filling techniques for deep cavities. These next-generation composites may be applied in increments up to 4 mm thick in a single step, and their high translucency allows for adequate polymerisation at this depth. Additionally, innovative initiator systems have reduced the light-curing time required for these materials.²⁴

Bulk fill composites can be classified on the basis of their viscosity and filler content. Those with a lower filler ratio are mechanically weaker, although they have a high penetration capability. These composites are typically used as base materials in restorative treatment, and it has been recommended that a traditional composite with greater mechanical properties be protectively applied over the top. As the filler content increases, the mechanical properties of bulk-fill composites improve. However, this also results in increased viscosity, which requires additional manipulation during application.^{24,25}

The literature indicates that SonicFill (KERR, Orange, CA, USA) bulk-fill material, despite its high filler ratio, can be effectively used in the production of attachments due to its spreadability in the application area.^{2,23,27} However, to achieve superior spreading performance, a specific hand tool that operates with compressed air and utilises sonic vibration technology is required to reduce the viscosity of the material. Chen et al.²⁷ conducted an in vitro study to evaluate the effectiveness of three different composite materials used in the production of attachments. The study investigated a high filler bulk-fill composite, a packable composite and a flowable composite. Based on the results, it was determined that the packable composite had a longer processing time, while the flowable composite showed weaker performance in wear tests, while the high filler bulk-fill composite,

SonicFill, showed the best result for bond strength. According to the results of the study, the high filler bulk-fill composite, SonicFill, is recommended for the production of attachments in clear aligner treatments due to its short application time, high bond strength and low wear volume loss.

Specialised attachment composites

Customised composites for the production of attachments have recently gained importance in orthodontic practice. According to the claims of the manufacturing company, GC Aligner Connect (GC Dental Products, Tokyo, Japan) has the ability to mimic the appearance of tooth enamel. Its fluidity and paste-like consistency make it easy to use and allows for optimal polymerisation through the aligner. In addition, it offers optical properties that resemble tooth enamel, thereby enhancing its aesthetic appeal.²⁸ TPH SPECTRA® ST Universal Composite Restorative (Dentsply Sirona Inc., Charlotte, NC, USA) is a product noted for its claimed resistance to wear and stains from food and beverages during use. According to the company's claims, this composite integrates with the surrounding tooth structure through a chameleon effect, providing optimised adaptation that prevents the formation of air bubbles.²⁹

The literature regarding specialised composites for attachment production is limited. Existing studies of bond strength and clinical application time have shown that these materials are successful.³⁰ However, further research is needed to provide more detailed information about long-term clinical performance.

Conclusion

The present review discusses the use of attachments used during clear aligner therapy. Attachments can improve aligner retention and orthodontic tooth movements, thereby playing a critical role in the success of treatment. The shape, size, and placement of attachments can directly affect the efficacy of targeted tooth movements and the overall outcome.

The placement and configuration of attachments play a significant role in efficiently transmitting planned orthodontic movements while minimising side effects. With one bevelled edge, traditional attachments have been found to be particularly

useful in providing anchorage and tooth movement. Most studies on the efficiency of placement and planned movements have been conducted using finite element analysis while the number of retrospective studies conducted on patients is limited. Therefore, prospective studies are needed to better understand the biomechanics of attachments and further develop treatment strategies.

The selection of composite materials for attachments has a significant impact on their performance. Flowable composites with high filler content are known for their short processing times and ease of application. Conventional composites, whether containing a low or high filler ratio, can also be used for attachment fabrication, mainly because of affordability. The choice of material should be based on the specific requirements of each case and the properties of the chosen material. Given the limited literature on specialised composites for attachment production, it is essential that the properties claimed by manufacturers are verified by independent studies.

In summary, the effective use of attachments in clear aligner therapy can significantly enhance the treatment process by facilitating complex tooth movements. The selection of materials, as well as the design and positioning strategies of attachments, should be customised for each patient to optimise treatment outcome. Likely future research may provide more information on the long-term performance of attachments and the materials used, thereby contributing to more effective and predictable outcomes in orthodontic practices.

Conflict of interest

The author declares that there is no conflict of interest.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used ChatGPT to improve readability and to assess the grammar of the original article. After using this tool/service, the author(s) reviewed and edited the content as necessary and take full responsibility for the content of the publication.

Data availability

The data that support the findings of this research article are available from the corresponding author, upon reasonable request.

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Authors' contribution

G.B.D.: Conceptualisation, Methodology Investigation, Resources, Data curation, Writing-original draft, Validation, Writing-review and editing, Visualisation

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