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Proposal of a New Attachment Design for the Optimization of Tip Movement with Clear Aligners

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Abstract

Clear aligners have proven to be an effective tool in orthodontics, but the predictability of certain movements, such as tip movement, remains a challenge. This study compares the efficacy of a new attachment design, the Double Gripping Zag (DGZ) Attachment, with the classic Invisalign double attachment to improve tip control. Through a biomechanical analysis based on physical models, the moments and forces generated by both attachments in the correction of the corono-distal tip of central incisors were evaluated. The results indicate that the DGZ attachment, by taking advantage of a greater separation between its active lobes, requires lower forces (~0.19 N) to generate an equivalent rotational moment (2 N·mm) to that of the classical attachment (~0.5 N). This suggests a possible benefit in terms of biomechanical efficiency and motion control.

Keywords

Clear aligners; Attachments; tip; angel aligner; Invisalign; bodily movement; biomechanics.

Introduction

Over the last decade, clear aligners have established themselves as an effective and aesthetic tool in orthodontic treatment. However, despite advances in 3D planning software and material optimization, there are dental movements that present significant challenges in terms of predictability and efficiency [1]. Prominent among these movements are those involving root control, such as tip and torque, which are essential for optimal dental alignment and stable clinical outcomes. The tip movement, in particular, represents one of the major difficulties in clear aligner therapy [2]. This movement, which requires the controlled inclination of the tooth root relative to the crown, is highly dependent on the ability of the aligners to generate accurate three-dimensional forces. However, the lack of predictability in tip expression has led to the development of multiple strategies to improve this movement, such as the use of rectangular attachments, double attachments, or even power arms in more complex cases. Despite these innovations, the results often fall short of what was prescribed in the initial planning, leading to a number of clinical and operational challenges.

Although some authors suggest that the presence and different designs of attachments are not determinant for the expression of planned movements [2, 3], most literature references emphasise that attachments are a crucial element in achieving the desired results. There is a notable lack of literature references addressing mesiodistal tip movement in anterior teeth. Most of the studies available in the literature focus on bodily movement of posterior teeth, particularly in cases of extractions [4].

Concluded that, after premolar extraction, adjacent teeth showed dental tipping when treated with aligners. However, their results did not rule out the ability of aligners to generate full body movements, making them a viable option for patients requiring premolar extractions. The authors suggested that the sizes and shapes of the attachments used in patients may not have been the most suitable for this type of movement, pointing to the need to explore new attachment designs and dimensions.

Reported that the average mesiodistal tip accuracy was 40.5%. Only 21 of 180 teeth had mesiodistal movement greater than 1.0 mm (range 1.0 to 3.8 mm), and only 8 teeth achieved movement greater than 2 mm. Maxillary lateral incisors (43.1%) and mandibular incisors (48.6%) achieved the highest accuracy, while maxillary canines (35.5%) and mandibular canines (26.9%), together with maxillary central incisors (38.6%), showed the lowest accuracy. These results suggest that teeth with larger roots may face greater difficulties in achieving effective mesiodistal movement [6].

Calculated the effect of closing the interincisal diastema betweent two upper centrals with clear aligners and the double tip attachment proposed by invisalign using finite elements. They showed that the attachment worked correctly, but the mathematical model only calculated the closure of a 0.2 mm diastema [7].

Evaluated the predictability of the mesiodistal tip in mandibular anterior teeth remaining after extraction of mandibular incisors in patients. The results showed that incisors achieved 78.89% of the digitally prescribed tip movement, while canines achieved 54.16% [8].

Emphasized that attachment configurations have a significant impact on the biomechanics of tooth movement, and their proper selection can improve both the accuracy and efficiency of treatment with clear aligners. Although bodily movement of the lower canines was achieved, a slight tendency to tipping

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was observed, attributed to skeletal resistance and the centre of rotation of the tooth. In addition, the simulations showed that the forces generated by the aligners tend to concentrate in specific areas, which underlines the importance of precise design and placement of the attachments to achieve more controlled tooth movements [9].

Concluded that the root angulation changes predicted at the start of treatment with Invisalign aligners were not fully achieved by the end of the initial treatment, showing significant differences between predicted and achieved angulations. The highest accuracy in angulation changes was observed in the premolars adjacent to the extraction site of the maxillary second premolar, while the least optimal expressions occurred in the canines, especially when movement towards the extractions its was expected. Furthermore, there was a tendency for movements to be over expressed when the crowns were predicted to incline towards the extraction space and the roots to move away, while the predicted movements of the roots towards the extraction space tended to be under-expressed or even directed in the opposite direction. Optimized attachments did not prove to be more effective than conventional attachments in controlling root angulation, and it was suggested that overcorrection of movements in digital planning might be a more effective strategy. Furthermore, no significant differences were found in movement accuracy according to wearing protocols, number of aligners prescribed, age or gender of patients. These findings highlight the need for adjustments in clinical planning and management to improve the predictability of root movement with Invisalign aligners [10].

When an aligner fails to correct the tip according to the 3D planning, the consequences are significant. For the orthodontist, this means an increase in treatment time, the need for case redesign and the ordering of new aligners, which increases the workload. For commercial companies, it means a greater consumption of resources, both in terms of technician hours and additional materials to manufacture new aligners. In addition, this process increases the environmental footprint due to the extra use of plastic and the transport needed to ship the aligners from the factory to the orthodontist's practice [11].

For these reasons, increasing efficiency in the expression of movements such as tipping is crucial not only to optimize the production loop, but also to improve the patient experience. More predictable and efficient treatment reduces overall therapy time, improves patient comfort and minimizes the environmental impact associated with manufacturing and transporting aligners. This article explores advanced biomechanical strategies to improve tip predictability and analyses the impact of these innovations on the success of clear aligner therapy.

Working Hypothesis

The hypothesis states that the proposed design optimizes the expression of tip movement, improving the efficacy of interincisal diastema closure following maxillary disjunction, a movement recognized for its low predictability. This is based on the increased ability of the new attachment to generate more precise and controlled three-dimensional forces.

Bio Mechanical Analysis

To justify the hypothesis, physical formulas were used, which describe the relationship between the forces generated by the aligner, the geometry of the attachment, and the efficiency of root movement. The moments and forces generated on the target teeth when using both types of attachments were calculated and compared:

Classic double attachment:

Evaluation of lateral forces and rotational moments generated during tip movement.

DGZ attachment:

Adjustments to the geometry of the attachment to maximise the transmission of forces in the desired direction. Analysis of the increase in efficiency by increasing retention and thus reducing mechanical energy losses.

Material and Method

Study design

This study was designed as a comparative analysis to evaluate the efficacy of a new attachment design proposed by the authors versus the classic double attachment for tip correction, which is widely used in the Invisalign system. A combined approach has been used, including a theoretical biomechanical analysis based on physical formulas.

Material

The DGZ attachment (Double Gripping Zag attachment) is beveled double lobe device, designed to optimize mesiodistal tooth inclination control when using clear aligners (FIGURE 1). Each of its lobes has an active bevelled surface: the incisal lobe, located close to the incisal edge, exerts a force in the gingival direction, while the gingival lobe, located in the area closest to the gingiva, applies its force in the incisal direction. In this way, two vertical and opposite force vectors are arranged, running on either side of the centre of resistance of the tooth. As there is no net translational force, these two parallel forces produce a pure rotational moment aimed at correcting the mesiodistal tip.

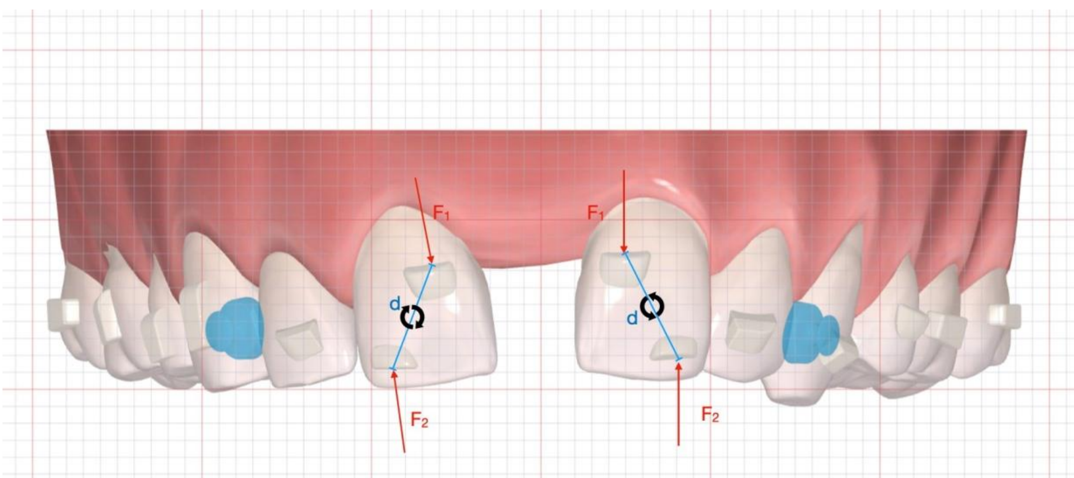

Figure 1: Double Gripping Zag attachment.

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Results

If we analyze the comparison of the two attachment designs on a central incisor, to correct 1° of mesial tip, which is the typical amount that each clear aligner exerts to correct this movement at each stage of treatment, we obtain the following results:

The following is the step-by-step physical reasoning for achieving 1° of inclination (corono-distaltip) on a standard central incisor using an Invisalign double attachment. An incisor 8.5 mm wide (mesiodistal), 10.5 mm high (incisogingival) at the clinical crown, 13 mm root and a centre of resistance (CR) 16 mm from the incisal edge are considered.

A. Physical Reasoning For Invisalign Double Attachment

1. **Tip angle and required moment:** For approximately 5°of tip on an anterior tooth, about10N·mm of moment is usually estimated. For1° tip, the moment is estimated to be around 2N·mm (direct ratio): 10N·mm 5∘ ≈2N·mm per degree With 1° of crown-distal tip, a rotational moment is therefore sought. M≈2N·mm.
2. **Placement and distance between active surfaces of the double attachment**
   - The Invisalign double attachment (sometimes referred to as a ‘double tipping attachment’) is usually designed so that its two lobes or active surfaces are separated vertically (incisal-gingival) or mesiodistally, depending on the prescription.
   - In a central incisor, the effective separation (distance d) between the two active surfaces can often be around 4 to 5 mm.
   - For this illustrative example, we will take a value of 4 mm effective distance between the active surfaces (in many Clin Check plans, this is often a range of spacing for mesiodistal lobes).
3. **Calculation of the force required**

We know that M=F×d.We want a moment M≈2N·mm.

Assuming d=4mm, then the force required one coactive surface would be:

$$F=M/d$$
$$=2N.mm/4mm$$
$$=0.5N.$$

Each lobe of the double attachment will apply, in opposite directions, a force of approximately 0.5N to generate a resultant moment of 2 N·mm.

4. **Pure moment around the center of resistance**
   - Being two equal and opposite forces, applied along parallel lines separated by d, there is no net translational force, but a pair of forces (coupling) that induces rotation.
   - The tooth, therefore, rotates around its centre of resistance, achieving the 1° crown-distal tip with minimal unwanted translation.

For 1° crown-distal tip on a central incisor, a moment of approximately 2 N·mm is required. An Invisalign double attachment with 4 mm effective gap between its active surfaces would require forces of 0.5 N per lobe to generate such a moment. By creating a purely rotational torque around the centre of resistance.

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In the following, the physical reasoning for correcting 1° crown-distal tip on a standard central incisor using a double DGZ attachment (Double Gripping Zag Attachment) is presented step by step. The same anatomical dimensions and reference orthodontic biomechanics as described above are considered. The attachment is placed using the maximum possible clearance, leaving a 1 mm margin at each boundary (incisal, gingival, mesial and distal). The gingival lobe is placed in the mesial area and 1 mm from the gingival margin, while the incisal lobe is placed in the distal area and 1 mm from the incisal edge.

B. Physical reasoning for Double Gripping Zag attachment (DGZ)

1. Tip angle and required moment

For 1° of tip (crown-distal tip), the usual orthodontic bio mechanical estimate is use data reference:

When 5° of tip is needed on an anterior tooth, an approximate moment of 10 N·mm is usually considered. Therefore, for 1º of tip, the required moment is estimated to be around2 N·mm (direct ratio: 10 N·mm /5=2N·mm per degree).
This value (2 N·mm) is an approximation that facilitates the initial biomechanical calculations and allows the force analysis to be illustrated.

2. Calculation of the distance between active points (lobes)

The DGZ design has two lobes with active surfaces spaced as far apart as possible both mesiodistally and incise gingivally, leaving a 1 mm margin at each end:

Free mesiodistal space:

- Crown width: 8.5 mm
- Mesial and distal margins of 1mm each
- Availablemesiodistalspace:8.5mm-2mm=6.5 mm

Free in CIS gingival space:

- Crown height: 10.5 mm
- Incisal and gingival margins:1mm each
- Available incisogingival space: 10.5mm- 2mm= 8.5mm

The lobes are positioned so that one is mesial-gingival and the other distal-incisal. Thus, the effective distance (d) between the centres of the two active surfaces approaches the diagonal in this plane:

$$\mathbf{d}=\sqrt{(6.5mm)^2+(8.5mm)^2}\approx\sqrt{114.5}\approx\mathbf{10.7mm}$$

Calculation of the necessary force:

To obtain the moment of 2N·mm (M) that allows 1°of tip:

F=M/D
=2N.mm/10.7mm
=0.19N

Each lobe (active surface) must exert approximately 0.19 N in the opposite direction to the other lobe, generating a pair of forces (or coupling) whose resultant is a pure moment of 2 N·mm on the tooth.

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Orientation of the vector sand centre of resistance:

- The mesial-gingivallo be applies its for revector in an incisal (and slightly distal) direction.
- The distal-incisal be applies its for revector in a gingival (and slightly mesial) direction.
- Both forces are almost parallel and opposite, so that no global translation is generated, but arotation around the centre of resistance (CR), located 16 mm from the incisal edge at the root.
- By acting on both sides of the CR, the corono-distal tip (1º) is performed with precision, using a relatively light force (0.19 N) that protects the periodontium and minimizes discomfort.

C. Bio Mechanical Results

- Larger moment arm: Locating the lobes of the DGZ attachment at opposite ends (mesial-gingival vs. distal-incisal) and taking full advantage of the height and crown width allows themto be separated ~10.7 mm.
- Lower forces: Thanks to the large distance between application points, only ~0.19 N is required to achieve the 2 N·mm moment
- Controlled movement: By creating a purely rotational pair of forces around the RC, the desired crown-distal tip (1°) is achieved accurately, without inducing unwanted translations.
- Comfort andefficiency: Comfort and efficiency: Lower forces mean less discomfort for the patient, less risk of root resorption and better biological response of the periodontal ligament. resorption and better biological response of the periodontal ligament.

In short, the strategic placement of the attachment DGZ lobes, respecting the incisal, gingival and proximal margins, maximizes the moment arm and favors precise control with light forces, optimising orthodontic biomechanics in tip correction on a central incisor.

Clinical Applications

The DGZ attachment is particularly useful for tooth movements requiring mesiodistal bodily displacement of the tooth, as well as for tip correction and molar straightening. Its use is mainly indicated for upper incisors, canines, premolars and molars. It has an anatomical limitation in the lower incisors, as the mesiodistal dimension and height of these teeth do not allow for the placement of the two elements that make up the attachment.

Clinical Applications Include

Closure of interincisal diastemas: allows correction of the tip of the incisors and improves predictability compared to classic systems, such as horizontal and vertical rectangular attachments, or the double tipping attachment. It avoids the use of power arms in severe cases Figure (2-4).

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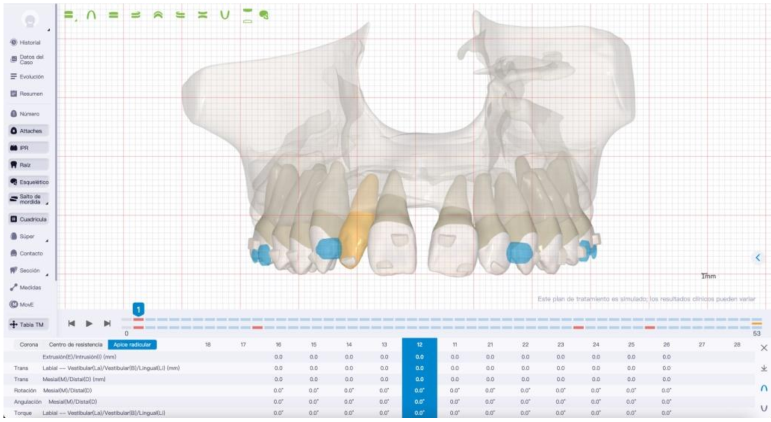

Figure 2: Initial Planning Status-Diastema Closure-Double Gripping Zag Attachment.

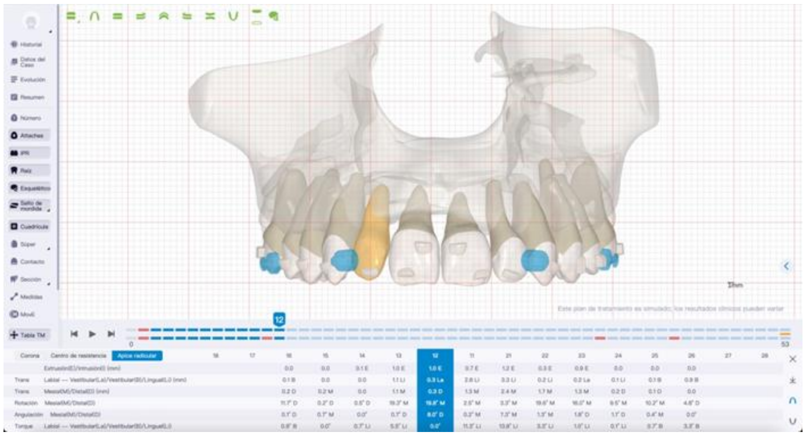

Figure 3: Evolution Of Planning To Diastema Closure-Double Gripping Zag Attachment.

Figure 4: Intraoral Photos of The Evolution of The Planned Treatment For The Closure of The Interincisal Diastema With The Double Grip Zag Attachment After Rapid Maxillary Expanxion With Marpe.

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- Tip correction of canines, premolar sand molars (Figure 5).

Figure 5: 3Dsetup of DGZ attachment for molar, premolar and canine tip correction.

Molar straightening: Especially useful for improving the position tipped molars, ensuring optimal alignment (Figure 6).

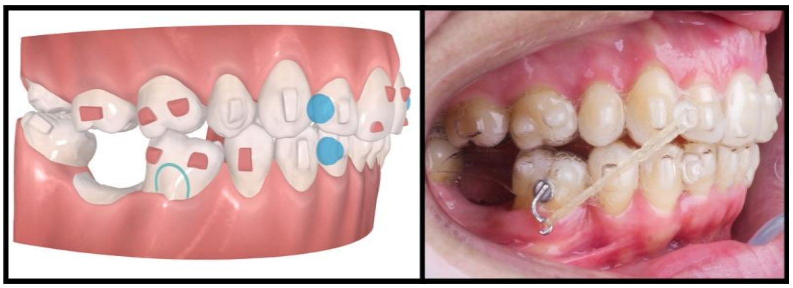

Figure 6: 3Dsetup of DGZ attachment for molar straightening.

Bodily movement of posterior teeth and canines: Ideal for cases of premolar extraction.

Conclusions

The Invisalign double tip attachment has proven to be a widely used resource in clear aligner treatments (3-10). However, because it has a moderate gap between its active surfaces, it requires higher forces to achieve a rotational moment equivalent to the design proposed in the article. This may result in a less efficient biomechanical response in situations of large inclinations or complex movements.

The DGZ attachment (Double Gripping Zag attachment) is characterized by maximizing the distance between its gingival and incisal lobes, reaching in many cases a clearly superior moment arm. By separating these force application points, the magnitude of force required to generate the same rotational moment is reduced, resulting in a reduced likelihood of periodontal overload and a potential increase in patient comfort. In addition, the gingival lobe design of the DGZ attachment may promote aligner retention by providing additional anchorage to minimize mis adaptation during tooth movement.

In situations of high biomechanical complexity or when very precise control with as little force as possible is desired, the DGZ attachment can be advantageous. The main advantage of this design lies in the maximum possible separation between the points of force application by taking advantage of the inciso gingival height and mesiodistal width of the tooth. By increasing this distance, the moment arm and the magnitude of force required to achieve the same clinical effect is reduced. This results in less stress on the periodontal ligament and greater comfort for the patient, while improving biomechanical efficiency in rotation control. Additionally, the location of the gingival lobe facilitates retention of the aligner in the cervical area, helping to minimize mis adaptations that could compromise the efficiency of movement. Another differentiating aspect of the DGZ attachment with respect to the Invisalign double tip (7) lies in the distribution of the force vectors generated during tooth movement. Although in both cases the force vectors have the same direction and opposite direction, their location and biomechanical effect differ significantly. In the Invisalign double tip attachment [3-10], the force application points are in relatively close proximity to each other and located in the incisal area of the tooth. As a result, the force vectors generated act far from the center of resistance (CR), which decreases their efficiency in generating a precise and controlled rotational moment. This arrangement may require a greater magnitude of force to achieve the same clinical effect, increasing the risk of generating unwanted secondary movements and increasing the biomechanical demand on the system.

On the other hand, the DGZ attachment design optimizes force distribution by widening the distance between the application lobes, allowing the force vectors to pass on both sides of the center of resistance of the tooth, i.e., mesally and distally (Figure 7). This arrangement has a key biomechanical advantage: by generating a more balanced torque around the RC, rotational motion control is improved and dispersion of the applied force is minimized. In practical terms, this allows for greater efficiency of rotational moment transmission with a lower force load, promoting a more predictable biomechanical response and reducing overload on the periodontium.

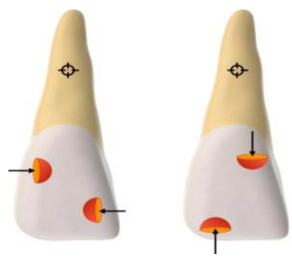

Figure 7: Comparative: Invisalign double tip attachment and DGZ attachment (Double Gripping Zag attachment).

Thanks to this optimized distribution of force vectors, the DGZ attachment not only improves movement precision, but also reduces the risk of side effects such as unwanted tilting or uncontrolled tooth slippage. As a result, a better balance between biomechanical efficiency and patient comfort is achieved, making it a preferred option in cases of complex movements or when finer control of tooth rotation is required.

Conflict of interest Statement

Declaration of interests: The authors have no conflicts of interest to declare.

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Availability of data and materials: The authors declare that the materials are available. Ethics approval and consent to participate: The study was performed in accordance with the Declaration of Helsinki.

Consent for publication: Written informed consent was obtained from the patient for publication of this short report and any accompanying images.

Disclosure of interest: The authors declare the a they have no competing interest.

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