

Control of Maxillary First Molar Inclination during Intrusion Using TAD-Supported Fixed Appliances versus Clear Aligners in Anterior Open Bite Correction

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Abstract

Background: Maxillary first molar intrusion is a key treatment goal for anterior open bite (AOB) patients. The effects of TAD-supported fixed appliances and clear aligners on vertical intrusion and molar inclination are not fully understood. **Objective:** To compare the effectiveness of TAD-supported fixed appliances and clear aligners in achieving vertical intrusion and controlling molar inclination in adult AOB patients. **Materials and methods:** Thirty-six adult patients with AOB were randomly assigned to two groups: 17 subjects treated with TAD-supported fixed appliances (TADs) and 19 with clear aligners (CA). Vertical and inclination changes of the maxillary first molars were measured using lateral cephalometric radiographs and CBCT. Spearman's rank correlation analysis was performed to assess the relationship between vertical and inclination changes. **Results:** Both groups showed significant vertical intrusion, with the TAD-supported fixed appliance group achieving greater intrusion (1.91 ± 0.88 mm) than the clear aligner group (1.04 ± 0.77 mm). Molar inclination varied significantly between groups, with the TAD group experiencing more tipping and the clear aligner group showing better control of inclination. No significant correlation was found between vertical and inclination changes in either group ($r = 0.17$ for TADs, $r = 0.15$ for CA, $P > 0.05$). **Conclusion:** TAD-supported fixed appliances offer superior vertical intrusion compared to clear aligners, while clear aligners provide better control of molar inclination. Tailored treatment based on biomechanical demands, using skeletal anchorage for vertical control and precise aligner design for inclination stability, is recommended. Further long-term studies are needed to refine treatment protocols for AOB.

Keywords: Anterior open bite, Clear aligners, Molar inclination, Molar intrusion, Skeletal anchorage

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Introduction

Molar intrusion is a key orthodontic strategy, particularly for hyperdivergent patients, to counteract posterior dentoalveolar extrusion and facilitate the closure of anterior open bites (AOBs). Increased stability in AOB correction through molar intrusion has been reported.¹ The introduction of temporary anchorage devices (TADs) has recently gained popularity for managing AOB. TAD-supported fixed appliances facilitate molar intrusion by delivering direct intrusive forces to the maxillary posterior segments. Studies have reported consistent vertical displacement of 3–5 mm within 6–8 months, with minimal root resorption and low periodontal risk maintained.^{2–4} However, despite their efficiency in achieving vertical control, several studies have shown that molar intrusion with TAD-supported fixed appliances still results in undesirable tipping. Buccal crown tipping of approximately 3–4 degrees often occurs when TADs are placed on the buccal side, as the force vectors do not pass through the tooth's center of resistance.^{5–7} Similarly, mesial or distal tipping can occur when force application is unbalanced or TADs are improperly positioned.⁵

Using bilateral TADs (on the buccal and palatal sides) or incorporating a transpalatal arch (TPA) can significantly reduce this effect.⁷ Using a rigid transpalatal arch (TPA) can further reduce unwanted molar movements.^{5,8} When combined with multiple TAD placements (buccal, palatal, mesial, distal), the risk of unwanted tipping is further minimized.^{8,9} However, the greater the number of TADs placements, the greater the potential harm. A clinical strategy involving the placement of a single TADs in the midpalatal area, combined with a TPA with soldered hooks on the palatal side, has been proposed,^{10,11} followed by the use of two NiTi-closed coil springs from midpalatal TADs to the TPA hooks to intrude the maxillary posterior segments. This technique could intrude the maxillary first molars by 1.5 mm within 6 months.¹⁰ However, the degree of molar inclination change resulting from

the application of this technique has not been studied.

Although clear aligners have become popular recently as a comfortable and esthetic appliance, vertical control and tipping correction of maxillary molars remain key limitations, even with optimized attachment designs. Studies have reported an average maxillary molar intrusion of 0.4–1.5 mm, accompanied by buccal and distal tipping ranging from 1.3° to 5.4°.^{12–14} Miao et al.¹³ found that molars intruded by an average of 0.39 mm, with distal tipping of 5.36° and buccal crown torque of 3.93°, exceeding the values initially programmed in the aligner software. A recent study incorporated a squeezing protocol into clear aligners treatment with the aim of maxillary molar intrusion without attachments placed on posterior teeth.¹⁰ It was found that after 6 months of treatment, this protocol could significantly intrude the maxillary first molar by 0.68 mm. Nevertheless, molar tipping was not quantified in the study.

Given that TAD-supported fixed appliances and clear aligners differ in the direction and continuity of force application, the tipping pattern of the intruded molars may vary. Since molar intrusion with minimal unwanted tipping is an ideal outcome required by orthodontists, understanding the extent to which inclination changes correlate with vertical changes in each type of appliance may provide insight into the biomechanical characteristics of each approach and help with proper appliance selection.

Loss of molar inclination control may compromise occlusal stability, root integrity, and long-term retention, whereas effective inclination control improves vertical correction and treatment predictability. This rationale underscores the significance of the present retrospective study.

The primary aim of this study was to compare differences in vertical intrusion and inclination change of the maxillary first molars between the TAD-supported fixed appliance (TADs) and clear aligner (CA) groups after six months of treatment in adult anterior open bite patients. The secondary aim was to investigate

the correlation between vertical distance change and inclination change within each appliance group.

Materials and methods

Study design and ethical considerations

This retrospective analytical study was a secondary analysis of a randomized controlled trial in adult patients with AOB,¹⁰ comparing the occurrence of root resorption during maxillary molar intrusion with TAD-supported fixed appliances and clear aligners. The study received ethical approval from the Human Research Ethics Committee of the Faculty of Dentistry, Prince of Songkla University (Approval No. EC6711-047). All procedures complied with institutional and national ethical guidelines and adhered to the principles outlined in the Declaration of Helsinki.¹⁵

Sample size calculation and study population

The required sample size was calculated using G*Power software (version 3.1.9.7; Düsseldorf, Germany).¹⁶ The calculated effect size was 1. With a significance level (α) of 0.05 and a statistical power of 0.80, the required sample size was estimated to be 17 participants per group. However, this study included all subjects from the main study who met the study criteria and had completed the necessary records.

Inclusion and exclusion criteria

Based on the inclusion and exclusion criteria of the main study,¹⁰ subjects were between 18 and 35 years of age, had an anterior open bite ranging from 0 to 4 mm, and exhibited Class I or II skeletal and dental relationships, as determined by an ANB angle between 0° and 5°. Facial pattern classification ranged from normodivergent to hyperdivergent, with a mandibular plane angle (MPA) of 23° to 39°. All participants were required to demonstrate good oral hygiene, with no clinical signs of gingivitis, and to have cone beam computed tomography (CBCT) scans that clearly visualized the apices of the maxillary first molars.

Exclusion criteria included the presence of moderate to severe dental crowding, absence of posterior teeth, or a history of trauma or endodontic treatment involving the maxillary first molars. Individuals with systemic diseases affecting bone metabolism, those taking medications known to influence orthodontic tooth movement, or patients with neuromuscular disorders were excluded. Additionally, patients presenting with extensive occlusal restorations on the maxillary first molars were not eligible for inclusion.

Appliance groups and data collection protocol

Based on the main study,¹⁰ subjects were randomly divided into two groups based on the orthodontic appliance modality employed: TAD-supported fixed appliances and clear aligners. Baseline records (T0) were obtained before the initiation of treatment, including patient records, lateral cephalometric radiographs, and cone beam computed tomography (CBCT). All records were collected again at six months following treatment commencement (T1).

TAD-supported fixed appliance

A miniscrew, 2.0 mm in diameter and 6.0 mm in length (AbsoAnchor®, Dentos, Daegu, Korea), was inserted in the midpalatal region corresponding to the maxillary first molar position to serve as skeletal anchorage. A stainless steel transpalatal arch (TPA), 0.9 mm in diameter, was utilized to stabilize the posterior segments. Segmental 0.018 × 0.025-inch stainless steel wires were passively placed in Roth 0.022 × 0.028-inch posterior slots. Two NiTi closed-coil springs were extended bilaterally from the midpalatal TADs to the TPA hooks, delivering an intrusive force of 150 grams per side. The force was calibrated with a force gauge and adjusted every three weeks.

Clear aligners group

The passive aligner protocol was chosen to represent a commonly applied clinical approach for the correction of anterior open bite in adults.

This method relies on posterior relative intrusion achieved through complete occlusal coverage and a structured squeezing exercise, combined with planned anterior extrusion. The intention was to contrast this approach with the active, direct intrusion produced by TAD-supported coil springs, thereby highlighting two distinct and clinically relevant treatment philosophies.

The maxillary dental arch was scanned (TRIOS 3; 3Shape, Copenhagen, Denmark). The rendered STL file was exported to the 3Shape OrthoAnalyzer, and models were printed using a 3D printer (Pro 4K; Asiga, Michigan, USA). The maxillary anterior teeth were programmed for extrusion at a rate of 0.2 mm per aligner, with each aligner worn for a 3-week interval. The clear aligners were fabricated using 1-mm Duran thermoplastic sheets. Participants were instructed to bite down on their clear aligners for one minute per session. Each session consisted of six cycles of 5-second isometric hard clenching, alternating with 5 seconds of rest. This exercise was performed at least five times per day. The clear aligners were worn for a minimum of 22 hours daily, and were only removed during meals and toothbrushing. Patient compliance was reinforced during each scheduled 3-week appointment. Adherence was evaluated through clinical inspection of aligner fit, seating, and oral hygiene, supplemented by structured self-reports of daily wear duration and the frequency of squeezing exercises. Objective electronic wear-time monitors were not employed in this study.

Lateral cephalometric radiographs

All lateral cephalograms were taken with the same cephalometric machine using the same protocol. Dolphin Imaging software (Dolphin Imaging and Management Solutions, Chatsworth, CA, USA) was used to trace the radiographs. Measurements of ANB, SNMP, and overbite were performed.

Cone beam computed tomography (CBCT)

CBCT images were taken using the same machine

with the same specifications (Veraviewepocs; J Morita MPG, Fushimi, Kyoto, Japan; 80 kV, 5 mA, 9.2 s exposure time, 0.125 mm voxel resolution, 80 x 80 mm field of view). One Volume Viewer Software (Version 11.0; J Morita, Chatsworth, CA, USA) was used to assess changes in the vertical position and inclination of the maxillary first molars.

First, the palatal plane was set. It was defined by a line connecting the anterior nasal spine (ANS) to the posterior nasal spine (PNS), identified in both coronal and axial views. This horizontal plane provided a stable craniofacial reference for evaluating the vertical position of maxillary structures.

To ensure longitudinal consistency, each CBCT volume was reoriented by aligning the palatal plane (ANS–PNS) parallel to the horizontal axis and positioning the midsagittal plane through ANS and PNS at the center. The T1 dataset was subsequently adjusted to match the T0 orientation by superimposing the ANS and PNS landmarks and rotating until the palatal plane was coincident in all views. All subsequent measurements were performed using this standardized orientation.

To quantify vertical intrusion, the perpendicular distance from the deepest point of the central pit of the maxillary first molar to the PP line was measured (Figure 1). The amount of intrusion was then determined by subtracting the T1 measurement from the T0 measurement.

Inclination changes were assessed by measuring the angle formed between a line drawn from the central pit to the furcation of the molar and its intersection with the PP line (Figure 2). A positive difference between T1 and T0 indicates buccal crown tipping, whereas a negative difference between T1 and T0 indicates palatal crown tipping.

Since the amount of vertical change and inclination changes in the right and left first molars of each subject were not statistically significantly different ($P > 0.05$), the right and left values were averaged to represent the subject's vertical and inclination changes.

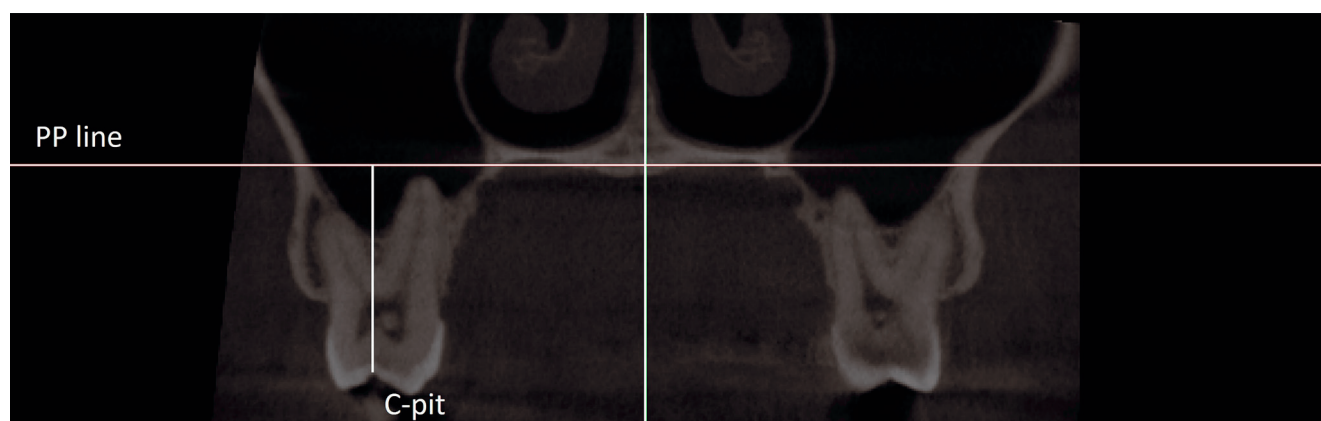


Figure 1 Measurement of vertical distance change.

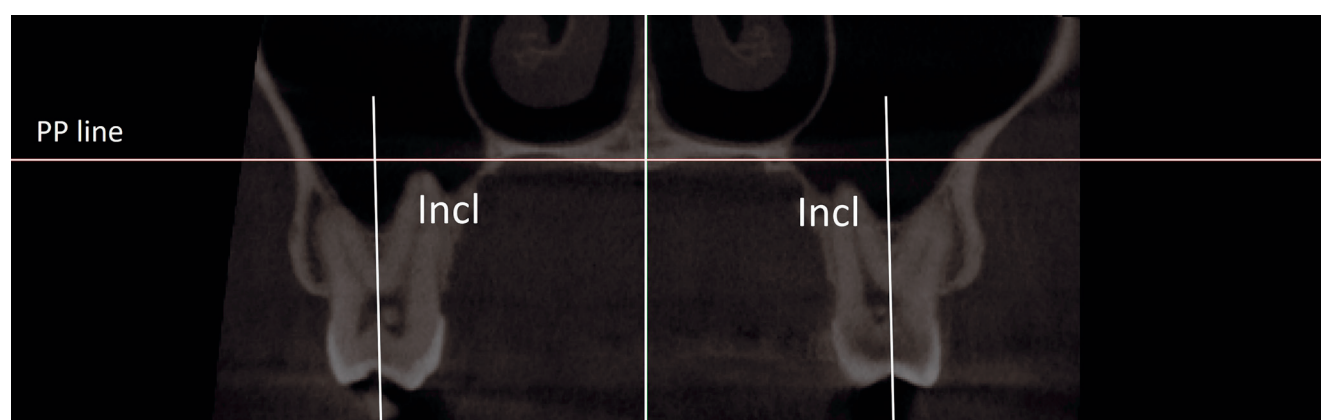


Figure 2 Measurement of molar inclination change.

The reference plane, termed the palatal plane (PP line), was defined as the line connecting the anterior nasal spine (ANS) and posterior nasal spine (PNS) and confirmed in the axial, coronal, and sagittal views, with the deepest point of the palatal vault also identified. Vertical distance was measured as the perpendicular distance from the deepest point of the central pit (C-pit) of the maxillary first molar to the PP line. The difference between pretreatment (T0) and posttreatment (T1) CBCT scans represented the amount of molar intrusion.

Inclination change was assessed by measuring the angle formed between the line connecting the deepest point of the central pit and the deepest point of the furcation of the maxillary first molar and its intersection with the palatal plane (PP line). The difference in this angle between pretreatment and posttreatment scans indicated the degree of

crown tipping. (Note: In this context, a positive value represents buccal crown tipping, while a negative value indicates palatal crown tipping.)

Statistical analysis

All linear and angular measurements were statistically analyzed using SPSS software (version 23.0; IBM Corp., Armonk, NY, USA). The normality of the data distribution was assessed using the Shapiro–Wilk test. To evaluate intra-examiner reliability, the Intraclass Correlation Coefficient (ICC) was calculated. Measurement error was determined using Dahlberg’s formula.¹⁷ For within-group comparisons, paired t-tests were used for normally distributed data; otherwise, the Wilcoxon signed-rank test was employed. For the comparison of variables, independent t-tests were used for data that followed a normal distribution, whereas the Mann–Whitney U test was applied for

non-parametric data. Spearman's rank correlation analysis was conducted within each treatment group to assess the relationship between vertical distance change and inclination change. Statistical significance was determined at a threshold of $P < 0.05$.

Results

Participant flow is shown in Figure 3 (CONSORT-style diagram summarizing screening, exclusions, and the analyzed sample for the present secondary analysis).

Of 40 subjects from the main study, 4 were excluded due to the lack of necessary data, resulting in 36 subjects included in the final analysis. Of these, 17 subjects were treated using TAD-supported fixed appliances (3 males and 14 females) with a mean age of 21.82 ± 2.77 years, and 19 subjects were treated with clear aligners (9 males and 10 females) with a mean age of 21.84 ± 2.65 years. There was no significant difference in age, pretreatment overbite, and divergent pattern between the two groups at T0 ($P > 0.05$) (Table 1).

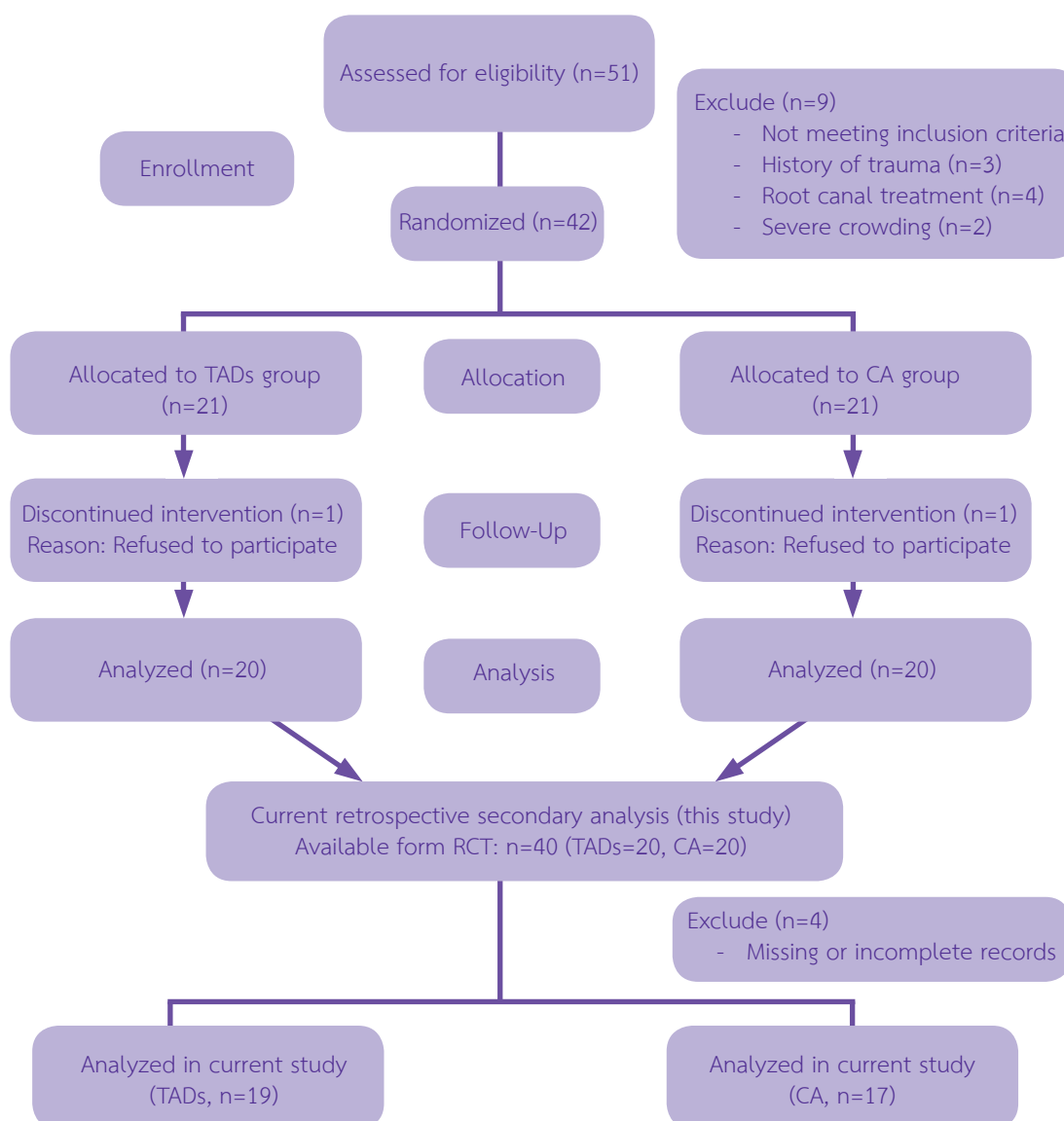


Figure 3 CONSORT (consolidated standards of reporting trials) flow diagram.

Table 1 Pretreatment demographic data and dentoskeletal Variables Between TAD-supported fixed appliance and clear aligner groups at Pretreatment (T0)

Measurements (Mean $\pm$ SD)	TAD-supported fixed appliances (TADs)	Clear Aligner (CA)	P value
Sex (male:female) (n)	3:14	9:10	0.080
Age (year)	21.82 $\pm$ 2.77	21.84 $\pm$ 2.65	0.982
SNMP ($^{\circ}$)	35.77 $\pm$ 2.42	34.23 $\pm$ 4.68	0.741
ANB ($^{\circ}$)	3.38 $\pm$ 2.51	3.17 $\pm$ 2.50	0.332
Overbite (mm)	-1.88 $\pm$ 0.77	-1.66 $\pm$ 0.62	0.313

Values are presented as mean $\pm$ standard deviation (SD). Sex is presented as number of males/females. Independent t-test was used for continuous variables, and chi-square test for categorical variables. No significant differences were observed between groups at baseline ($P > 0.05$).

Table 2 Comparison of vertical distance change and Inclination change between TAD-supported fixed appliances and clear aligners (Note: Values are presented as mean $\pm$ standard deviation. A positive inclination change indicates buccal crown tipping, while a negative value indicates palatal crown tipping. *Statistically significant at $P < 0.05$.)

Measurements (Mean $\pm$ SD)	TAD-supported fixed appliances (TADs)	Clear Aligner (CA)	P value
Vertical Distance Change (mm)	1.91 $\pm$ 0.88	1.04 $\pm$ 0.77	$< 0.001^{***}$
Inclination Change ($^{\circ}$)	-1.32 $\pm$ 0.73 $^{\circ}$	0.47 $\pm$ 0.67 $^{\circ}$	$< 0.001^{***}$

Values are mean $\pm$ SD. Independent t-tests were used for comparisons. Positive values indicate buccal crown tipping; negative values indicate palatal crown tipping. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

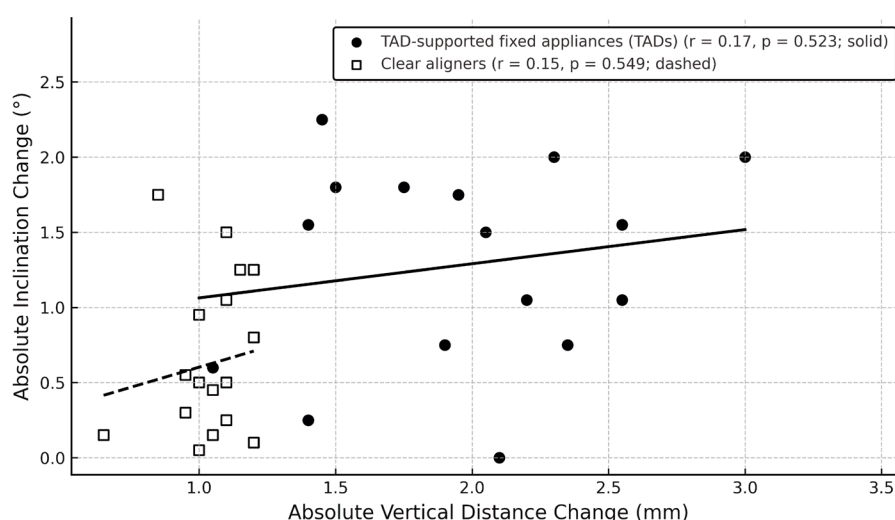


Figure 4 Correlation between absolute vertical distance change (mm) and absolute inclination change ($^{\circ}$) of maxillary first molars in the two appliance groups.

TAD-supported fixed appliances ($\bullet$; solid regression line, $r = 0.17$, $P = 0.523$) and clear aligners ($\square$; dashed regression line, $r = 0.15$, $P = 0.549$).

Significant reductions in maxillary first-molar vertical distance were observed within both groups (paired t-tests: TAD-supported fixed appliances, 1.91 ± 0.88 mm; clear aligners, 1.04 ± 0.77 mm; both $P < 0.05$). The between-group comparison showed a greater reduction in the TAD-supported fixed-appliance group than in the clear aligner group (independent t-test, $P < 0.05$) (Table 2).

In terms of inclination change, a statistically significant negative difference in inclination was observed in the TAD-supported fixed appliance group ($-1.32 \pm 0.73^\circ$, paired t-tests, $P < 0.05$), indicating a tendency toward palatal crown tipping. On the other hand, a statistically significant positive difference in inclination was found in the clear aligner group ($0.47 \pm 0.67^\circ$, paired t-tests, $P < 0.05$). Between-group comparison showed a significant difference in inclination change (independent t-test, $P < 0.001$) (Table 2).

Spearman's correlation analysis revealed a non-statistically significant weak positive correlation between absolute vertical change and absolute inclination change in both the TAD-supported fixed appliance group ($r = 0.17$, $P > 0.05$) and the clear aligner group ($r = 0.15$, $P > 0.05$) (Figure 4).

Discussion

It is important to note that this study compared two fundamentally different treatment protocols: an active approach involving direct posterior intrusion with TAD-supported coil springs, and a passive approach using clear aligners that relied on posterior occlusal coverage, a squeezing exercise, and simultaneous anterior extrusion. Thus, the superior inclination control demonstrated in the aligner group should be interpreted in the context of an absence of direct intrusive force applied to the maxillary molars.

The study demonstrated that the group treated with TAD-supported fixed appliances achieved significantly greater vertical intrusion of the maxillary first molars than the group treated with clear aligners.

However, the results revealed a greater amount of crown tipping in the TAD-supported fixed appliance group compared to the clear aligner group. In addition, the amount of tipping was not correlated with the amount of vertical change.

These findings can be explained by the distinct biomechanics of the two treatment protocols. In the TAD-supported group, direct and continuous intrusive forces were applied from a mid-palatal miniscrew to palatal TPA hooks, producing greater vertical intrusion but also a higher tendency for molar inclination changes. In contrast, the clear aligner group relied on full occlusal coverage, programmed anterior extrusion, and a squeezing exercise without posterior attachments, which limited the amount of vertical intrusion but provided better control of molar inclination. When interpreting the weak, non-significant correlations observed between vertical and inclination changes ($P \approx 0.15 - 0.17$), it should be recognized that each appliance generated different combinations of vertical and horizontal force vectors. As a result, intrusion and tipping did not necessarily occur together, and the correlations reflect appliance-specific mechanics rather than a universal relationship.^{12-14,18-20}

The observed palatal tipping in the fixed appliance group can be explained by the palatal positioning of the midpalatal TADs, which likely caused the intrusive force vector to pass palatal to the center of resistance of the maxillary molars. This misalignment between the force vector and the center of resistance generates a moment around the root apex, resulting in palatal crown inclination, although a TPA was employed to reinforce transverse anchorage and assist in controlling molar inclination. Moreover, the rigidity of the band material, the precise fitting of the bands, and the type of cementation may also play a role in the control of the arch width and molar inclination.

Another anatomical factor that may have contributed to the palatal tipping observed in the TAD group is the depth of the palatal vault. When the palate is deeper, the intrusive force vector from

the mid-palatal TAD to the TPA hooks becomes more oblique relative to the palatal plane, thereby increasing its horizontal component and the resulting moment that promotes palatal crown inclination if not adequately counteracted by the stiffness of the TPA.^{8,12} Although palatal depth was not measured in this study, such variability could partly explain the degree of tipping recorded. Future studies should therefore incorporate palatal depth as a covariate, and its omission here is recognized as a limitation.

Studies show that stainless steel wires, particularly those with a diameter larger than 1.2 mm, offer better anchorage control than more elastic alternatives like TMA, reducing unwanted movements.^{8,21,22} Thicker wires used with TADs help minimize torque and tipping, while fully cast or 3D-printed TPAs provide superior control due to better crown adaptation.²³ It is likely that the use of 0.9 mm stainless steel wire with preformed stainless steel bands to fabricate the TPA in the present study could not withstand the intrusive force of 150 gm/side produced by NiTi closed-coil springs. Further investigations are needed to identify the optimal TPA design and material for effective inclination control.

In contrast to the mechanical rigidity provided by TAD-supported appliances, the design of clear aligners introduces a different form of vertical control. The 1-mm thermoplastic shell acts like a posterior bite-block, redistributing occlusal forces along the long axis of the teeth and limiting further eruption. When combined with the prescribed squeezing exercise, this occlusal coverage likely accounted for the modest amount of molar intrusion achieved in the aligner group, even in the absence of posterior attachments.^{14,18–20}

The designed clear aligner in the present study had attachments on six maxillary anterior teeth, with none on the posterior teeth. Therefore, the intrusion of the maxillary first molars was due to two possible factors: daily occlusal force directed onto the posterior occlusal coverage and squeezing exercise.

Although no posterior attachments or distalization mechanics were included in this protocol, buccal tipping of the maxillary molars was still observed. This can be attributed to the inherent flexibility of the aligner material and the tendency of force vectors to deviate from the tooth's center of resistance. Previous studies on distalization with aligners have reported buccal torque and distal crown tipping of molars.¹³ The present finding of buccal inclination under a vertical-only protocol suggests that similar side effects can arise, though to a lesser extent. Therefore, comparisons with distalization studies should be made with caution, recognizing the differences in force direction and attachment design.

Molar tipping during maxillary intrusion with clear aligners is primarily due to biomechanical limitations such as misaligned force vectors, the flexibility of thermoplastic materials, and the design or absence of attachments.^{24,25} Since clear aligners forces often fail to pass through the tooth's center of resistance, unwanted rotational moments lead to crown tipping rather than true intrusion.¹⁸ The elastic nature of clear aligners also reduces force precision, compromising vertical control.^{18,19} Finite element studies show that symmetrical attachment placement improves torque control, whereas buccal-only attachments increase buccal tipping.¹⁸ The buccal tipping observed in the present study is consistent with previous reports, which have attributed this phenomenon to aligner deformation and insufficient root control, particularly in the absence of skeletal anchorage.^{18–20} Nevertheless, the relatively reduced inclination change in the clear aligner group may reflect the benefits of full occlusal coverage and anterior attachments, which may have helped distribute intrusive forces more evenly and minimized uncontrolled molar tipping.

In the present study, the reduced inclination change in the clear aligner group may be attributed to full occlusal coverage and anterior attachments, which helped limit uncontrolled posterior force transmission.

The stabilizing effect of anterior attachments is particularly important in this context. By improving retention and reducing deformation of the anterior portion of the clear aligners, these attachments allow forces to be transmitted more consistently across the arch and help to counteract unwanted posterior moments. This mechanism likely explains why the clear aligner group in the present study exhibited smaller overall inclination changes despite achieving only limited absolute intrusion.¹⁸⁻²⁰ In addition to the effects of full occlusal coverage and anterior anchorage, the scheduled replacement of aligners at three-week intervals may also enhance inclination control. Each new, undeformed appliance effectively resets the material's stiffness and geometry, thereby reducing deformation-related moments and minimizing the accumulation of buccal tipping over time.

From a clinical perspective, these findings highlight the importance of appliance design in controlling molar inclination. For TAD-supported intrusion, modifications such as lowering hook positions, shortening lever arms, and employing stiffer TPAs (casted or 3D-printed) may help minimize palatal crown tipping. For aligner therapy, strategic use of posterior attachments or auxiliary anchorage should be considered when greater vertical change is required, while full occlusal coverage combined with anterior attachments remains crucial for maintaining inclination control.^{8,12,20}

To optimize vertical control and reduce molar tipping during intrusion, clinicians should focus on precise attachment placement, use biomechanically effective designs, and incorporate auxiliary anchorage like TADs when needed. Anchorage design and adjunctive appliances significantly influence both the extent of intrusion and the direction of tooth movement. TAD-supported fixed appliances offer superior vertical control, especially when combined with TPAs to manage inclination. In contrast, clear aligners, while limited in achieving deep intrusion, can provide better inclination control when properly designed.

The amount of vertical change may not be a contributor to the amount of inclination change, according to the Spearman rank correlation analysis. These results suggest that tipping and intrusion may occur independently, influenced by appliance-specific mechanics and patient-specific responses. Emphasis on precise force control is essential, and future studies incorporating larger samples and 3D simulations are recommended to enhance understanding of these interactions.

Despite these insights, several limitations of the present study should be acknowledged. Palatal depth, variability in TPA rigidity, and patterns of occlusal contact during the squeezing exercise were not quantified, yet each of these factors could influence the horizontal force component and thereby affect molar inclination. Finally, the six-month observation period and the vertical-only aligner protocol restrict the direct comparability of our findings with studies that investigated longer treatment durations or included distalization mechanics and posterior attachments.

Conclusion

This study found that TAD-supported fixed appliances achieve more effective vertical intrusion of maxillary first molars than clear aligners in adult AOB patients, while clear aligners offer better control of molar inclination. The results highlight the need to tailor treatment based on biomechanical demands, using skeletal anchorage and TPAs for vertical control, and precise aligner design for inclination stability. Further long-term studies are needed to refine AOB treatment protocols.

Author contributions

Karnrawee Rangsitsathian: Conceptualization, Methodology, Data curation, Formal analysis, Writing – Original draft preparation; **Chanchai Pattanaviriyapisan:** Supervision, Validation; **Udom Thongudomporn:** Supervision, Validation, Writing – Reviewing and Editing.

Ethical statement

The study received ethical approval from the Human Research Ethics Committee of the Faculty of Dentistry, Prince of Songkla University (Approval No.EC6711-047). All procedures complied with institutional and national ethical guidelines and adhered to the principles outlined in the Declaration of Helsinki.

Disclosure statement

The authors have no conflict of interest.

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AI-assisted writing declaration

The authors used ChatGPT (OpenAI, GPT-5 series) solely for language editing and manuscript refinement. All scientific content was developed and verified by the authors, who take full responsibility for the accuracy, integrity, and originality of the manuscript.

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References

1. Lopez-Gavito G, Wallen TR, Little RM, Joondeph DR. Anterior open-bite malocclusion: a longitudinal 10-year postretention evaluation of orthodontically treated patients. *Am J Orthod* 1985;87(3):175–86.
2. Kuroda S, Sakai Y, Tamamura N, Deguchi T, Takano-Yamamoto T. Treatment of severe anterior open bite with skeletal anchorage in adults: comparison with orthognathic surgery outcomes. *Am J Orthod Dentofacial Orthop* 2007;132(5):599–605.
3. Xun C, Zeng XL, Wang X. Clinical application of mini-screw implant anchorage in the treatment of skeletal anterior open bite. *Angle Orthod* 2007;77(1):47–56.
4. Erverdi N, Keles A, Nanda R. The use of skeletal anchorage in open-bite treatment: a cephalometric evaluation. *Angle Orthod* 2004;74(3):381–90.
5. Yao CC, Lee JJ, Chen HY, Chang ZC, Chang HF, Chen YJ. Maxillary molar intrusion with fixed appliances and mini-implant anchorage studied in three dimensions. *Angle Orthod* 2005;75(5):754–60.
6. Kawamura J, Park JH, Tamaya N, Oh JH, Chae JM. Biomechanical analysis of the maxillary molar intrusion: a finite element study. *Am J Orthod Dentofacial Orthop* 2022;161(6):775–82.
7. Park HS, Jang BK, Kyung HM. Maxillary molar intrusion with micro-implant anchorage (MIA). *Aust Orthod J* 2005;21(2):129–35.
8. Tangsumroengvong V, Patanaporn V, Rungsiyakul C, Chalermwong H. Intrusion of maxillary posterior teeth with miniscrew anchorage: a finite element study. *CM Dent J* 2021;42(1):91–101.
9. Ritchie C, McGregor S, Bearn DR. Temporary anchorage devices and the forces and effects on the dentition and surrounding structures during orthodontic treatment: a scoping review. *Eur J Orthod* 2023;45(3):324–37.
10. Withayanukonkij W, Chanmanee P, Promsawat M, Viteporn S, Leethanakul C. Root resorption during maxillary molar intrusion with clear aligners: a randomized controlled trial. *Angle Orthod* 2024;94(5):629–37.
11. Tasanapanont J, Wattanachai T, Apisariyakul J, Pothacharoen P, Ongchai S, Kongtawelert P, et al. Biochemical and clinical assessments of segmental maxillary posterior tooth intrusion. *Int J Dent* 2017;2017:1–6.
12. Wang X, Zhao Y, Fan M, Zhou T, Fang B, Ye N. Effects of transpalatal arch wire dimension and temporary skeletal anchorage device position on maxillary molar intrusion. *Angle Orthod* 2024;94(4):408–13.
13. Miao Z, Zhang H, Yang Y, Han Y, Leng J, Wang S. Influence of maxillary molar distalization with clear aligners on three-dimensional direction: molar distal movement, intrusion, distal tip and crown buccal torque. *Prog Orthod* 2023;24(1):18.
14. Papadimitriou A, Mousouleas S, Gkantidis N, Kloukos D. Clinical effectiveness of Invisalign® orthodontic treatment: a systematic review. *Prog Orthod* 2018;19(1):37.
15. World Medical Association. Declaration of Helsinki:

- ethical principles for medical research involving human subjects. *JAMA* 2013;310(20):2191–4.
16. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods* 2007;39(2):175–91.
 17. Dahlberg G. Statistical methods for medical and biological students. *Br Med J* 1940;2:358–9.
 18. Rossini G, Parrini S, Castroflorio T, Deregibus A, Debernardi CL. Efficacy of clear aligners in controlling orthodontic tooth movement: a systematic review. *Angle Orthod* 2015;85(5):881–9.
 19. Talens-Cogollos LM, García-Sanz V, Paredes-Gallardo V, Cibrián R, Gandía JL, Peñarrocha-Diago M. Influence of attachment shape and placement on molar movement with aligners: a finite element study. *J Clin Exp Dent* 2021;13(3):e252–9.
 20. Harris K, Ojima K, Dan C, Upadhyay M, Alshehri A, Kuo CL, et al. Evaluation of open bite closure using clear aligners: a retrospective study. *Prog Orthod* 2020;21(1):23.
 21. Vilamas K, Leethanakul C. The root length change in posterior teeth intrusion in anterior open bite patient. *Proc Multidiscip Res* 2024;2(5):59.
 22. Kravitz ND, Kusnoto B, Begole E, Obrez A, Agran B. How well does Invisalign work? A prospective clinical study evaluating the efficacy of tooth movement with Invisalign. *Am J Orthod Dentofacial Orthop* 2009;135(1):27–35.
 23. Hoederath H, Bourauel C, Drescher D. Differences between two transpalatal arch systems upon first-, second-, and third-order bending activation. *J Orofac Orthop* 2001;62(1):58–73.
 24. Crismani AG, Celar AG, Burstone CJ, Bernhart TG, Bantleon HP, Mittlboeck M. Sagittal and vertical load-deflection and permanent deformation of transpalatal arches connected with palatal implants: an in-vitro study. *Am J Orthod Dentofacial Orthop* 2007;131(6):742–52.
 25. Rebellato J. Two-couple orthodontic appliance systems: transpalatal arches. *Semin Orthod* 1995;1(1):44–54.