

TJO

Thai Journal of Orthodontics



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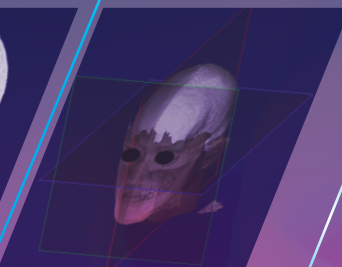
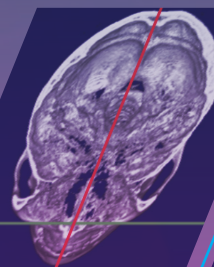
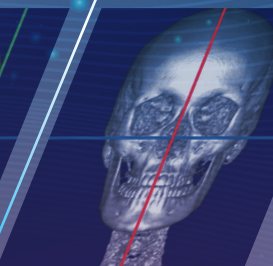
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Control of Maxillary First Molar Inclination during Intrusion Using TAD-Supported Fixed Appliances versus Clear Aligners in Anterior Open Bite Correction

Karnrawee Rangsitsathian* Chanchai Pattanaviriyapisan** Udom Thongudomporn***

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.

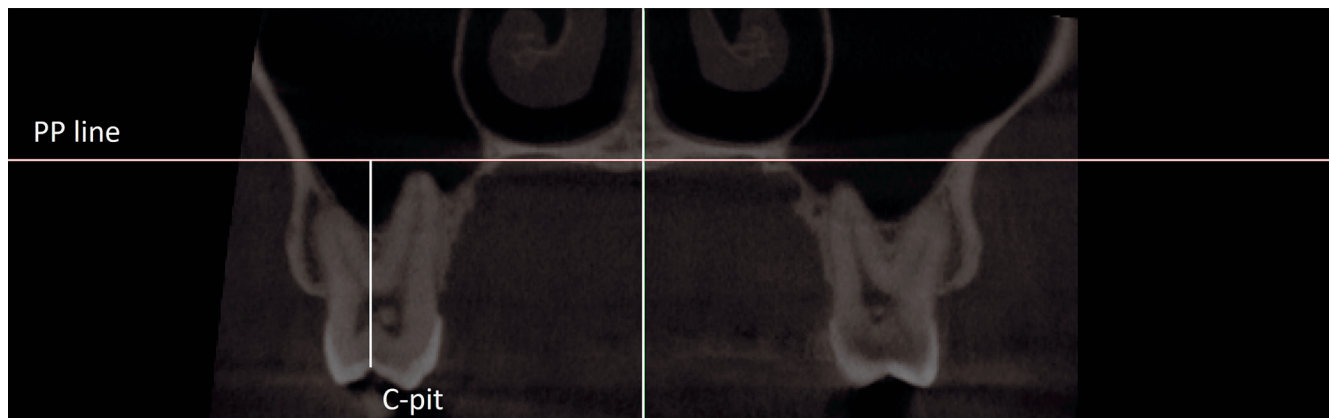


Figure 1 Measurement of vertical distance change.

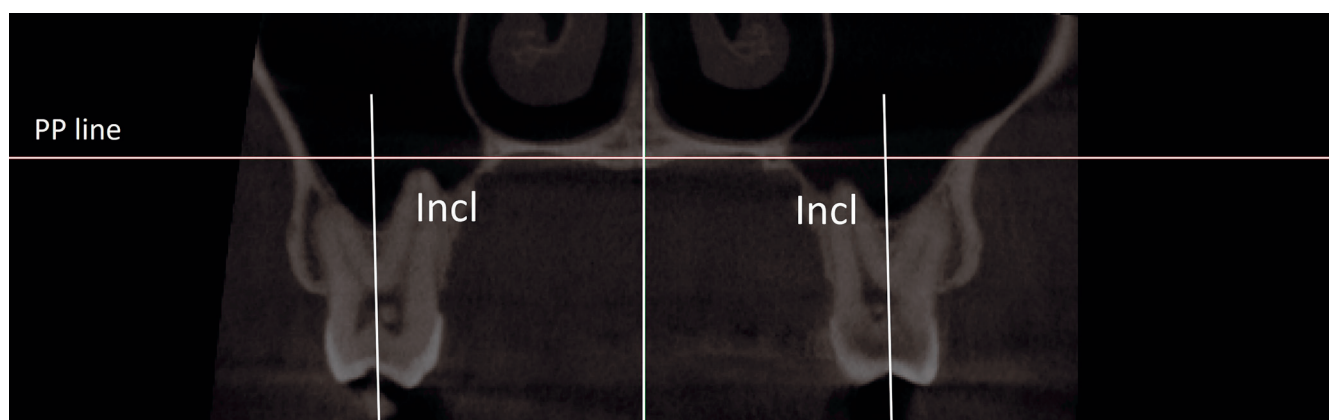


Figure 2 Measurement of molar inclination change.

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).

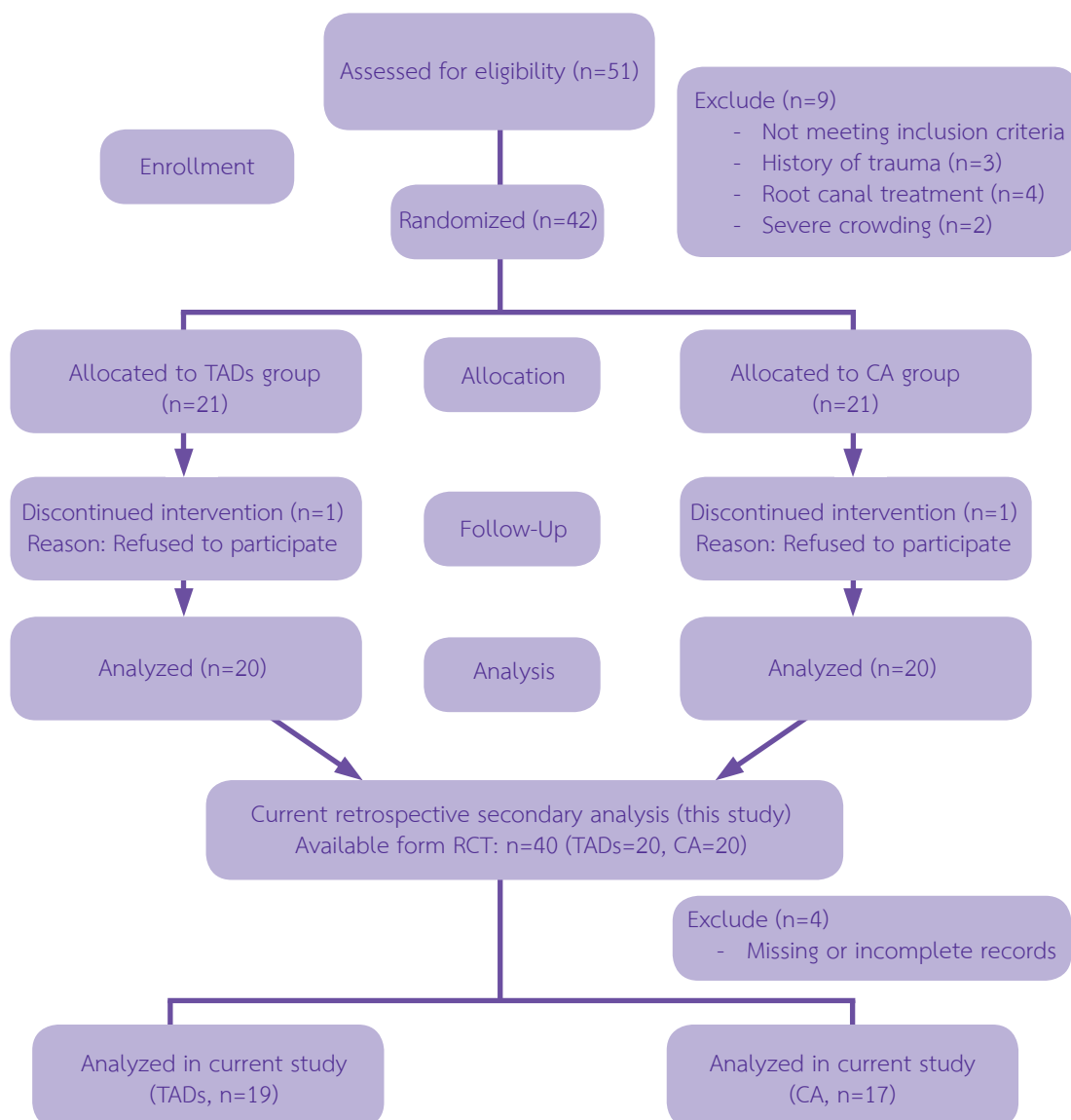


Figure 3 CONSORT (consolidated standards of reporting trials) flow diagram.

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. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

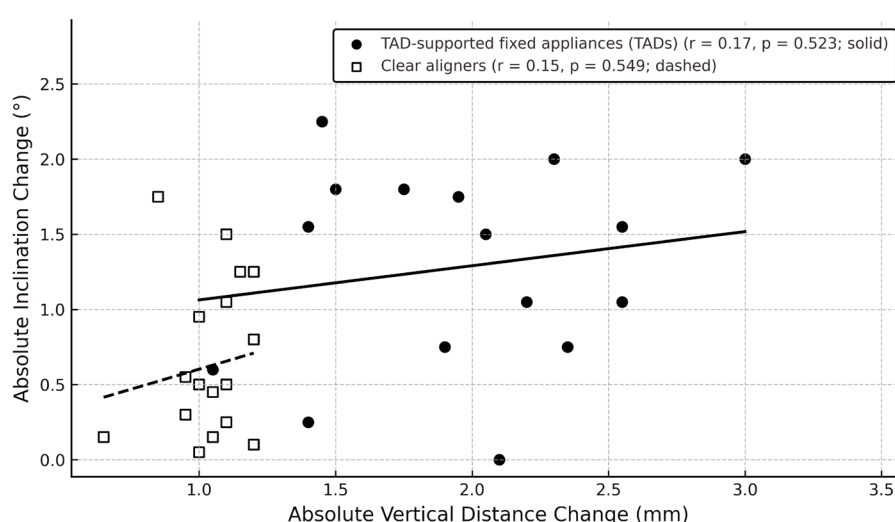


Figure 4 Correlation between absolute vertical distance change (mm) and absolute inclination change ($^{\circ}$) of maxillary first molars in the two appliance groups.

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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Comparison of Convolutional Neural Networks Architectures for Screening Mandibular-Plane-to-Hyoid Distance as a Risk Indicator of Obstructive Sleep Apnea on Lateral Cephalograms

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Abstract

Background: Lateral cephalometric radiographs can aid in screening obstructive sleep apnea (OSA) through the mandibular-plane-to-hyoid (MP-H) distance. An automated tool based on this measure could support OSA screening. However, the accuracy of such tools depends on the performance of AI-assisted models, making it essential to evaluate and compare their effectiveness in detecting MP-H distance for reliable clinical application. **Objective:** To evaluate the performance of different convolutional neural network (CNN) architectures in classifying patients into short and long MP-H groups. **Materials and methods:** A total of 304 pre-orthodontic lateral cephalometric radiographs from adults (age 18-56 years) were classified into short MP-H (< 18 mm) and long MP-H ($\geq$ 18 mm) groups. Four CNN architectures (DenseNet-121, ResNet-50, EfficientNet-B0, and MobileNetV3) were trained to classify short and long MP-H groups. To address class imbalance, weighted binary cross entropy loss functions (weights ranging from 1 to 5) were applied, assigning greater penalties to misclassification of the minority class. **Results:** In the scenario without application of weighted cross entropy loss, DenseNet-121 achieved the overall high screening performance, with sensitivity = 0.87, specificity = 0.95, precision = 0.79, F1-score = 0.82, accuracy = 0.93, AUROC = 0.91, and AUPRC = 0.83. MobileNetV3 consistently demonstrated the lowest performance. Weighted loss functions provided inconsistent benefits across architectures. DenseNet-121 showed consistent performance among all weights. **Conclusion:** DenseNet-121 shows potential of screening long MP-H distance from lateral cephalograms. Weighted loss functions may provide improvements, but model selection remains the more critical factor.

Keywords: Cephalometry, Convolutional neural networks, Hyoid bone, Mandible, Sleep apnea

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Introduction

Obstructive sleep apnea (OSA), a multifactorial disorder, is characterized by recurrent episodes of partial (hypopnea) or complete (apnea) upper airway obstruction during sleep.¹ The prevalence of OSA in the Thai population has been reported to be 11.40 % with gender variation of 15.40 % in men and 6.30 % in women.² The standard diagnostic procedure for OSA is polysomnography (PSG), a comprehensive sleep study, which aids in classifying OSA severity based on the Apnea-Hypopnea Index (AHI). It quantifies the average number of apnea and hypopnea events per hour of sleep. The severity of OSA is classified into three categories: mild ($5 \leq \text{AHI} < 15$) moderate ($15 \leq \text{AHI} < 30$), and severe ($\text{AHI} \geq 30$).¹

Orthodontists are involved in the early screening of OSA, as they often see patients who have risk factors and craniofacial features linked to the condition. However, it is not practical to refer all patients without symptoms for a full PSG. Also, PSG availability is often restricted to large hospitals equipped with specialized sleep centers, and the associated costs can be considerable. Normally, dentists are positioned to screen and detect potential patients with an examination and screening questionnaire before referral.³

Lateral cephalometric radiographs offer a non-invasive method for identifying anatomical risk factors related to OSA. By analyzing specific anatomical structures, orthodontists can gain valuable insights into a patient's airway morphology, potentially serving as a cost-effective and efficient initial screening tool.⁴

Several cephalometric anatomical parameters have been reported in association with OSA, including reduction in posterior airway space, enlargement and elongation of uvula, increased tongue size, alteration in cranial base length and angulation, maxillomandibular size and anteroposterior position, increase in anterior lower facial height (ALFH), and hyoid bone position.^{5,6} Nevertheless, evidence from a recent systematic review

indicates that, among these variables, only an increased ALFH, a reduced pharyngeal airway space, and an inferiorly displacement of hyoid bone demonstrated consistent associations with OSA in adult subjects, with negligible heterogeneity across studies.⁶

Hyoid bone is a crucial structure for maintaining airway patency as it anchors several muscles.⁷ The maintenance of pharyngeal airway patency involves at least four muscle groups: the hyoid muscles (the mylohyoid and geniohyoid), which facilitate anterior movement of the hyoid; the muscles of the soft palate, such as the tensor palatini; the pharyngeal constrictor muscles; and the muscles of the tongue, all of which collectively contribute to the dilation or narrowing of the pharynx.⁸

A lower position of the hyoid bone was related to greater mandibular-plane-to-hyoid (MP-H) distance which was reported to be reliability parameter associated in determining severity of OSA.⁹⁻¹¹ Significant variations in MP-H have been observed among patients with different degrees of OSA severity.⁹ The MP-H cutoff values were varied depending on the studied population. In the Thai population, an MP-H cutoff value of ≥ 18 mm is associated with an increased risk of an $\text{AHI} \geq 15$, indicating moderate-to-severe OSA (AUROC = 0.65-0.86).⁹ A study examined the association between hyoid bone position and OSA severity in 133 Korean patients with an $\text{AHI} \geq 5$. A threshold value of 19.45 mm (AUROC = 0.62) was identified as predictive of increased OSA severity, including higher frequency of respiratory events, reduced oxygen saturation, and interrupted sleep patterns.¹⁰ Another study reported a MP-H distance of more than 15.40 mm could indicate OSA in American patients.¹² In Iranian population, a MP-H distance of 14 mm correlated with moderate OSA (AUROC = 0.98).¹³ While in Swedish population, the MP-H distance of greater than 22.80 mm was found in patients with OSA.¹⁴ Although, the cutoff value varied among different population, it was confirmed that the longer the MP-H distance or the more inferior the hyoid

bone placed was associated with OSA severity regardless of ethnicities.⁹⁻¹¹ While multiple craniofacial features may contribute to OSA pathophysiology, inferiorly displaced hyoid represented the most robust and reproducible cephalometric landmark. To clarify, soft tissue landmarks used to indicate airways are often obscured in radiographs due to superimposed structures, making them less reliable. Hence, bony landmarks provide orthodontists with more dependable reference points.¹⁵

Computer vision, employing convolutional neural networks (CNN), enables machines to efficiently process and interpret visual data. In image classification, algorithms identify the objects presented within an image by analysing features such as color, shape, and edges to distinguish between different object classes.¹⁶

Developing an automated diagnostic tool to differentiate patients based on MP-H distance in lateral cephalometric radiographs could be beneficial for screening, early detection and diagnosis and then referred for further investigation. Our study used MP-H as OSA screening parameter as the MP-H distance may serve as an additional diagnostic tool for the screening of severe OSA. The objective of this study was to evaluate the image classification performance of different CNN models in classifying patients by the 18-mm MP-H cutoff using adult pretreatment lateral cephalometric radiographs.

Materials and methods

A total of 304 pre-orthodontic treatment lateral cephalometric radiographs of adults were collected from a private dental clinic in Uttaradit, Thailand. The digital formats of the radiographs were gathered from Orthophos XG 5 DS Ceph (Dentsply, Sirona) radiographic machines and exported as JPEG format (.jpg) with a resolution of 1804 × 2136 pixels. The inclusion criteria included pretreatment lateral cephalograms from orthodontic patients with

permanent dentition (aged 18 years or older). All patients were asymptomatic for OSA and undiagnosed. Patients' information, including gender, date of birth, and date of radiograph being taken, were collected. Lateral cephalograms with improper image quality, poor visual image quality, including brightness, contrast, and noise, poor geometric image quality, including distortion, artifacts, and blur were excluded. Also, patients with a history of head and neck trauma who had been diagnosed with head and neck tumors or cancers and had undergone head and neck surgery were also excluded. All images were manually labeled with Labelme, an open-source image labeling tool.¹⁷ Main examiner (Examiner A) was standardized with an experienced radiologist (Examiner B), and an experienced orthodontist (Examiner C). The annotated landmarks and related measurements were presented in Figure 1.

An interexaminer reliability among three examiners was performed. After one month, the intraexaminer reliability between the first and second trials of the main examiner was performed one month apart to check reproducibility for human ground teeth MP-H distance using intraclass correlation coefficient.

In this study, the short and long MP-H groups were defined based on an 18 mm cutoff value, which was proposed by Banhiran et al. as being correlate with moderate-to-severe OSA in Thai population.⁹ Therefore, the samples with MP-H less than 18 mm were labelled as short MP-H group, those over 18 mm as long MP-H group.

Kolmogorov-Smirnov and Shapiro-Wilk tests were performed to check for normal distribution of data characteristics (age, gender, skeletal classification, divergent pattern, and MP-H distance) in training, validating and test group. All collected data were partitioned using stratified random sampling based on gender and MP-H groups into training, validation, and test sets, with ratios of 0.70, 0.15, and 0.15, respectively. The training set was used to train the models. The validation set was used to optimize

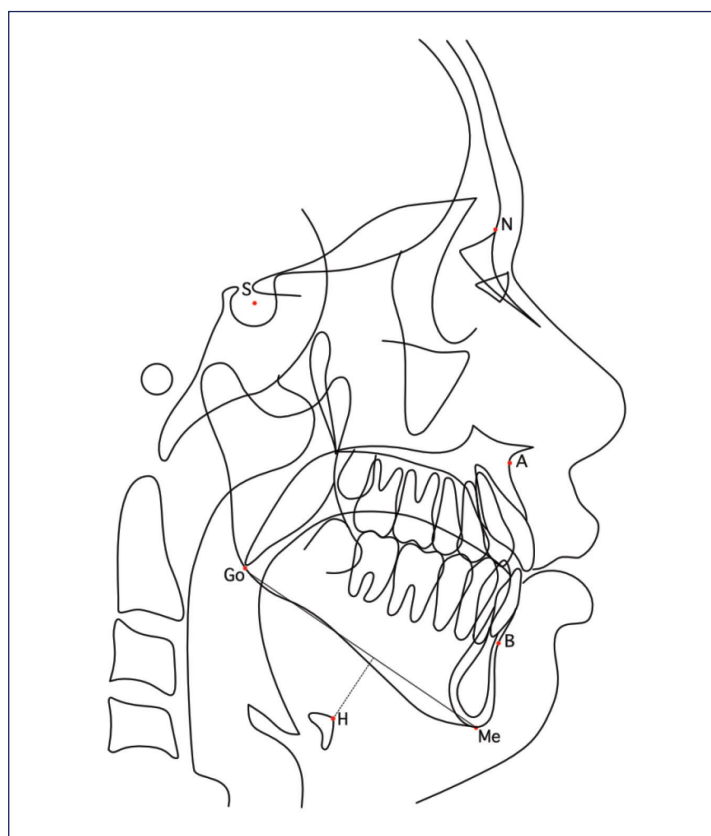


Figure 1 The annotated landmarks included S (Sella), N (Nasion), A (Point A), B (Point B), Go (Gonion), Me (Menton), and H (Hyoidal - the most anterosuperior point of hyoid bone) The SNA, SNB, SN-GoMe angles, and MP-H distance were measured. The ANB and SN-GoMe angle were used to analyze the skeletal classification and divergent pattern of the patients consecutively. The mandibular plane (MP) was constructed using line passing through Go-Me. The MP-H was measured in millimetres by constructing a line from H perpendicular to MP line.

the hyperparameters of a classifier during the training process. Finally, the test set was used to evaluate the performance of the models. For the image preprocessing, the collected radiographs were pre-processed using an automated segmentation pipeline to eliminate non-informative white borders. Using the OpenCV library, a dynamic threshold was established for each image based on the 60th percentile of its pixel intensity distribution to remove peripheral white borders. To standardize the dataset for downstream analysis, images were centrally zero-padded to a uniform dimension of 2037×2037 pixels. This approach preserved the original aspect ratio and spatial integrity of the samples while ensuring a consistent input architecture. Finally, these standardized images

were resized to 224×224 pixels before subsequent processing through the deep learning models (Figure 2). In addition, during the training process, image transformations were applied to the training data as data augmentation, enhancing the model's ability to generalize to unseen data. Augmentation techniques included adding Gaussian noise and rotating images $\pm 10\%$. For the training parameters, model training was performed using the AdamW optimizer with an initial learning rate of 1×10^{-3} and a weight decay of 10×10^{-4} . A OneCycle learning rate scheduling strategy was applied, with the maximum learning rate set to 1×10^{-3} . Thirty percent of the total training steps were allocated to the warm-up phase, followed by cosine annealing. The learning rate was

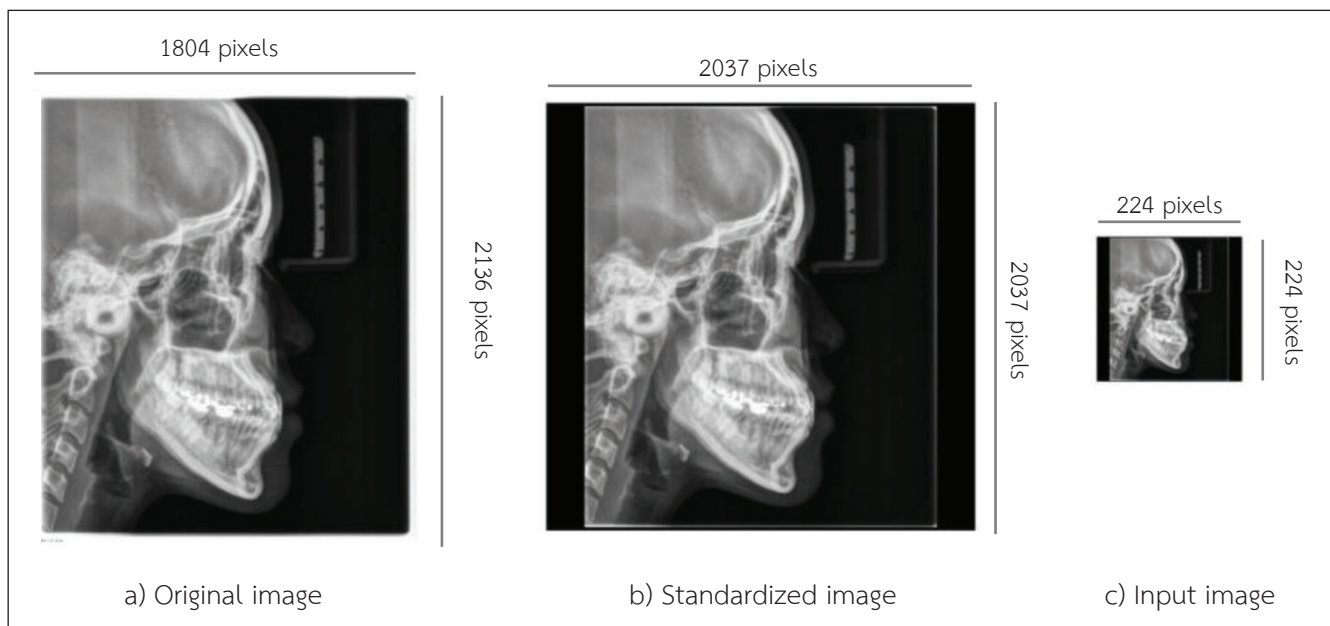


Figure 2 Preprocessing workflow of lateral cephalometric images for CNN input

initially reduced using a division factor of 25 and further decreased with a final division factor of 1×10^4 . All models were trained for a maximum of 100 epochs with a batch size of 64. Early stopping with a patience of 10 epochs was employed to terminate training when no further performance improvement was observed.

Four CNN models, including DenseNet-121, ResNet-50, EfficientNet-B0 and MobileNetV3, were utilized to classify images into risk assessment as either short MP-H or long MP-H group following Thai MP-H cutoff value. Due to the existing constraints in knowledge concerning the most suitable deep learning architecture for airway classification problem, a variety of models were selected. These models represent different methodological approaches designed to improve image classification accuracy, enabling a comprehensive assessment of model performance within this framework. DenseNet, ResNet, EfficientNet architectures were used by previous researchers in CNN-aided airway image classification and landmark detection.^{15,18,19} However, the inclusion of MobileNetV3, a lightweight model, was intended to explore potential use in clinical environments with limited computational resources. Each of these models

uses a unique approach to feature extraction and efficiency. DenseNet-121 (approximately 8 million parameters), invented by Cornell University & Facebook AI Research in 2017, improves feature propagation and reuse by densely connecting each layer to every other layer within a block. It connects each layer to all subsequent layers, promoting feature reuse and improving parameter efficiency.²⁰ ResNet-50 (approximately 25.60 million parameters), developed by Microsoft research in 2016, utilizes residual learning through shortcut connections to bypass layers, solving the vanishing gradient problem, and enabling deeper networks training with high accuracy. Its deep architecture excels at extracting rich, multi-scale features.²¹ EfficientNetB0 (approximately 5 million parameters), proposed by Google brain in 2019, employs a compound scaling method that uniformly scales the network's depth, width, and resolution, achieving a superior balance between accuracy and computational efficiency.²² Finally, MobileNetV3 (approximately 5 million parameters), introduced by Google AI in 2019, is a lightweight and efficient model designed for mobile devices, making it suitable for applications with limited computational resources.²³ Multiple studies reported

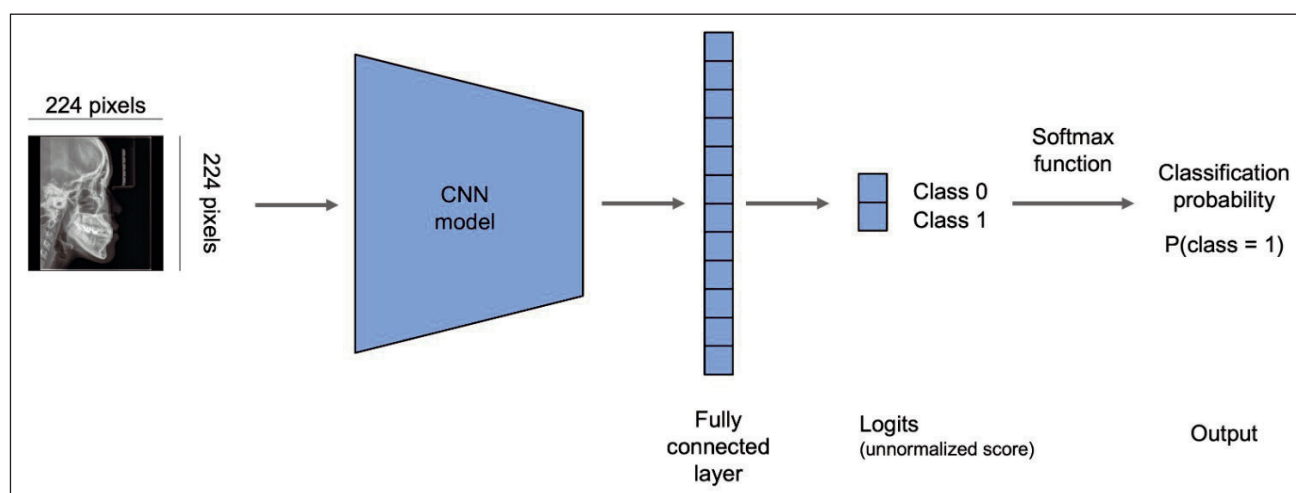


Figure 3 Schematic overview of the CNN-based binary classification workflow

using CNN models to screen patients with OSA or with potential airway obstruction from lateral cephalometric radiographs through image classification with distinct accuracy.^{18,19,24} The overall workflow of CNN models are demonstrated in Figure 3.

The binary cross-entropy loss function was used for the training process. However, as samples classified as long MP-H had relatively low number compared to group with short MP-H, contributed to an imbalanced dataset. Therefore, we further investigated the strategy to deal with image classification task with imbalanced dataset. In this study, we labelled the short MP-H group as class 0 and the long MP-H group as class 1, with class 1 being the minority class in our dataset. Normally, binary cross entropy (CE) loss can be calculated following formula:

$$\mathcal{L}_{CE} = -[y \log(p) + (1-y) \log(1-p)]$$

Where;

y is defined as the true label class which is 0 or 1 representing class 0 or 1, respectively.

p is defined as the predicted probability for class 1, which value ranging from 0 to 1 ($0 < P < 1$).

As we are dealing with the class imbalanced data due to low prevalence of OSA; therefore, we employed the weighted binary cross entropy (WCE) loss in the experiment which can be described as follow:²⁵

$$\mathcal{L}_{WCE} = -[w_1 y \log(p) + w_0 (1-y) \log(1-p)]$$

Where;

w_1 = weight for class 1

w_0 = weight for class 0

As the weight for class 1 and class 0 could be determined differently, we assigned more weight to the minority class. This resulted in more penalties in the training process, when the models predicted the minority class incorrectly. To mitigate class imbalance commonly observed in disorders with low prevalence, we explore the ratio for w_0 and w_1 for training the model with class imbalanced dataset. The class-weight ratios applied for w_0 and w_1 were [1, 5], [1, 4], [1, 3], [1, 2], and [1, 1]. This approach aimed to determine appropriate penalization for incorrectly screening long MP-H cases.

The results from the classification models can be defined as follows:

True Positive (TP): Cases that truly belonged to the long MP-H group and were correctly classified by the model as long MP-H.

True Negative (TN): Cases that truly belonged to the short MP-H group and were correctly classified by the model as short MP-H.

False Positive (FP): Cases that truly belonged to the short MP-H group but are incorrectly classified by the model as long MP-H.

False Negative (FN): Cases that truly belong to the long MP-H group but are incorrectly classified by the model as short MP-H.

A confusion matrix was generated for each model to visualize class-level performance, showing the distribution of true and false classifications between the short and long MP-H groups.

Performance metrics included accuracy, precision, sensitivity (recall), specificity, F1-score, area under the receiver operating characteristic curve (AUROC) and area under the precision-recall curve (AUPRC). To clarify, accuracy is the proportion of correct predictions (both true positives and true negatives) among the total number of cases. Precision is the proportion of positive predictions that are correct. Sensitivity is the proportion of actual positives that are correctly identified. All metrics were calculated based on TP, TN, FP and FN. Moreover, F1 Score is the harmonic mean of precision and recall, providing a single metric that balances the two. Furthermore, AUROC is a measurement for classification models at various threshold levels. The curves were plotted using Matplotlib library, a visualization utility in Python. AUROC represented the overall ability of the model to differentiate between positive and negative classes. The model was interpreted as follows:²⁶

AUROC = 0.50: The model performance is equivalent to random choosing.

$0.50 < \text{AUROC} < 0.70$: The model had a poor performance.

$0.70 \leq \text{AUROC} < 0.80$ is the model with acceptable performance.

$0.80 \leq \text{AUROC} < 0.90$ is the model with excellent performance.

$\text{AUROC} \geq 0.90$ is the model with distinguished performance.

AUPRC serves as a key metric for assessing the performance of classification models, particularly in situations involving imbalanced datasets. The precision-recall curve represents precision on the y-axis and recall on the x-axis across various decision thresholds.

AUPRC provided comprehensive summary of the model's ability to sustain both high precision and recall over the range of thresholds.²⁷ Each model's performance was assessed under all five loss weighting scenarios.

To evaluate the robustness and reliability of our performance metrics, the stratified bootstrap was used to estimate 95 % confidence intervals (CIs) for each model by 1000 iterations. Conduction of bootstrap iterations by randomly sampling with replacement from the set was done. For each resampled dataset, all evaluation metrics were calculated. The 95 % confidence intervals were determined to offer a quantitative assessment of the uncertainty.

Results

The human reliability test of intraexaminer reliability (ICC = 0.97) and interexaminer reliability (ICC = 0.99) of MP-H distance were found to be high. The intraclass correlation coefficient (ICC) value above 0.90 indicated an excellent reliability.²⁸

Of the 304 patients, 210 (69.08 %) were female, and 94 (30.92 %) were male. The mean age was 26.67 ± 7.80 (Min = 18, Max = 56) years. Patients had an average ANB angle of $3.45^\circ \pm 3.17^\circ$ (Min = -6.44° , Max = 12.42°) and SN-GoMe angle of $34.31^\circ \pm 6.31^\circ$ (Min = 20.83° , Max = 59.41°). The mean distance of MP-H was 12.63 ± 5.36 mm (Min = 0.61, Max = 27.62).

Kolmogorov-Smirnov and Shapiro-Wilk tests revealed a normal distribution in SNA, SNB, ANB angle, SN-GoMe angle and MP-H distance among training, validating, and test set ($P > 0.05$). Hence, the data were properly stratified allocation among three datasets. (Table 1).

Confusion matrices of each model under all weighting scenarios are shown in Figure 4, illustrating the class-level prediction outcomes between the short and long MP-H groups. Figure 5 summarize the classification performance of DenseNet-121, ResNet-50, EfficientNet-B0, and MobileNetV3 under

Table 1 Demographic data of all dataset

	Overall dataset (n = 304)	Training dataset (n = 212)	Validating dataset (n = 46)	Test dataset (n = 46)
Short MP-H (n, %)	253 (83.22 %)	177 (83.49 %)	38 (82.61 %)	38 (82.61 %)
Long MP-H (n, %)	51 (16.78 %)	35 (16.51 %)	8 (17.39 %)	8 (17.39 %)
Age (mean $\pm$ SD, years)	26.67 $\pm$ 7.80	26.22 $\pm$ 7.27	28.65 $\pm$ 9.10	26.76 $\pm$ 8.60
Gender				
Female (n, %)	210 (69.08 %)	149 (70.28 %)	31 (67.39 %)	30 (65.22 %)
Male (n, %)	94 (30.92 %)	63 (29.72 %)	15 (32.61 %)	16 (34.78 %)
SNA (mean° $\pm$ SD)	85.21 $\pm$ 3.57	85.20 $\pm$ 3.42	85.43 $\pm$ 3.89	85.09 $\pm$ 3.96
SNB (mean° $\pm$ SD)	81.76 $\pm$ 4.32	81.89 $\pm$ 4.29	81.63 $\pm$ 4.44	81.34 $\pm$ 4.42
ANB (mean° $\pm$ SD)	3.45 $\pm$ 3.17	3.31 $\pm$ 3.38	3.81 $\pm$ 2.55	3.75 $\pm$ 2.67
SN-GoMe (mean° $\pm$ SD)	34.31 $\pm$ 6.31	34.04 $\pm$ 6.36	34.58 $\pm$ 6.84	35.27 $\pm$ 5.54
MP-H Distance (mean $\pm$ SD, mm)	12.63 $\pm$ 5.36	12.68 $\pm$ 5.38	12.50 $\pm$ 4.96	12.51 $\pm$ 5.77

MP-H: Mandibular-plane-to-hyoid bone

SD: Standard deviation

Min: Minimum

Max: Maximum

five class-weight configurations, based on bootstrap-estimated evaluation metrics. When comparing model performance, AUROC served as the primary metric, as it provides a measure of overall discriminative ability. Across all architectures, AUROC values ranged from 0.41 to 0.96. The highest AUROC was obtained with ResNet-50 (weight 4; AUROC = 0.96, 95 % CI 0.88 – 1.00), which also achieved perfect specificity (1.00) and precision (1.00). DenseNet-121 maintained consistently high performance across weight settings, with AUROC values $\geq$ 0.89. EfficientNet-B0 achieved its highest AUROC with weight 4 (0.93, 95 % CI 0.83 – 0.99). MobileNetV3 exhibited substantial variability, with its highest AUROC at weight 5 (0.94, 95 % CI 0.86 – 0.99). Based on the AUROC metric, DenseNet-121 and ResNet-50 achieved excellent to distinguished performance, whereas EfficientNet-B0 showed acceptable to excellent performance. MobileNetV3,

however, exhibited performance ranging from poor to distinguished across weight settings.

However, because the study sample was imbalanced, with comparatively fewer cases of long MP-H, AUPRC was additionally considered, as it better reflects discriminative performance under class imbalance and is less sensitive to the predominance of negative cases. Among all models, AUPRC values ranged from 0.19 to 0.90. With ResNet-50, weight = 4 had the highest AUPRC of 0.90 (95 % CI 0.73 – 1.00) followed by Densenet-121, weight = 3 with AUPRC of 0.88 (95 % CI 0.67 – 1.00). Both maintained an excellent performance. Notably, DenseNet-121 demonstrated consistently stable performance across all weighting scenarios. The model achieved AUROC values ranging from 0.89 to 0.92 and AUPRC values from 0.83 to 0.88.

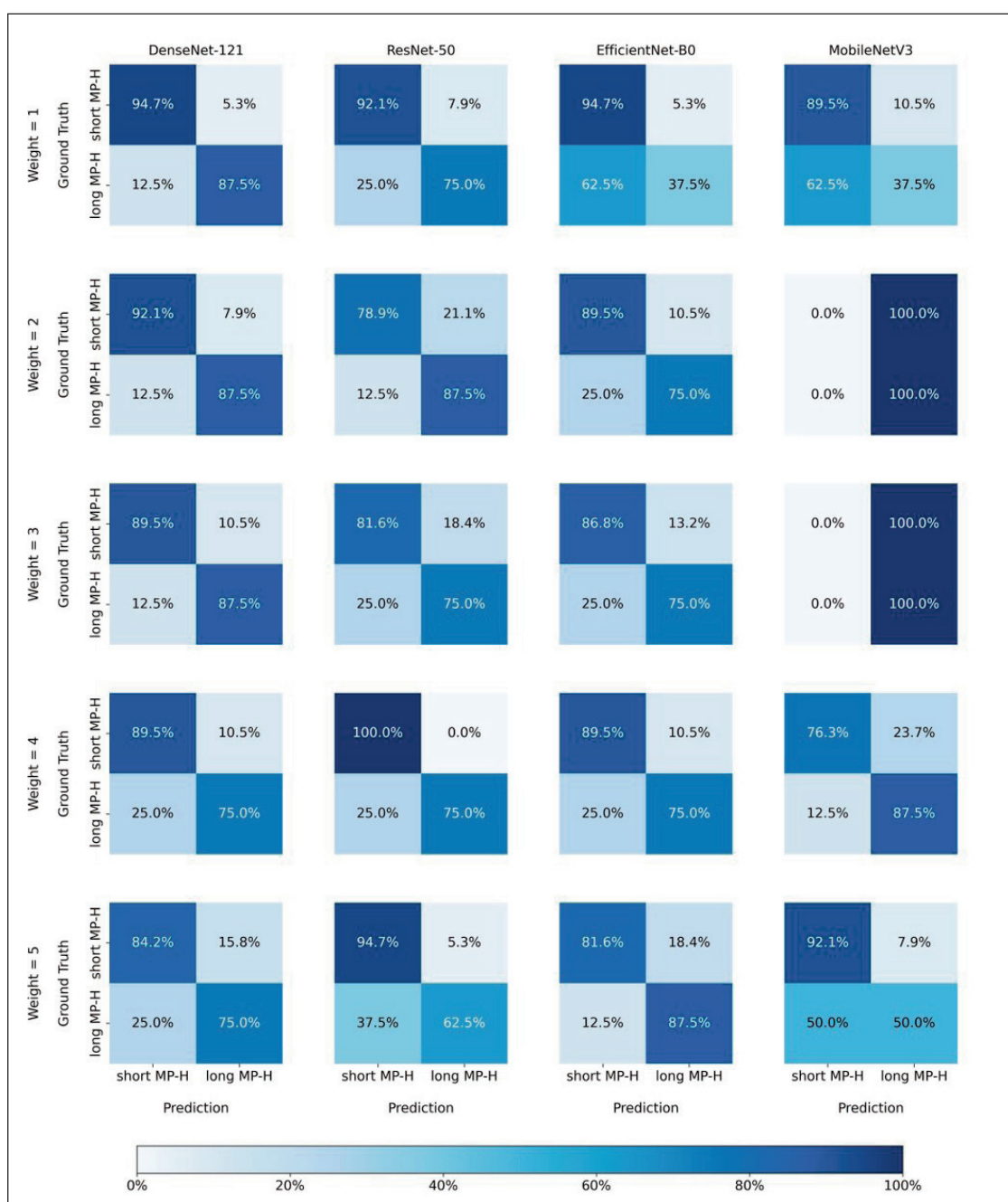


Figure 4 Confusion matrix of DenseNet-121, ResNet-50, EfficientNet-B0, and MobileNetV3 with varying weights (from 1 to 5). ChatGPT 5.5 (OpenAI) was used to assist with the development of the Python code for development of the figure.

Discussion

Assessment of the risk for OSA is considered essential for formulating an effective treatment plan, as undiagnosed or underestimated cases may lead to inadequate management of the condition.³ The study could lead to a development of a beneficial screening tool for dentists to detect possible risk. This study demonstrated the feasibility of employing CNN

models to classify patients into short or long MP-H based on the measurement of the MP-H distance in lateral cephalometric radiographs. The proposed approach demonstrates the potential of AI-assisted imaging analysis as an automated screening tool for OSA risk assessment adjunct to questionnaire, offering advantages over conventional manual measurements, which are often time-consuming and susceptible to

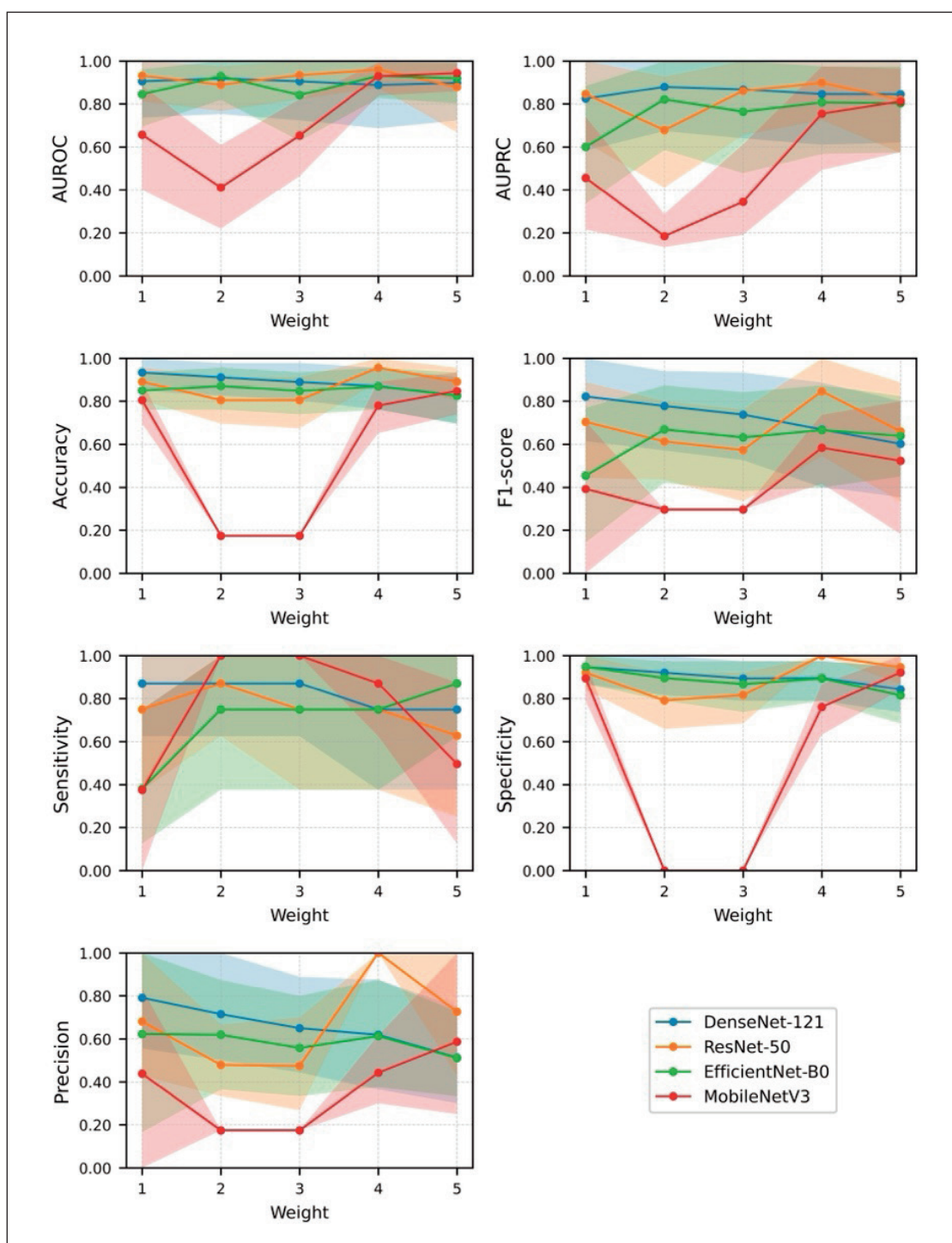


Figure 5 Model performance of DenseNet-121, ResNet-50, EfficientNet-B0, and MobileNetV3 across weight settings (w = 1 – 5). Mean metric values are shown with shaded 95 % confidence intervals for AUROC, AUPRC, accuracy, F1-score, sensitivity, specificity, and precision. ChatGPT 5.5 (OpenAI) was used to assist with the development of the Python code for development of the figure.

inter-examiner variability.

From our study, DenseNet-121 recorded high F1 score, sensitivity, specificity, accuracy, AUROC, and AUPRC, followed by ResNet-50, EfficientNet-B0, and

MobileNetV3. To clarify, DenseNet-121(weight = 1) achieving high F1 score (0.82), sensitivity (0.87), and specificity (0.95), along with acceptable precision (0.79). To develop a radiographic screening tool for identifying

long MP-H patients, minimizing false negatives is important to avoid mis-screened long MP-H groups. DenseNet-121 achieved high sensitivity (0.87) and high specificity (0.95). This suited a medical screening tool, as it minimized missed long MP-H group as most true cases were accurately detected, while also keeping false positives low to avoid unnecessary referral. It also maintained a high F1 score, reflecting a balanced trade-off between sensitivity and precision, which was essential to avoid alarming healthy individuals unnecessarily. Also, ResNet-50 also showed strong performance but had slightly lower sensitivity (0.75). In contrast, EfficientNet-B0, and MobileNetV3 had lower F1 scores and precision, making them less reliable for clinical use. Conversely, MobileNetV3 models demonstrated suboptimal performance in clinical screening contexts, exhibiting low precision and specificity. When the penalty weight was increased from 1 to 3, the model achieved a sensitivity of 1 but a specificity of 0. Increasing the loss function weight for the minority class (long MP-H) caused the model to prioritise minimising false negatives, ultimately resulting in all cases being classified as long MP-H. In terms of AUPRC, DenseNet-121 achieved superior overall performance in classifying MP-H within an imbalanced dataset, where short MP-H outnumbered long MP-H cases. AUPRC and AUROC of DenseNet-121, ResNet-50, EfficientNet-B0, and MobileNetV3 were shown (Figure 2, and 3). With imbalanced nature of data, AUPRC was assessed.²⁷ All DenseNet-121 revealed AUPRC of more than 0.80 which indicated a strong performance. Although, ResNet-50 ($w = 4$) showed highest AUPRC (0.90). However, the model demonstrated a sensitivity of 0.75, indicating that around 25 % of long MP-H cases were not correctly identified during screening. Overall, DenseNet-121 ($weight = 1$) offered the best trade-off between sensitivity and precision, aligning well with the clinical goals of early detection of long MP-H. As the clinical goal is to prioritize screening of long MP-H cases, the high sensitivity is considered. Clinically, DenseNet-121

may be useful for large-scale screening in orthodontic settings, extending beyond traditional cephalometric analysis. The extensive cephalometric databases can be rapidly assessed to identify individuals with long MP-H, facilitating population-based risk assessment, epidemiological investigations, and early detection of patients who may require additional airway evaluation. However, it was never intended to be used as an independent tool, since human validation, clinical examination, and consideration of other risk factors remain necessary.

Previously, CNN model based on ResNet backbone was developed to automatically detect upper airway obstruction in lateral cephalograms based on upper pharyngeal width and lower pharyngeal width cut off value from McNamara's analysis.¹⁸ The developed model possessed a high performance with a sensitivity of 0.86, specificity of 0.89, precision of 0.90, negative predictive value (NPV) of 0.85, and F1-score of 0.88, respectively.¹⁸ Also, researchers utilised DenseNet-121 models to classify patients with OSA and normal patients using lateral cephalometric radiographs labelled according to polysomnography results. The model achieved an accuracy of 0.74. Sensitivity, specificity, F1 score, and AUROC were recorded as 0.77, 0.73, 0.87, and 0.82, respectively. The precision was 0.71, while the NPV was 0.79.¹⁹ In terms of performance, our study found that DenseNet-121 (AUPRC = 0.83-0.88, sensitivity = 0.75-0.87) demonstrated higher performance than ResNet (AUPRC = 0.68-0.90, sensitivity = 0.63-0.87); however, both could be utilized for image classification to short and long MP-H. Since, the polysomnography was not incorporated into the study, we suggested using as screening tool.

Commonly, medical data is imbalanced as the normal population outweighed the number of diseased populations. Multiple strategies are proposed to deal with class imbalanced data including image augmentation and Generative adversarial

networks (GANs) and weighted cross entropy loss. Image augmentation made a slight change (rotation, translation, and flipping) to the original data to allow the models to learn from more diverse data.²⁹ GANs are an advanced machine learning approach used to create new synthetic data that mimics real data, making it difficult to differentiate them apart.³⁰ While, weighted cross entropy loss is a variation of the standard loss function used in model training, where additional weight is given to the minority class to address class imbalance.²⁵ However, the results showed that weights varied across different models. It was therefore important to identify appropriate weights for specific problems. There was no universally applicable solution.

The limitations of this study include the relatively small sample size of lateral cephalometric radiographs, all of which were obtained from a single source, as well as the retrospective nature of the research design. The information on BMI, additional health conditions, and smoking status was unavailable. Nevertheless, all patients were asymptomatic for OSA and undiagnosed. These constraint affects the generalizability of the findings. Future research should include larger datasets collected from multiple centers. Hence, prospective cohort evaluations are recommended to further assess model performance. Inclusion of OSA patients with multiple risks ranging from mild to severe OSA with incorporation of polysomnography for validation and comparison of how models predicted OSA risk from MP-H distance and their performance are also advised. Also, a development of a multimodal, multifactorial screening tools could also be advantageous for screening of other risk factors.

Conclusion

The proposed deep learning-based system shows potential for future clinical implementation in assessing long MP-H distance from lateral cephalometric

radiographs. Among the evaluated configurations, DenseNet-121 with weight = 1 provided the most favorable balance between sensitivity and precision, aligning well with the clinical objectives of screening patients with a long MP-H distance. The effects of weighted loss functions varied across architectures, whereas DenseNet-121 consistently demonstrated high performance across all weighting scenarios, indicating that backbone selection plays a more influential role than class weighting in this task.

Author contributions

Nichakorn Songsang: Software, Formal analysis, Data curation, Visualization, Writing- Original draft preparation, Investigation, Resources, Validation, Writing- Reviewing and Editing, Project administration, Funding acquisition; **Udom Thongudomporn:** Conceptualization, Methodology, Supervision, Investigation, Resources, Validation, Writing- Reviewing and Editing, Project administration, Funding acquisition; **Witsarut Upalananda:** Conceptualization, Methodology, Supervision, Software, Formal analysis, Data curation, Visualization.

Ethical statement

This study was approved by the Human Research Ethics Committee, Faculty of dentistry, Prince of Songkla University (EC6712-053). All data were anonymized to protect participants confidentiality.

Disclosure statement

The authors have no conflicts of interest.

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AI-assisted writing declaration

The authors used Microsoft Copilot for language editing and ChatGPT (OpenAI, GPT-5.5) for assistance with Python code development for Figures 4 and 5. All content was reviewed by the authors, who take full responsibility for the final manuscript.

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Mechanical Indicators of Primary Stability of Orthodontic Miniscrews: Effects of Pilot-Hole Diameter Across Three Commercial Systems with Different Thread External Diameters and Designs: An In Vitro Study

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Abstract

Background: Pre-drilling of pilot holes has been suggested to facilitate miniscrew placement in dense palatal bone. **Objective:** To compare mechanical indicators of primary stability (maximal insertion torque and pull-out strength) of miniscrew systems with different thread external diameters under varying pre-drilled pilot-hole diameters. **Materials and methods:** This study included 120 titanium alloy miniscrew implants with a thread length of 6.0 mm. The implants were classified into three groups according to thread external diameter (1.8, 1.9, and 2.0 mm). Each group was subdivided into four pilot-hole conditions: 0.0 mm (control), 1.1 mm, 1.2 mm, and 1.3 mm. All implants were inserted into synthetic composite palatal bone. Primary stability was evaluated by maximum insertion torque and vertical pull-out strength. **Results:** Both miniscrew system group and pre-drilled pilot-hole diameter significantly affected maximal insertion torque and pull-out strength ($P < 0.001$). A significant interaction between miniscrew system/design group and pilot-hole diameter was observed ($P < 0.001$). Maximal insertion torque decreased as pilot-hole diameter increased across all systems. The 2.0-mm system/design group consistently demonstrated the highest insertion torque under all drilling conditions. Pull-out strength remained relatively stable at 1.1-1.2 mm pilot-holes in the 1.8 mm system, whereas larger pilot-hole diameters resulted in significant reductions in some systems/designs. **Conclusion:** Both miniscrew implant design and pre-drilled pilot-hole diameter influence primary stability. Pilot-hole diameters of 1.1–1.2 mm provide an optimal balance between insertion torque and pull-out strength for 1.8–2.0 mm diameter miniscrews; however, the ideal pilot-hole size should be determined according to the specific miniscrew implant design.

Keywords: Insertion torque, Miniscrew implant, Palatal bone, Pre-drilled pilot-hole, Pull-out strength

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Introduction

Application of temporary anchorage devices, particularly miniscrew implants may expand the possibilities of orthodontic treatment, such as molar distal movement, incisor and molar intrusion, en-masse retraction, and complete arch distalization.^{1,2} The thread shape of miniscrew implants can affect their resistance to removal when the miniscrew implant's diameter, length, and bone characteristics remain constant. Gracco et al. investigated five different thread shapes: 1) buttress reverse, 2) buttress, 3) 75° joint profile, 4) round, and 5) trapezoid. Their findings indicated that the buttress reverse thread provided the highest pull-out resistance, suggesting the greatest primary stability,³⁻⁵ followed by the 75° joint profile thread. The superior resistance of the buttress reverse design may be explained by the inclination of the thread toward the implant head. These results are consistent with other studies reporting that thread angles between 45° and 90° enhanced miniscrew implant stability.^{4,6-8}

Palatal bone has been suggested as a suitable site for miniscrew implant placement because of its characteristics, such as thick and dense cortical bone, few vital anatomical structures, and an abundance of keratinized tissue. However, difficulty in miniscrew implant placement in dense palatal bone has been reported.⁹⁻¹¹ Over-tightening during placement might cause microfractures or necrosis of the surrounding bone.¹²⁻¹⁶ Accordingly, the use of a pre-drilled pilot hole has been suggested for miniscrew implant placement, particularly in dense palatal sites. Several factors influence the primary stability of miniscrew implants—commonly assessed by insertion torque and pull-out strength—including bone density, insertion angle, thread outer diameter, thread length, drilling protocols (e.g., pre-drilled pilot holes), and, importantly, the shape and design of the implant thread.^{7,17-22} The diameter of miniscrews has also been reported to influence primary stability. Larger diameters generally increase the bone-implant

contact area and mechanical retention, resulting in higher insertion torque and greater resistance to displacement. However, an increased diameter may also elevate insertion stress and the risk of cortical bone damage. Therefore, evaluating the effects of different external diameters under standardized conditions is clinically relevant.^{3,14,23}

In this study, maximal insertion torque and pull-out strength were used as mechanical indicators reflecting primary stability rather than direct measurements of primary stability. Therefore, the pre-drilled pilot-hole insertion technique is recommended for placing miniscrew implants into thick and dense cortical palatal bone in order to reduce compression at the thread-bone interface. However, as the diameter of the pre-drilled pilot hole increases, insertion torque decreases, resulting in reduced primary stability.^{24,25} Our previous study suggested that pre-drilled pilot holes with diameters of 1.1 mm and 1.2 mm (corresponding to 62 % and 67 % of the implant thread external diameter) provided optimal primary stability and were recommended for the placement of 1.8 × 6.0 mm (thread external diameter × length) titanium alloy implants in synthetic palatal bone.²⁶ The present in vitro study aimed to assess and compare the primary stability of miniscrew implants with three different thread external diameters during placement with pre-drilled pilot holes.

Materials and methods

This in vitro comparative study involved 120 miniscrew implants with a uniform thread length of 6.0 mm, categorized into three groups according to thread external diameter. Each group was further subdivided based on pre-drilled pilot-hole diameter for the measurement of maximum insertion torque and vertical pull-out strength, as follows.

The sample size of $n = 10$ per subgroup was based on previous in vitro studies evaluating miniscrew

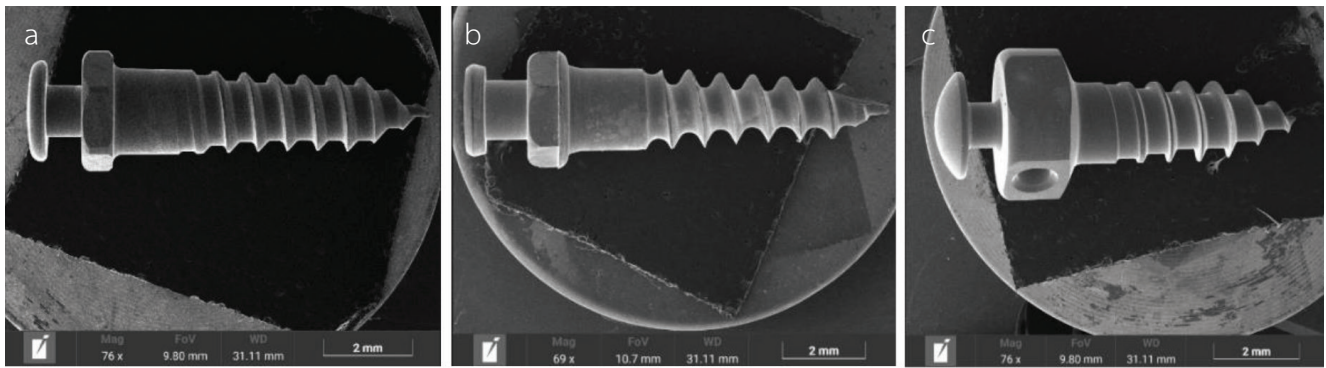


Figure 1 Scanning Electron microscope pictures of (a) Osstem miniscrew implant; 6-mm long with 1.8-mm outer diameter, (b) RJ (Rajavithi) miniscrew implant; 6-mm long with 1.9-mm outer diameter, and (c) Syntec miniscrew implant; 6-mm long with 2.0-mm outer diameter

mechanical stability and was considered sufficient to detect significant differences under controlled experimental conditions.

Group A forty titanium alloy miniscrew implants (Osstem Implant Co., Seoul, Korea: thread external diameter, 1.8 mm; length, 6.0 mm) (Figure 1a) were divided into four subgroups ($n = 10$ per subgroup), as follows: pre-drilled subgroup A1 (0.0 mm or no pre-drilled pilot-hole as negative control), pre-drilled subgroup A2 (1.1 mm pre-drilled pilot-hole or 61.10 %), pre-drilled subgroup A3 (1.2 mm pre-drilled pilot-hole or 66.70 %), and pre-drilled subgroup A4 (1.3 mm pre-drilled pilot-hole or 72.20 %). The percentage in parentheses represented the ratio between the pre-drilled pilot-hole diameter and the external thread diameter of the investigated miniscrew implant.

Group B forty titanium alloy miniscrew implants (RJ, Rajavithi Hospital, Thailand: thread external diameter, 1.9 mm; length, 6.0 mm) (Figure 1b) were divided into four subgroups ($n = 10$ per subgroup), as follows: pre-drilled subgroup B1 (0.0 mm or no pre-drilled pilot-hole as negative control), pre-drilled subgroup B2 (1.1 mm, pre-drilled pilot-hole or 57.90 %), subgroup B3 (1.2 mm, pre-drilled pilot-hole or 63.20 %) and pre-drilled subgroup B4 (1.3 mm pre-drilled pilot-hole or 68.40 %).

Group C forty titanium alloy miniscrew implants (Syntec Scientific Corporation, Taiwan: thread external diameter, 2.0 mm; length, 6.0 mm) (Figure 1c) were divided into four subgroups ($n = 10$ per subgroup), as follows: pre-drilled subgroup C1 (0.0 mm or no pre-drilled pilot-hole as negative control), pre-drilled subgroup C2 (1.1 mm pre-drilled pilot-hole or 55.0 %), pre-drilled group C3 (1.2 mm pre-drilled pilot-hole or 60.0 %) and pre-drilled group C4 (1.3 mm pre-drilled pilot-hole or 65.0 %).

The RJ miniscrew showed the greatest neck length (1.79 mm), widest thread pitch (0.80 mm), and deepest thread depth (0.37 mm), indicating a more aggressive thread design. The Osstem system demonstrated intermediate values (neck length 1.51 mm, thread pitch 0.69 mm, thread depth 0.25 mm), whereas the Syntec miniscrew exhibited the smallest neck length (0.93 mm) and shallowest thread depth (0.22 mm), suggesting a less pronounced thread profile.

In our previous study, synthetic composite bone blocks (Sawbones®, Pacific Research Laboratories, Inc., Vashon, WA, USA) were used. To simulate human palatal bone, a 2.0-mm-thick layer of 40 pcf (0.64 g/cc) epoxy-reinforced polyurethane (cortical bone) was attached to a 12.0-mm-thick block of 20 pcf (0.32 g/cc) rigid polyurethane (cancellous bone). A custom-made

instrument-holding system was used to position the digital torque gauge (IMADA Inc., Northbrook, IL, USA) and the synthetic bone blocks to ensure a consistent direction of the pre-drilled pilot-hole line and implant insertion path.⁶

Pre-drilled pilot-holes with diameters of 1.1, 1.2, and 1.3 mm were prepared manually using the corresponding drill bits to a standardized depth of 5.0 mm. The drill bits were secured in the chuck of a digital torque gauge attached to a custom-made instrument-holding system. To control the pilot-hole depth, a color-coded stop was positioned 5.0 mm from the drill-bit tip. The same protocol was applied to all three miniscrew groups (A, B, and C) and to all pre-drilled pilot-hole subgroups (2, 3, and 4), corresponding to the 1.1-, 1.2-, and 1.3-mm drill bits.

For the maximum insertion torque assessment, cubical Sawbones® blocks in the control group were fixed in a custom-made synthetic bone holder, which was rigidly secured to one of the instrument-holding system's bearings. A miniscrew implant was attached to the digital torque gauge via the implant screwdriver shaft. A red line was drawn on the torque-gauge holder of the holding system 5.0 mm from its edge as a stop mark. The implant was driven 5.0 mm into the bone block (not the entire thread length) at a constant speed of twelve rotations per minute until the edge of the torque-gauge holder reached the red line. The maximum insertion torque was then recorded. The same protocol was applied to the previously drilled synthetic bone.²⁶

After the maximum insertion torque tests, the synthetic bone cube was transferred and rigidly fixed to the inferior clamp of a Universal Testing Machine (Instron Corp., Canton, MA, USA). The miniscrew implant was secured using a pulling apparatus attached to the superior clamp of the Universal Testing Machine. The test was performed with a 500 N load cell. A vertical force was applied parallel to the long axis of the implant at a crosshead speed of 10 mm/min until the implant was detached from the block. The maximum

force at the moment of implant detachment was defined as the pull-out strength.² The details of the measurement method were already described in our previous publication.²⁶

Statistical analysis

Data were analyzed using SPSS software (version 17.0; SPSS Inc., Chicago, IL, USA). Data normality was assessed using the Kolmogorov–Smirnov test, which confirmed normal distributions across all twelve subgroups ($P > 0.05$). Given the overall distribution and the robustness of ANOVA to mild violations of normality, parametric analyses were performed. When significant differences were detected, multiple comparisons were conducted using Tukey's honestly significant difference (HSD) post hoc test. Means and standard deviations of maximal insertion torque and pull-out strength were calculated.

Results

Maximal insertion torque

The means and standard deviations of maximal insertion torque are presented in Figure 2. The data met the assumptions for parametric analysis. Two-way ANOVA revealed significant main effects of miniscrew system group and pilot-hole diameter on maximal insertion torque (both $P < 0.001$), as well as a significant interaction between these factors ($P < 0.001$) (Table 1). Overall, maximal insertion torque decreased as pilot-hole diameter increased across all miniscrew systems.

Within-group comparisons by pilot-hole diameter

Group A (Osstem, external diameter 1.8 mm)

Maximal insertion torque decreased progressively from the control group to larger pilot holes (0.0 mm: 11.58 ± 0.38 Ncm; 1.1 mm: 9.49 ± 0.37 Ncm; 1.2 mm: 8.46 ± 0.33 Ncm; 1.3 mm: 7.55 ± 0.32 Ncm). Tukey's test showed that maximal insertion torque was

Table 1 Two-way ANOVA (Type III sums of squares) evaluating the effects of miniscrew system/design group, pilot-hole diameter, and their interaction on maximal insertion torque (Ncm).

	df	Sum of squares	Mean square	F ratio	P value
Miniscrew system group	2	325.66	162.83	382.85	< 0.001***
Pilot-hole diameter	3	409.09	136.36	320.62	< 0.001***
System × pilot-hole diameter	6	20.63	3.43	8.08	< 0.001***
Error	108	45.93	0.42		

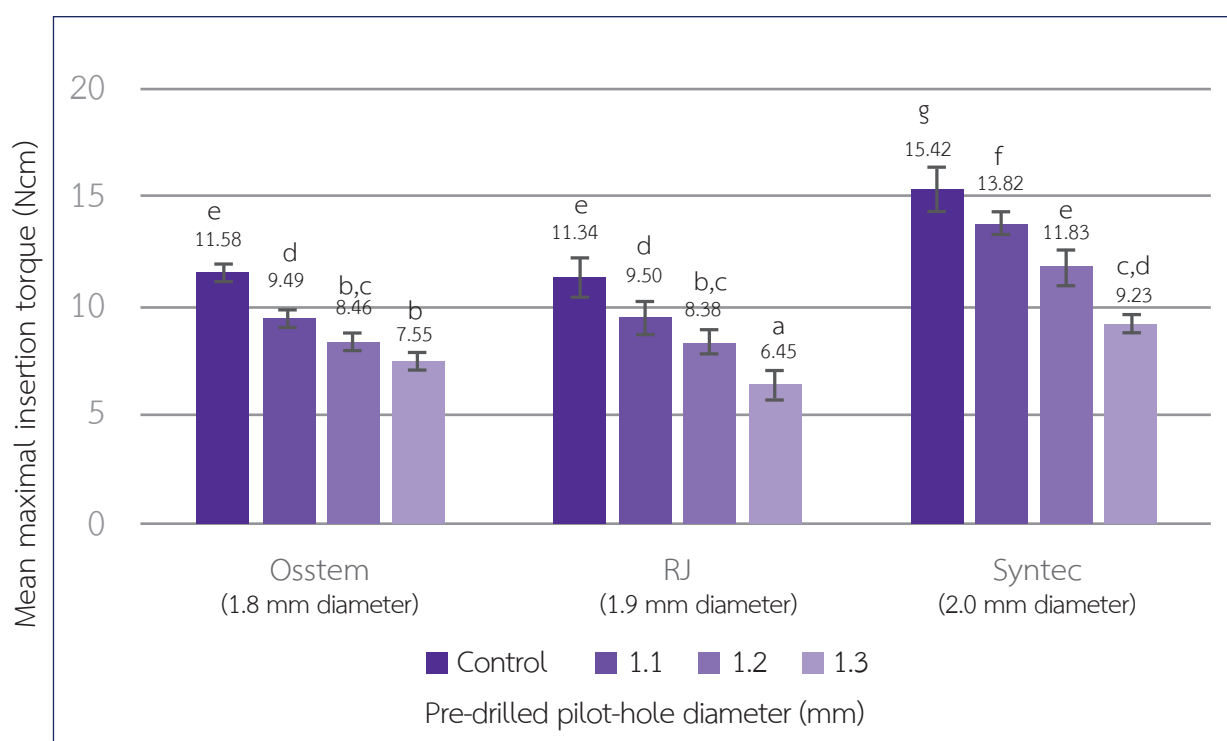


Figure 2 Mean ($\pm$ SD) maximal insertion torque (Ncm) for three miniscrew systems (Osstem 1.8 mm, RJ 1.9 mm, and Syntec 2.0 mm) inserted into synthetic composite palatal bone using pilot-hole diameters of 0.0 mm (control), 1.1 mm, 1.2 mm, and 1.3 mm. Superscript letters indicate pairwise comparisons across all 12 system $\times$ pilot-hole combinations using Tukey's HSD ($P < 0.05$). Bars sharing at least one letter are not significantly different.

significantly greater in the control condition compared with all pre-drilled conditions ($P < 0.001$). The post-hoc test also confirmed that there were significant differences in maximal insertion torque associated with pre-drilled pilot-hole diameters ($P < 0.001$).

Group B (RJ, external diameter 1.9 mm)

A similar decreasing trend was observed (0.0 mm: 11.34 ± 0.91 Ncm; 1.1 mm: 9.50 ± 0.80 Ncm; 1.2 mm: 8.38 ± 0.56 Ncm; 1.3 mm: 6.45 ± 0.66 Ncm). Tukey's test showed that maximal insertion torque was significantly greater in the miniscrew implant

inserted without using pre-drilled pilot-holes than in those inserted with using pre-drilled pilot-holes. The differences between the control group and the groups with 1.1-mm, 1.2-mm and 1.3-mm pre-drilled pilot-hole diameters were also statistically significant ($P < 0.001$). The post-hoc test also confirmed that there were significant differences in maximal insertion torque associated with pre-drilled pilot-hole diameters ($P < 0.001$).

Group C (Syntec, external diameter 2.0 mm)

Syntec demonstrated the highest torque values across drilling conditions, with a consistent decline as pilot-hole diameter increased (0.0 mm: 15.42 ± 1.02 Ncm; 1.1 mm: 13.82 ± 0.59 Ncm; 1.2 mm: 11.83 ± 0.85 Ncm; 1.3 mm: 9.23 ± 0.45 Ncm). Tukey's test showed that maximal insertion torque was significantly greater in the miniscrew implant inserted without using pre-drilled pilot-holes than in those inserted with using

pre-drilled pilot-holes. The differences between the control group and the groups with 1.1-mm, 1.2-mm and 1.3-mm pre-drilled pilot-hole diameters were also statistically significant ($P < 0.001$). The post-hoc test also confirmed that there were significant differences in maximal insertion torque associated with pre-drilled pilot-hole diameters ($P < 0.001$).

Between-group comparisons at each pilot-hole diameter

When comparing maximal insertion torque among three different miniscrew implant systems (Figure 2), Syntec consistently demonstrated significantly higher torque values than RJ and Osstem in all pre-drilled pilot-hole conditions. In the control group, Syntec showed the highest torque (15.42 ± 1.02 Ncm), while Osstem (11.58 ± 0.38 Ncm) and RJ (11.34 ± 0.91 Ncm) were comparable.

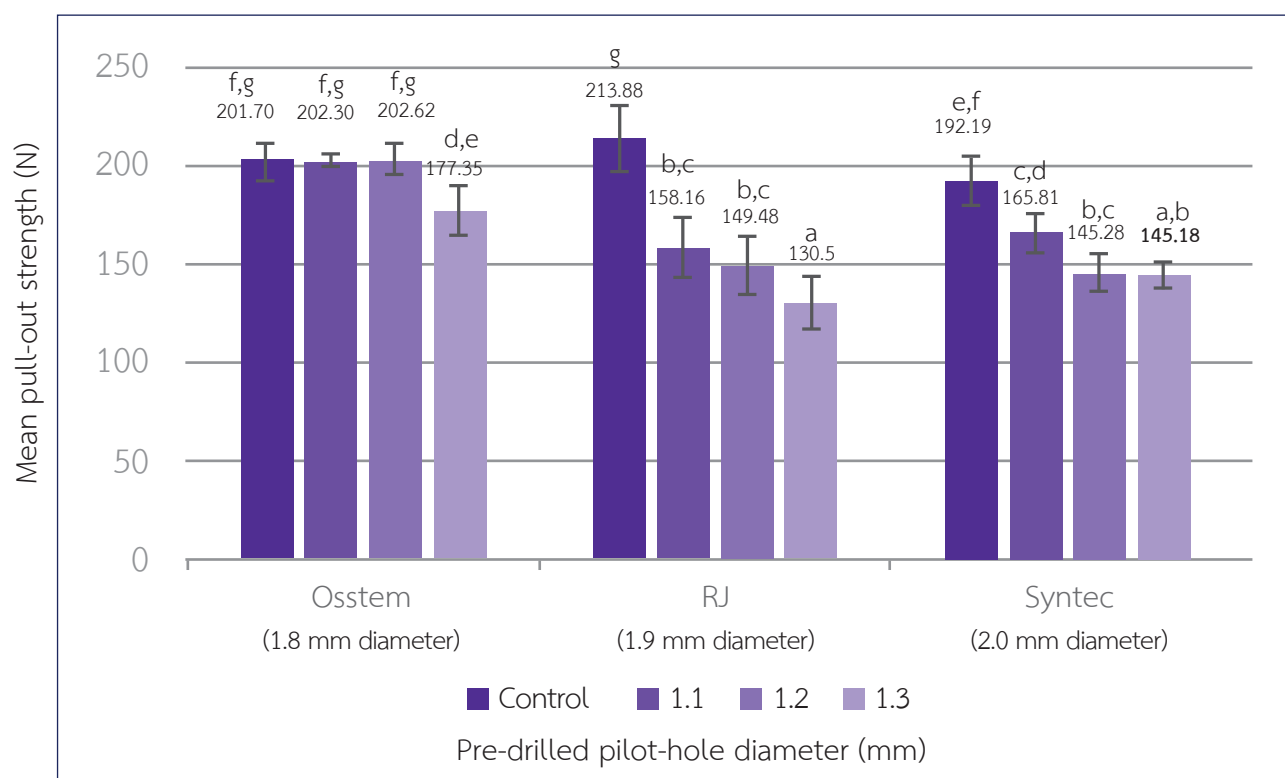


Figure 3 Mean ($\pm$ SD) pull-out strength (N) for three miniscrew systems (Osstem 1.8 mm, RJ 1.9 mm, and Syntec 2.0 mm) inserted into synthetic composite palatal bone using pilot-hole diameters of 0.0 mm (control), 1.1 mm, 1.2 mm, and 1.3 mm. Superscript letters indicate pairwise comparisons across all 12 system $\times$ pilot-hole combinations using Tukey's HSD ($P < 0.05$). Bars sharing at least one letter are not significantly different.

Table 2 Two-way ANOVA (Type III sums of squares) evaluating the effects of miniscrew system/design group, pilot-hole diameter, and their interaction on pull-out strength (N).

	df	Sum of squares	Mean square	F ratio	P value
Miniscrew system group	2	29,828.28	14,914.14	110.83	< 0.001***
Pilot-hole diameter	3	42,453.06	14,151.02	105.16	< 0.001***
System × pilot-hole diameter	6	15,591.42	2,598.57	19.31	< 0.001***
Error	108	14,532.43	134.56		

The same pattern was observed at 1.1 mm (Syntec: 13.82 ± 0.59 Ncm; RJ: 9.50 ± 0.80 Ncm; Osstem: 9.49 ± 0.37 Ncm), 1.2 mm (Syntec: 11.83 ± 0.85 Ncm; Osstem: 8.46 ± 0.33 Ncm; RJ: 8.38 ± 0.56 Ncm), and 1.3 mm (Syntec: 9.23 ± 0.45 Ncm; Osstem: 7.55 ± 0.32 Ncm; RJ: 6.45 ± 0.66 Ncm), with statistically significant differences between Syntec and the other groups at each drilling condition post hoc ($P < 0.001$) (Table 1).

Pullout strength

The means and standard deviations of pull-out strength are presented in Figure 3. The data met the assumptions for parametric analysis. Two-way ANOVA showed significant main effects of miniscrew system group and pilot-hole diameter on pull-out strength (both $P < 0.001$), with a significant interaction between factors ($P < 0.001$) (Table 2). Overall, pull-out strength tended to decrease as pilot-hole diameter increased, although the magnitude of reduction differed across miniscrew systems.

Within-group comparisons by pilot-hole diameter

Group A (Osstem, external diameter 1.8 mm)

Pull-out strength remained stable across the control and smaller pilot holes (0.0 mm: 201.70 ± 9.42 N; 1.1 mm: 202.30 ± 3.82 N; 1.2 mm: 202.62 ± 8.40 N),

but decreased at the largest pilot-hole diameter (1.3 mm: 177.35 ± 12.09 N). Tukey's test showed that the 1.1-mm and 1.2-mm groups demonstrated comparable pull-out resistance to the control, with no significant differences detected. A significant decrease was observed only in the 1.3-mm group compared with the control ($P < 0.001$). Post-hoc analysis confirmed that pre-drilled pilot-hole diameter significantly affected pull-out strength ($P < 0.001$).

Group B (RJ, external diameter 1.9 mm)

Pull-out strength decreased substantially with pre-drilling (0.0 mm: 213.88 ± 16.47 N; 1.1 mm: 158.16 ± 15.42 N; 1.2 mm: 149.48 ± 14.88 N; 1.3 mm: 130.50 ± 13.49 N). Tukey's test demonstrated that the control group exhibited significantly greater pull-out resistance than all pre-drilled groups ($P < 0.001$). All pre-drilled pilot-hole diameters resulted in significant reductions compared with the control group. The post-hoc test further confirmed significant differences in pull-out strength across pre-drilled pilot-hole diameters ($P < 0.001$).

Group C (Syntec, external diameter 2.0 mm)

Pull-out strength also decreased with increasing pilot-hole diameter (0.0 mm: 192.19 ± 12.58 N; 1.1 mm: 165.81 ± 9.58 N; 1.2 mm: 145.28 ± 9.44 N; 1.3 mm: 145.18 ± 6.46 N). Tukey's test revealed that the control group had significantly greater pull-out resistance than all pre-drilled groups ($P < 0.001$). Pull-out

strength decreased progressively with increasing pilot-hole diameter, and no significant difference was observed between the 1.2-mm and 1.3-mm groups. Post-hoc analysis confirmed that pre-drilled pilot-hole diameter had a significant effect on pull-out strength ($P < 0.001$).

Between-group comparisons at each pilot-hole diameter

When comparing pull-out strength among three different miniscrew implant systems, several significant inter-group differences were observed (Figure 3). In the control condition (0.0 mm), pull-out strengths were 201.70 ± 9.42 N (Osstem), 213.88 ± 16.47 N (RJ), and 192.19 ± 12.58 N (Syntec). RJ showed significantly greater pull-out strength than Syntec ($P < 0.05$), while Osstem did not differ significantly from either group.

At pilot-hole diameters of 1.1, 1.2, and 1.3 mm, Osstem consistently demonstrated the highest pull-out strength. In the 1.1-mm pre-drilled pilot-hole group, Osstem exhibited the highest pull-out strength (202.30 ± 3.82 N), which was significantly greater than RJ (158.16 ± 15.42 N) and Syntec (165.81 ± 9.58 N); RJ and Syntec did not differ significantly. For the 1.2-mm pre-drilled pilot-hole category, Osstem maintained the highest pull-out strength (202.62 ± 8.40 N), exceeding both RJ (149.48 ± 14.88 N) and Syntec (145.28 ± 9.44 N) with statistically significant differences. RJ and Syntec did not differ significantly from one another. A similar pattern was observed in the 1.3-mm pre-drilled pilot-hole category, where Osstem (177.35 ± 12.09 N) demonstrated significantly greater pull-out strength than RJ (130.50 ± 13.49 N) and Syntec (145.18 ± 6.46 N). Again, no significant difference was found between RJ and Syntec.

Discussion

One limitation of the present investigation relates to the study design and sample selection. The primary objective was to compare miniscrews with

three different thread external diameters; however, these diameters were not available within a single commercial system. Consequently, the three diameter groups were drawn from different manufacturers (Osstem 1.8 mm, RJ 1.9 mm, and Syntec 2.0 mm), and certain design-related variables (e.g., thread depth, pitch, taper, and core diameter) could not be fully controlled. Therefore, differences observed among the tested miniscrew groups should be interpreted as reflecting the combined effect of external diameter and system-specific thread design rather than external diameter alone. At the same time, this approach mirrors routine clinical decision-making, where clinicians choose among available commercial miniscrew systems rather than custom-manufactured implants with identical geometries, and thus may enhance the external validity of the findings.

The present study evaluated the influence of miniscrew system/design and pilot-hole diameter on two parameters of primary stability, insertion torque and pull-out strength, by comparing three different designs (Syntec, RJ, and Osstem). The results clearly demonstrated that both factors had statistically significant effects and, most importantly, that their interaction was significant ($P < 0.001$) for both torque and pull-out strength. This interaction suggests a synergistic relationship between thread geometry and pilot-hole preparation, consistent with previous reports indicating that variations in thread configuration can substantially modify bone engagement, compressive behavior, and mechanical interlock.^{25,27-30}

These findings expand upon our previous study, performed using Osstem screws alone, which concluded that 1.1–1.2 mm pilot-hole diameters (approximately 62–67 % of the outer diameter) provide an optimal balance between insertion torque and pull-out strength.²⁶ In the current investigation, Osstem again demonstrated relatively stable pull-out strength at 1.1–1.2 mm, even as insertion torque decreased progressively. The slightly higher mean pull-out strength in these groups compared

with the control may be attributed to the reduction of excessive compression during insertion. While high insertion torque is often associated with primary stability, it can also lead to localized microdamage of the surrounding material. Moderate pre-drilling may optimize thread engagement by preserving the structural integrity of the bone-thread interface, thereby maintaining or slightly improving mechanical interlock; however, this numerical difference was not statistically significant ($P > 0.05$). Furthermore, the fact that Syntec and RJ systems produced distinct patterns under the same protocol underscores that pilot-hole guidelines must be tailored to specific miniscrew designs rather than generalized.

For Syntec, insertion torque remained highest in the control (no pre-drill pilot-hole) and 1.1 mm groups and decreased markedly with larger pilot holes, suggesting that this design benefits from tighter bone engagement. In contrast, RJ screws exhibited a pronounced decline in both insertion torque and pull-out strength with increasing pilot-hole diameter, suggesting greater sensitivity to pilot-hole enlargement ('over-drilling') relative to the other systems. This pattern may reflect a stronger dependence on frictional retention and compressive engagement at the cortical layer in this synthetic bone model. These findings emphasize that a single pre-drilled pilot-hole guideline cannot be universally applied across different miniscrew implant thread design. Biomechanically, the differences can be attributed to variations in thread depth, pitch, and taper configuration, which collectively influence cortical bone compression and mechanical interlock.

From a clinical perspective, smaller pilot holes generally increase insertion torque and immediate mechanical stability; however, excessive torque may also increase cortical compression and microdamage, potentially compromising early stability, particularly when early loading is planned.¹⁴ Accordingly, moderate pre-drilled pilot-holes (1.1–1.2 mm) appear to offer a practical compromise, maintaining adequate stability

while minimizing cortical bone stress. Accordingly, moderate pre-drilled pilot-holes (1.1–1.2 mm) appear to offer a practical compromise, maintaining adequate stability while minimizing cortical bone stress, particularly for the 1.8–2.0 mm diameter miniscrews evaluated in this study. Overall, this study demonstrates that primary stability behavior is design-specific: Syntec responds optimally to smaller pilot-hole diameters, RJ is more sensitive to over-drilling, and Osstem remains relatively stable across the tested diameters. These interactions underscore the need for system-specific pilot-hole recommendations rather than a universal protocol.

The differences in thread geometry among the miniscrew systems may contribute to the variations observed in insertion torque and pull-out strength. Miniscrews with deeper and sharper thread profiles, such as the RJ system, may enhance mechanical interlocking with the surrounding material, resulting in greater resistance to dislodgement and higher pull-out strength. In contrast, the Syntec miniscrew, characterized by a relatively shallow thread depth and wider thread pitch, may provide reduced thread engagement and mechanical retention, potentially leading to lower pull-out resistance. Therefore, the mechanical performance of miniscrews should be interpreted with consideration of thread design as a potential cofactor influencing stability outcomes. However, further investigation is required to clarify the extent to which these geometric characteristics affect insertion torque and pull-out strength.

Several factors should be considered when translating these findings to clinical practice. The synthetic bilayer model provides standardized conditions but cannot fully reproduce the heterogeneity and viscoelastic behavior of human palatal bone, where cortical thickness and density vary by anatomical site and patient. In addition, miniscrews were inserted to a standardized depth of 5.0 mm rather than the full thread length, and pull-out testing was performed under purely axial loading; both factors

may influence the absolute values and limit direct clinical extrapolation. Future studies incorporating variation in cortical thickness, oblique and cyclic loading, and detailed geometric characterization of thread parameters (e.g., core diameter, pitch, thread depth, and taper) would help refine system-specific pilot-hole recommendations.

Conclusion

Miniscrew system/design group and pilot-hole diameter significantly affected maximal insertion torque and pull-out strength (all $P < 0.001$), with a significant system $\times$ pilot-hole interaction for both outcomes ($P < 0.001$), indicating design-dependent responses to pre-drilling. Syntec showed the highest insertion torque across conditions, Osstem maintained relatively stable pull-out strength at 1.1–1.2 mm, and RJ exhibited the greatest reductions with increasing pilot-hole diameter. Therefore, pilot-hole selection should be system-specific; 1.1–1.2 mm may represent a practical compromise across the tested systems.

Author contributions

Poomsthira Joitkashira: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Project administration, Funding acquisition; **Prajak Jariyapongpaiboon:** Resources, Writing - Review & Editing; **Petchpailin Phusantisampan:** Methodology, Writing - Review & Editing; **Kachaphol Kuharattanachai:** Conceptualization, Methodology, Formal analysis, Writing - Review & Editing, Visualization, Supervision, Project administration, Funding acquisition

Ethical statement

None.

Disclosure statement

The authors have no conflict of interest.

AI-assisted writing declaration

The authors used ChatGPT (OpenAI, GPT-5.5) 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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Direction-Dependent Soft Tissue Thickness in Facial Asymmetry: A Three-Dimensional Analysis Using Facial Scanning and Cone Beam Computed Tomography

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Abstract

Background: Facial asymmetry is a common craniofacial condition affecting facial aesthetics and function. Although skeletal discrepancies are the primary determinant, the role of direction-dependent soft tissue thickness in shaping facial morphology remains unclear. **Objective:** To investigate direction-dependent patterns of soft tissue thickness in patients with facial asymmetry using integrated three-dimensional facial scanning and cone beam computed tomography. **Materials and methods:** This cross-sectional study included 60 adults aged 18–35 years undergoing orthodontic and orthognathic evaluation. Cone beam computed tomography and three-dimensional facial scan datasets were fused to construct composite craniofacial models. Bilateral skeletal landmarks were identified, and soft tissue thickness was measured relative to the midsagittal plane in transverse and sagittal directions. Paired statistical tests compared measurements between deviated and contralateral sides. **Results:** Significant skeletal asymmetry was observed at multiple craniofacial landmarks, particularly at the antegonial notch (2.09 ± 4.40 mm), orbitale (1.66 ± 3.16 mm), and anterior ramus notch (1.34 ± 1.94 mm), among others ($P < 0.01$). Direction-dependent patterns of soft tissue thickness was identified. In the transverse, soft tissue was generally thinner on the deviated side at the anterior ramus notch, canini, antegonial notch, and gonion ($P < 0.01$). In contrast, sagittal measurements showed greater soft tissue thickness on the deviated side at the condylion, antegonial notch, and gonion ($P < 0.01$). **Conclusion:** Soft tissue thickness in facial asymmetry demonstrates direction-dependent patterns and only partially reflects skeletal deviations. Integrated three-dimensional imaging may improve evaluation of skeletal–soft tissue relationships and assist orthodontic and orthognathic treatment planning.

Keywords: Cone beam computed tomography, Face, Facial asymmetry, Soft tissue, Imaging three-dimensional

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Introduction

Facial asymmetry is a common clinical condition that affects both facial aesthetics and function, with studies reporting that up to one-third of individuals exhibit some degree of asymmetry, most frequently presenting as chin deviation.^{1,2} The etiology is multifactorial and may involve congenital conditions, developmental disturbances, trauma, and abnormalities in skeletal or muscular growth. Accurate assessment of facial asymmetry is therefore essential for diagnosis, treatment planning, and orthognathic surgical decision-making in craniofacial patients.

Evaluation of facial asymmetry typically involves visual inspection, two-dimensional (2D) photography, and cephalometric analysis. However, these approaches are limited in their ability to capture the complex three-dimensional (3D) relationships of craniofacial structures. Advances in imaging technologies, particularly 3D facial scanning and cone beam computed tomography, have substantially improved the precision and reproducibility of craniofacial assessment.³⁻⁵ The integration of these modalities enables comprehensive visualization of both hard and soft tissues, facilitating accurate landmark identification and spatial evaluation.

Soft tissues play an important role in the clinical manifestation and perception of facial asymmetry due to their close relationship with underlying skeletal structures. Previous studies have demonstrated strong correlations between hard and soft tissue landmarks, with soft tissue generally reflecting rather than fully compensating for skeletal deviations.^{6,7} Even in individuals with normal occlusion, soft tissue asymmetry may range from 0.6 to 4.6 mm, often exceeding the discrepancies observed in the skeletal framework, particularly in the lower and lateral facial regions.⁸ While certain soft tissue components may partially mask skeletal discrepancies, this compensation is inconsistent and often insufficient in moderate to severe asymmetry. Features such as chin position, gonial contour, lip canting, and midline alignment

significantly influence the clinical perception of facial imbalance.^{4,9}

Understanding the relationship between soft tissue thickness and underlying skeletal asymmetry is essential for accurate diagnosis, realistic treatment planning, and prediction of postoperative outcomes in orthodontics and orthognathic surgery.^{1,4,10} However, conventional two-dimensional approaches cannot adequately quantify region-specific or direction-dependent variations in soft tissue thickness. Recent advances in 3D imaging allow simultaneous evaluation of skeletal morphology and overlying soft tissues, enabling more comprehensive analysis of craniofacial asymmetry.^{4,11}

Despite increasing use of 3D imaging, limited studies have investigated how soft tissue thickness varies between deviated and contralateral sides and whether these variations differ according to measurement direction. A clearer understanding of these direction-dependent soft tissue patterns may improve diagnostic accuracy and support individualized orthodontic and orthognathic treatment planning.

Therefore, this study aimed to evaluate differences in soft tissue thickness between deviated and contralateral sides in patients with facial asymmetry using integrated cone beam computed tomography and 3D facial scanning. In addition, the relationship between skeletal deviations and direction-specific soft tissue thickness patterns was investigated across multiple craniofacial landmarks. This study provides a landmark-based, direction-dependent assessment of soft tissue thickness in both the transverse and sagittal dimensions to better characterize soft tissue adaptation to skeletal asymmetry.

Materials and methods

Informed consent was obtained from all participants prior to data acquisition. Sample size calculation was performed using G*Power software (version 3.1.9.7; University of Kiel, Kiel, Germany) with

a significance level of 0.05, statistical power of 80 %, and an effect size of 0.80 based on previously reported bilateral differences in landmark measurements.¹² A minimum sample size of 60 patients was required to detect significant bilateral differences, and 60 eligible patients were included in the study.

Inclusion and exclusion criteria

Facial asymmetry was defined as a skeletal menton deviation of ≥ 2 mm from the midsagittal plane, consistent with previously reported diagnostic thresholds.¹³ This cross-sectional study included adult patients aged 18–35 years presenting with facial asymmetry who were scheduled for orthodontic treatment and orthognathic surgery evaluation between January 2022 and January 2024. None of the participants had received prior orthodontic treatment or were undergoing active orthodontic therapy at the time of imaging. Exclusion criteria included craniofacial syndromes, cleft lip and/or palate, systemic conditions affecting craniofacial development, and a history of facial trauma or craniofacial surgical procedures. CBCT and 3D facial scan datasets from all eligible patients were used to construct virtual 3D craniofacial models for analysis.

Data acquisition and assessment

CBCT scans were obtained using a Planmeca Viso® G7 system (Planmeca Oy, Helsinki, Finland) with the following parameters: voxel size 400 μ m, field of view 30 $\times$ 30 cm, 120 kV, and 8.0 mA. Patients were positioned in natural head posture with teeth in maximum intercuspation and relaxed lips.

Three-dimensional facial scans were obtained using the integrated facial scanning function of the same system under standardized conditions. CBCT and facial scan datasets were imported into Dolphin Imaging software (version 11.9; Dolphin Imaging Systems, Los Angeles, CA, USA) and fused using a surface-based registration approach. Spatial alignment was performed using the Iterative Closest Point algorithm,

which minimizes the root-mean-square error between corresponding surface points to generate accurate composite 3D craniofacial models.

Reference planes were established based on previously validated methods.^{4,12,14,15} The horizontal reference line (HRL) was defined by connecting the right and left Orbitale, while the vertical reference line (VRL) was constructed perpendicular to the HRL and passing through the anterior nasal spine (ANS). The sagittal reference line (SRL) was defined by connecting the anterior nasal spine (ANS) and posterior nasal spine (PNS). These reference planes were used to orient the three-dimensional models for standardized analysis (Figure 1).

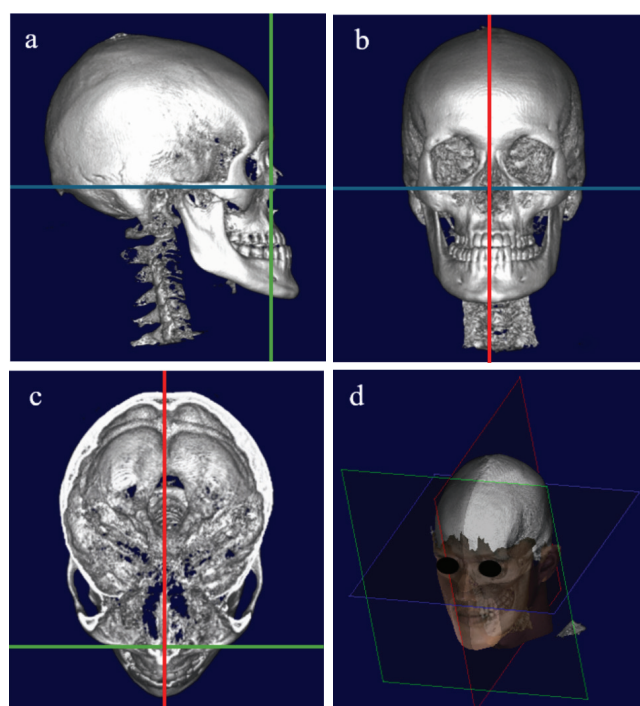


Figure 1 Images of the orientation settings of a 3D virtual head: (a) horizontal reference line (blue line), (b) vertical reference line (red line), (c) sagittal reference line (green line), and (d) final construction of reference planes in a 3D view.

Hard tissue landmarks used in this study are summarized in Figure 2 and included the condylion, zygion, orbitale, sigmoid notch, posterior ramus notch, anterior ramus notch, antegonial notch, canini, and gonion.

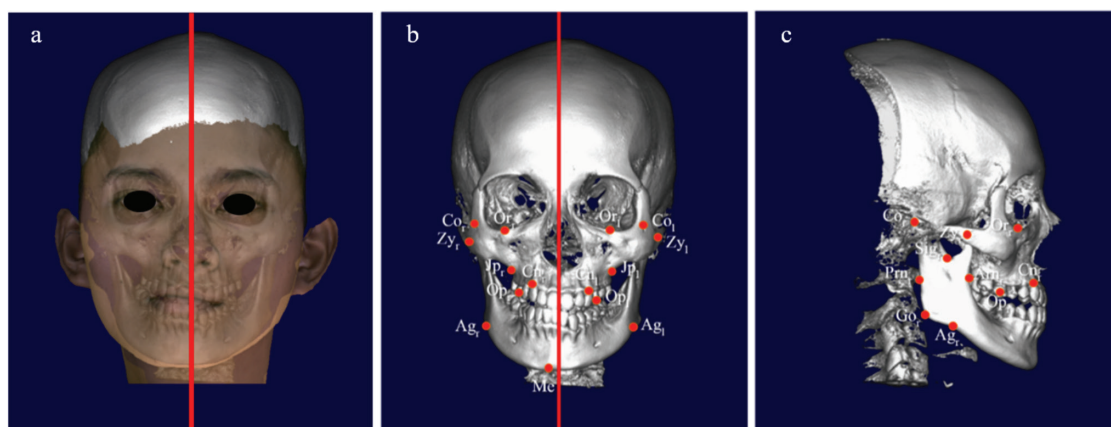


Figure 2 (a) 3D virtual head composed of hard and soft tissue (b) Landmarks of hard tissue in frontal view (c) Landmarks of hard tissue in lateral view

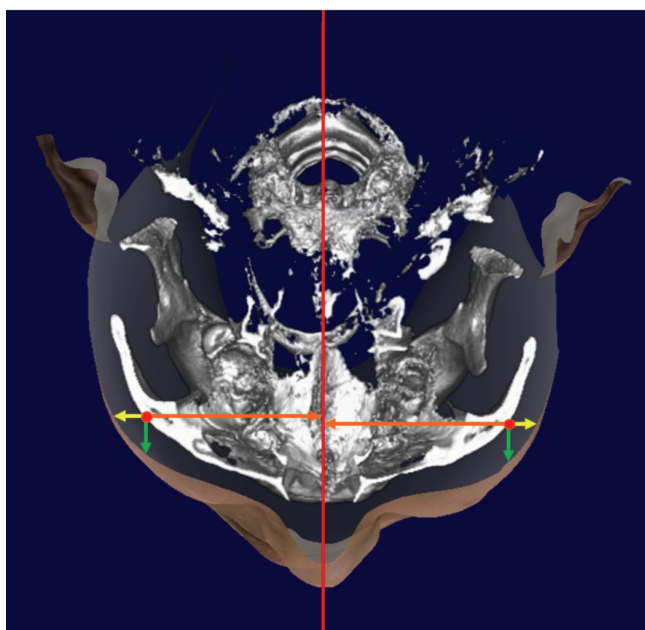


Figure 3 Measurement of soft tissue thickness at each bilateral landmark (red dot) in the transverse direction (yellow arrow), sagittal direction (green arrow). Skeletal asymmetry was assessed as the perpendicular distance from the midsagittal plane (orange arrow).

All landmarks were identified by a single calibrated investigator. Calibration was performed prior to the study using 10 randomly selected cases to ensure consistency in landmark localization.

Measurements were obtained in two stages. Skeletal asymmetry was assessed by measuring the perpendicular distance from each landmark to the

midsagittal plane. Soft tissue thickness was measured in two directions. The transverse direction was defined as the horizontal distance from each skeletal landmark to the corresponding external soft tissue point perpendicular to the midsagittal plane. The sagittal direction was defined as the anteroposterior distance from the skeletal landmark to the outermost soft tissue surface along the sagittal axis. The corresponding soft tissue point was identified as the closest external surface point aligned with each measurement direction using the fused 3D model.

Three parameters were recorded for each landmark: skeletal deviation, transverse soft tissue thickness, sagittal soft tissue thickness, as shown in Figure 3. All measurements were performed twice by the same investigator, and the mean values were used for statistical analysis.

Statistical analysis

Statistical analysis was performed using SPSS software (version 26.0; IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated as means and standard deviations. Data normality was assessed using the Kolmogorov–Smirnov test, which confirmed normal distribution of all variables. Paired t-tests were used to compare measurements between deviated and contralateral sides. Statistical significance was defined as $P < 0.05$.

Prior to data collection, ten cases were used for examiner calibration to ensure consistency in landmark identification. After completion of all measurements, intra-examiner reliability was assessed using 15 randomly selected cases, which were re-measured after a two-week interval, so that the

sample used for ICC calculation was independent from the initial calibration set. Reliability was assessed using the intraclass correlation coefficient, demonstrating excellent reproducibility (ICC = 0.94; 95 % confidence interval, 0.90 – 0.97).

Table 1 General characteristics of the patients including the menton deviation direction.

	Total n = 60	Female n = 33	Male n = 27
Age (year, mean $\pm$ SD)	24.11 $\pm$ 3.88	24.12 $\pm$ 4.34	24.10 $\pm$ 3.45
Menton deviation (mm, mean $\pm$ SD)	3.97 $\pm$ 1.41	4.34 $\pm$ 1.61	3.52 $\pm$ 0.98
Side of menton deviation			
Right	34	23	11
Left	26	10	16

Table 2 Distance from hard tissue landmarks to midsagittal plane

Landmark	Deviated side	Contralateral side	Difference	P value
Condylion (Co)	51.24 $\pm$ 2.91	50.39 $\pm$ 2.89	0.90 $\pm$ 2.66	0.001**
Zygion (Zy)	61.08 $\pm$ 4.22	60.52 $\pm$ 3.74	0.69 $\pm$ 3.10	0.164
Orbitale (Or)	33.39 $\pm$ 4.07	31.94 $\pm$ 2.97	1.66 $\pm$ 3.16	< 0.0001***
Sigmoid notch (Sig)	49.37 $\pm$ 2.12	48.39 $\pm$ 2.34	1.03 $\pm$ 1.52	0.001**
Posterior ramus notch (Pmn)	49.06 $\pm$ 2.08	48.16 $\pm$ 2.20	0.84 $\pm$ 1.68	0.001**
Anterior ramus notch (Arn)	44.63 $\pm$ 1.80	43.33 $\pm$ 1.96	1.34 $\pm$ 1.94	0.001**
Antegonial notch (Ag)	44.79 $\pm$ 3.28	42.71 $\pm$ 5.13	2.09 $\pm$ 4.40	0.001**
Canini (Cn)	19.85 $\pm$ 2.10	19.22 $\pm$ 2.08	0.72 $\pm$ 1.62	0.004**
Gonion (Go)	45.90 $\pm$ 3.34	44.79 $\pm$ 3.19	1.06 $\pm$ 2.24	0.001**

Values are presented as mean $\pm$ standard deviation (SD). Comparisons between the deviated and contralateral sides were performed using paired t-tests.

** P < 0.01; *** P < 0.001.

Results

A total of 60 patients (33 females and 27 males) with facial asymmetry were included in this study. The mean age was 24.11 ± 3.88 years. The mean menton deviation was 3.97 ± 1.41 mm, with greater deviation observed in females (4.34 ± 1.61 mm) than in males (3.52 ± 0.98 mm). Right-sided deviation was observed in 34 patients (56.7 %), whereas 26 patients (43.3 %) showed left-sided deviation. Female patients more frequently exhibited right-sided deviation (69.7 %), while left-sided deviation was more common among male patients (59.3 %) (Table 1).

Distances from hard tissue landmarks to the midsagittal plane are presented in Table 2. Significant differences between the deviated and contralateral sides were observed at multiple landmarks, including the antegonial notch (2.09 ± 4.40 mm, $P < 0.001$), orbitale (1.66 ± 3.16 mm, $P < 0.001$), and anterior ramus notch (1.34 ± 1.94 mm, $P < 0.01$). Additional significant

differences were identified at the condylion, sigmoid notch, posterior ramus notch, canini, and gonion. No significant difference was observed at the zygion.

The total distance from the midsagittal plane to the outermost soft tissue surface at each corresponding hard tissue landmark was evaluated. These measurements, which incorporate both skeletal deviation and overlying soft tissue thickness, are summarized in Table 3 for the deviated and contralateral sides. The largest differences were observed at the orbitale (1.22 ± 4.31 mm), antegonial notch (0.91 ± 4.39 mm), and condylion (0.79 ± 2.95 mm). However, only the anterior ramus notch demonstrated a statistically significant difference (-0.57 ± 2.08 mm, $P < 0.01$). No significant differences were observed at the other landmarks.

Soft tissue thickness in the transverse direction is presented in Table 4. Significant differences between the deviated and contralateral sides were identified at several landmarks. The anterior ramus

Table 3 Total distance from the midsagittal plane to the outermost soft tissue surface

Landmark	Deviated side	Contralateral side	Difference	P value
Condylion (Co)	71.87 ± 2.81	71.13 ± 3.18	0.79 ± 2.95	0.051
Zygion (Zy)	71.08 ± 4.33	71.46 ± 3.54	-0.25 ± 3.12	0.348
Orbitale (Or)	53.35 ± 5.13	52.23 ± 5.45	1.22 ± 4.31	0.051
Sigmoid notch (Sig)	70.05 ± 3.08	69.91 ± 2.99	0.16 ± 1.88	0.058
Posterior ramus notch (Prn)	66.58 ± 2.99	66.44 ± 2.70	0.06 ± 2.38	0.642
Anterior ramus notch (Arn)	65.47 ± 2.36	66.02 ± 2.52	-0.57 ± 2.08	0.001**
Antegonial notch (Ag)	57.05 ± 3.51	56.66 ± 3.41	0.91 ± 4.39	0.300
Canini (Cn)	44.77 ± 5.27	45.40 ± 5.88	-0.63 ± 2.99	0.109
Gonion (Go)	59.51 ± 4.35	59.40 ± 4.43	0.11 ± 2.23	0.692

Values are presented as mean $\pm$ standard deviation (SD). Comparisons between the deviated and contralateral sides were performed using paired t-tests.

** $P < 0.01$; *** $P < 0.001$.

Table 4 Soft tissue thickness in transverse direction

Landmark	Deviated side	Contralateral side	Difference	P value
Condylion (Co)	20.64 ± 2.75	21.49 ± 6.26	-0.10 ± 2.51	0.278
Zygion (Zy)	9.97 ± 2.14	11.23 ± 3.05	-0.95 ± 1.48	0.001**
Orbitale (Or)	19.84 ± 4.10	20.20 ± 4.77	-0.50 ± 2.62	0.303
Sigmoid notch (Sig)	20.68 ± 1.90	22.04 ± 4.15	-0.85 ± 1.57	0.001**
Posterior ramus notch (Prn)	17.55 ± 2.65	19.16 ± 6.75	-0.75 ± 1.75	0.070
Anterior ramus notch (Arn)	20.84 ± 2.12	23.09 ± 3.08	-1.94 ± 1.59	0.001**
Antegonial notch (Ag)	12.29 ± 1.86	14.11 ± 4.93	-1.21 ± 1.68	0.006**
Canini (Cn)	24.84 ± 5.33	26.14 ± 5.35	-1.37 ± 2.76	0.001**
Gonion (Go)	13.67 ± 3.95	15.59 ± 7.97	-0.98 ± 1.41	0.004**

Values are presented as mean ± standard deviation (SD). Comparisons between the deviated and contralateral sides were performed using paired t-tests.

** $P < 0.01$; *** $P < 0.001$.

Table 5 Soft tissue thickness in sagittal direction

Landmark	Deviated side	Contralateral side	Difference	P value
Condylion (Co)	64.36 ± 3.01	63.56 ± 3.90	0.93 ± 2.93	0.004**
Zygion (Zy)	24.26 ± 2.93	24.61 ± 3.37	0.47 ± 5.61	0.368
Orbitale (Or)	8.03 ± 1.67	7.95 ± 1.75	0.26 ± 1.03	0.724
Sigmoid notch (Sig)	51.84 ± 2.98	51.33 ± 3.32	0.57 ± 2.62	0.153
Posterior ramus notch (Prn)	64.93 ± 3.30	64.47 ± 4.17	0.72 ± 3.17	0.281
Anterior ramus notch (Arn)	41.22 ± 2.82	40.85 ± 2.69	0.49 ± 2.86	0.347
Antegonial notch (Ag)	42.82 ± 5.08	41.86 ± 5.69	1.26 ± 4.73	0.006**
Canini (Cn)	17.02 ± 4.64	17.05 ± 4.37	0.12 ± 2.40	0.016
Gonion (Go)	59.30 ± 6.33	58.63 ± 6.51	1.11 ± 3.92	0.004**

Values are presented as mean ± standard deviation (SD). Comparisons between the deviated and contralateral sides were performed using paired t-tests.

** $P < 0.01$; *** $P < 0.001$.

notch showed the greatest difference (-1.94 ± 1.59 mm, $P < 0.01$), followed by the canini, antegonial notch, and gonion. Additional significant differences

were observed at the zygion and sigmoid notch. No significant differences were found at the condylion or orbitale.

Finally, soft tissue thickness in the sagittal direction is shown in Table 5. Significant differences were observed at the condylion (0.93 ± 2.93 mm), antegonial notch (1.26 ± 4.73 mm), and gonion (1.11 ± 3.92 mm), with thicker soft tissue observed on the deviated side. Other landmarks, including the zygion, sigmoid notch, anterior ramus notch, and canini showed no statistically significant differences.

Discussion

The present study evaluated the relationship between skeletal asymmetry and soft tissue thickness in patients with facial asymmetry using integrated 3D facial scanning and cone beam computed tomography. The findings demonstrate that skeletal discrepancies—particularly at landmarks such as the antegonial notch, orbitale, and anterior ramus notch—were more pronounced and consistently significant than those observed in the overlying soft tissues. Although variations in soft tissue thickness was detected at several landmarks, including the orbitale, antegonial notch, and condylion, their magnitude was generally smaller and statistical significance less consistent. These observations are consistent with previous studies reporting that soft tissue typically reflects, rather than compensates for, underlying skeletal asymmetry.^{7,16,17} For instance, in patients with skeletal Class III malocclusion, soft tissue asymmetry is often detectable but rarely offsets skeletal discrepancies, and strong correlations have been reported between corresponding hard and soft tissue landmarks.¹

When analyzed according to measurement direction, a distinct pattern of soft tissue adaptation emerged. In the transverse dimension, soft tissue thickness tended to be thinner on the deviated side. This reduction in soft tissue thickness may partially reduce the prominence of skeletal deviation when viewed from the frontal perspective, thereby providing a limited camouflage effect.^{17,18} However, this effect was inconsistent across anatomical regions and did not fully

compensate for the underlying skeletal discrepancy. In contrast, sagittal measurements demonstrated a tendency for soft tissue to be thicker on the deviated side at several landmarks. This directional difference suggests that soft tissue adaptation does not occur uniformly but varies according to the measurement plane. Similar observations have been reported in previous investigations, indicating that soft tissue responses to skeletal asymmetry are complex and often region-specific.^{17,19}

The presence of thinner soft tissue in the transverse plane and thicker soft tissue in the sagittal plane on the deviated side highlights a direction-dependent pattern of soft tissue adaptation. While mild soft tissue thinning may visually reduce the lateral projection of skeletal deviation, increased soft tissue thickness in the sagittal dimension may accentuate asymmetry in profile or oblique views. These findings support earlier reports suggesting that soft tissue compensation is limited and often inconsistent, particularly in cases with pronounced skeletal discrepancies.²⁰ Furthermore, certain mandibular regions have been shown to demonstrate compensatory responses on the contralateral side, emphasizing the individualized and complex nature of soft tissue adaptation to skeletal imbalance.^{21,22}

Landmark-specific differences in both skeletal deviation and soft tissue thickness was also observed in the present study. Lower facial landmarks—especially the antegonial notch, and gonion,—demonstrated the most pronounced asymmetries. Among these, the antegonial notch exhibited the largest bilateral discrepancy. These results are consistent with previous reports indicating that asymmetry is more prominent in the lower and lateral facial regions, whereas the midfacial structures tend to remain relatively symmetrical.^{4,7,8} This distribution is commonly attributed to the longer growth period and greater biomechanical mobility of the mandible compared with the relatively stable midfacial skeleton.^{1,23}

Although soft tissue generally followed the pattern of skeletal asymmetry, the degree of correspondence varied across anatomical regions. In some areas, soft tissue partially reflected the underlying skeletal imbalance, whereas in others it appeared to exaggerate the visible asymmetry. Notably, regions associated with the condylar and ramal structures sometimes demonstrated inverse relationships between skeletal displacement and soft tissue thickness. These findings emphasize the importance of region-specific three-dimensional analysis when evaluating patients with facial asymmetry and planning orthodontic or orthognathic treatment.²⁴

From a clinical perspective, the present findings highlight the limitations of relying solely on visual assessment or two-dimensional imaging when diagnosing facial asymmetry. Because soft tissue thickness may partially mask or accentuate skeletal discrepancies depending on the measurement direction and anatomical region, two-dimensional evaluation may underestimate the extent of skeletal imbalance. The integration of cone beam computed tomography and three-dimensional facial scanning allows simultaneous visualization of both skeletal structures and the overlying soft tissues, enabling more accurate diagnosis and individualized treatment planning.²⁵⁻²⁷ From a clinical standpoint, these findings suggest that virtual surgical planning should take direction-dependent soft tissue behavior into account when estimating soft tissue-to-hard tissue movement ratios. In the transverse dimension, thinner soft tissue on the deviated side may partially reduce the visible prominence of the underlying bony deviation, meaning that a simple one-to-one skeletal correction may underestimate the remaining soft tissue asymmetry. In contrast, thicker soft tissue in the sagittal dimension on the deviated side may enhance the appearance of asymmetry after mandibular or ramal repositioning. This suggests that adjustments in planned skeletal movements, or consideration of adjunctive soft tissue procedures,

may help achieve more balanced facial contours. Incorporating these direction-specific considerations into three-dimensional simulations may improve the accuracy of aesthetic outcome prediction and help clinicians communicate more realistic expectations to patients with facial asymmetry.

In addition, landmark-based analysis provides valuable information regarding the regional behavior of soft tissues in response to skeletal asymmetry. While mild cases may exhibit limited soft tissue camouflage, more pronounced skeletal deviations often remain clearly visible in the overlying soft tissues. Moreover, postoperative soft tissue responses remain partly unpredictable, and residual asymmetry may persist despite adequate skeletal correction.²⁸⁻³⁰ Consequently, comprehensive three-dimensional evaluation and careful preoperative planning are essential for achieving optimal functional and aesthetic outcomes.

This study has some limitations. First, the cross-sectional design does not allow evaluation of longitudinal changes in soft tissue following surgical correction. Second, the study population consisted of patients seeking orthodontic and orthognathic treatment, which may limit generalizability to the broader population. Future longitudinal studies incorporating postoperative outcomes may further clarify the dynamic relationship between skeletal correction and soft tissue adaptation.

The use of 3D simulation and virtual planning has become a critical tool, allowing clinicians to better predict hard and soft tissue changes and align treatment with patient-specific anatomy and aesthetic goals.^{25,27} Evidence from systematic reviews supports improved outcomes with these approaches, though individual variability in soft tissue response remains a key consideration.²⁸

Overall, the present findings demonstrate that soft tissue thickness in facial asymmetry exhibits a direction-dependent pattern rather than uniform compensation for skeletal deviation. Comprehensive

three-dimensional evaluation of both skeletal structures and soft tissues is therefore essential for accurate diagnosis and effective treatment planning in patients with facial asymmetry.

Conclusion

Soft tissue thickness in facial asymmetry demonstrates direction-dependent patterns rather than uniform compensation for underlying skeletal deviations. In the transverse dimension, soft tissue tends to be thinner on the deviated side, whereas in the sagittal dimension it may be relatively thicker. These findings indicate that soft tissue morphology may partially reflect or even accentuate skeletal asymmetry depending on the anatomical region and measurement direction. Therefore, comprehensive three-dimensional evaluation using cone beam computed tomography combined with facial scanning is essential for accurate diagnosis and individualized orthodontic and orthognathic treatment planning in patients with facial asymmetry.

Author contributions

Tanapat Jearanai: Conceptualization, data curation, formal analysis, investigation, methodology, software, validation, visualization, writing - original draft preparation, writing - review and editing. **Bancha Samruajbenjakun:** Conceptualization, methodology, supervision, validation, visualization, writing - review and editing.

Ethical statement

This study was approved by the Human Research Ethics Committee of the Faculty of Dentistry, Prince of Songkla University (EC6602-006).

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 revision. All scientific content was developed and verified by the authors, who take full responsibility for the accuracy and integrity of the manuscript.

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Dentoalveolar Effects of Miniscrew-Assisted Transpalatal Arch versus Clear Aligner in Anterior Open Bite: A Prospective Cephalometric Study

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Abstract

Background: Treatment of anterior open bite commonly involves anterior extrusion, posterior intrusion, or both. Miniscrew-assisted transpalatal arch (MT) mechanics have been used for maxillary posterior intrusion, whereas clear aligner (CA) therapy has become popular because of its esthetic advantages. However, the mechanics of open-bite correction with clear aligners remain controversial. **Objective:** To compare dentoalveolar changes following anterior open bite treatment with MT mechanics versus CA therapy using lateral cephalometric analysis. **Materials and methods:** In this single-center prospective cohort study, 34 adults with anterior open bite (0–4 mm) were treated and evaluated: 15 in the MT group and 19 in the CA group. Lateral cephalograms were obtained at pretreatment (T0) and after 6 months (T1). Within- and between-group dentoalveolar changes were analyzed using paired and independent *t*-tests ($P < 0.05$). **Results:** Both treatments significantly reduced the anterior open bite, with no significant between-group difference in overbite change (MT = 3.17 mm, CA = 3.11 mm). MT produced greater maxillary first molar intrusion than CA (U6-PP: MT = 2.01 mm, CA = 0.82 mm). Only the CA group showed a significant increase in anterior dental height (ADH: CA = +1.93 mm). CA showed greater decreases in U1-NA angulation (CA = -5.87° , MT = $+2.67^\circ$) and U1-NA distance (CA = -1.98 mm, MT = +0.76 mm). Overjet decreased more with CA ($P < 0.05$). **Conclusion:** MT with partial fixed anterior archwire primarily produced posterior intrusion and minimal incisor changes, whereas CA predominantly produced maxillary incisor extrusion and retroclination with limited molar intrusion.

Keywords: Anterior open bite, Clear aligner, Dentoalveolar change, Miniscrew

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Introduction

An anterior open bite is characterized by a lack of vertical overlap between the incisal edges of the maxillary and mandibular anterior teeth.¹ The etiology of anterior open bite is multifactorial, involving skeletal, dental, soft tissue, and habitual factors. Therefore, multiple treatment strategies have been developed according to the underlying etiologies and dentoskeletal characteristics of each patient.² Anterior open bite can adversely affect smile esthetics, speech function, swallowing due to lingual interposition, and incisal biting function.^{1,3-7} Various treatment methods aim to correct anterior open bite by eliminating etiologic factors, improving function and esthetics, and promoting treatment stability.⁸⁻¹¹ Treatment modalities are selected based on the patient's age and the underlying etiology. These may include correction of parafunctional habits such as tongue thrusting, interceptive treatment in growing patients, orthodontic camouflage treatment for mild to moderate anterior open bite, and a combined orthodontic-surgical approach for severe skeletal problems.¹²

In non-growing patients with mild to moderate anterior open bite, treatment modalities include camouflage approaches involving incisors extrusion, posterior teeth intrusion, or a combination of both. In patients requiring premolar extraction due to space deficiency or anterior protrusion, the drawbridge effect may also contribute to open bite correction.¹²

Skeletal anchorage provides absolute anchorage for posterior teeth intrusion, followed by counterclockwise mandibular rotation, thereby contributing to anterior open bite reduction.¹³⁻¹⁶ Retrospective studies have reported an association between maxillary molar intrusion and reduction of anterior open bite.^{10,13-16} Several methods have been proposed to prevent transverse tipping of maxillary posterior teeth during intrusion, including bilateral miniscrew placement combined with a continuous archwire and application of intrusive forces through the

center of resistance (CRe) of the posterior segments.¹⁷ However, without posterior segment consolidation, these methods require at least two miniscrews, one on each side, to achieve posterior tooth intrusion. Moreover, the magnitude of the vertical intrusive force on each side must be equal. The transpalatal arch (TPA) has been widely used for anchorage control in orthodontic treatment. The use of a miniscrew combined with TPA^{15,18} (a miniscrew-assisted TPA) helps consolidate the posterior segment during intrusion, prevent transverse tipping of the molars, and reduce the need for force calibration at each activation, while requiring only a single palatal miniscrew. However, full-fixed orthodontic appliances may be necessary for other mechanics, such as leveling and aligning the entire arch following maxillary posterior teeth intrusion.¹³

Recently, clear aligners have been widely used for the treatment of anterior open bite because of their esthetic advantages and avoidance of miniscrew placement. Previous studies on clear aligner treatment for anterior open bite correction have reported varying tooth movement mechanics, including anterior extrusion and molar intrusion. Although some aligner protocols have demonstrated successful anterior teeth extrusion, the effectiveness of posterior teeth intrusion remains controversial.¹⁹⁻²⁴ Therefore, further optimization of aligner protocols is required to achieve predictable outcomes.

Masticatory exercises have been recommended as an adjunctive treatment for open bite malocclusion, which is often associated with reduced masticatory muscle function. These exercises may improve vertical control and reduce aberrant vertical growth patterns. Previous studies incorporating squeezing (clenching) during clear aligner therapy have also reported increased bite force in anterior open bite patients.²⁵ Therefore, the present clear aligner protocol with squeezing exercises was designed based on these biomechanical considerations to enhance vertical control and promote favorable posterior dentoalveolar

changes. This study aimed to compare dentoalveolar changes produced by two different mechanics, anterior teeth extrusion and posterior teeth intrusion, to provide clinicians with information for selecting appropriate treatment approaches for anterior open bite.

Materials and methods

Study design, setting, participants, and criteria

This study was a single-center prospective cohort study. The participants were adult patients with anterior open bite, aged 18–35 years, who met the following inclusion criteria: 1) anterior dental open bite of 0–4 mm, measured from canine to canine; 2) incisal show at rest of 0–2 mm; 3) normal smile line; 4) skeletal

Class I or mild Class II relationship ($ANB = 0-5^\circ$); 5) hyperdivergent facial pattern ($SN-MP = 33-39^\circ$); and 6) available lateral cephalograms at pretreatment (T0) and after 6 months of treatment (T1).

The exclusion criteria included: 1) loss of any maxillary posterior teeth except third molars; 2) anterior crossbite; 3) transverse discrepancy; 4) moderate to severe crowding (space deficiency > 7 mm); 5) history of dentoalveolar trauma; 6) neuromuscular or temporomandibular disorders; 7) craniofacial deformities; 8) poor compliance; and 9) use of medications or presence of systemic diseases affecting tooth movement. A total of 34 patients were included: 15 in the MT group and 19 in the CA group.

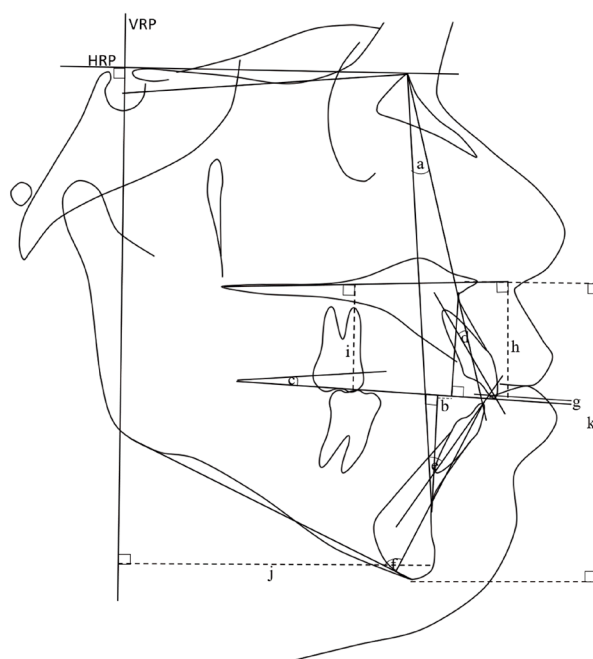


Figure 1 Definition of cephalometric measurements used in this study: ANB, A point-Nasion-B point angle (a); Wits appraisal, the distance between the perpendicular projections of points A and B on the functional occlusal plane (b); OP-SN, the angle between the functional occlusal plane and the SN plane (c); U1-NA, the angle between the long axis of the maxillary incisor and the Nasion-A line (d); L1-NB, the angle between the long axis of the mandibular incisor and the Nasion-B line (e); L1-MP, the angle between the long axis of the mandibular incisor and the mandibular plane (f); U1-OP, the perpendicular distance from the maxillary incisor edge to the functional occlusal plane (g); ADH, anterior dental height, the perpendicular distance from the maxillary incisor edge to the palatal plane (h); U6-PP, the perpendicular distance from the mesial cusp tip of the maxillary first molar to the palatal plane (i); Pg-VRP, the perpendicular distance from Pogonion to the vertical reference plane (VRP) (j); and LAFH, lower anterior facial height, defined as the vertical distance from the anterior nasal spine to Menton (k).

Outcomes

The primary outcomes of this study were the amount of maxillary molar intrusion, measured as the change in the vertical position of the maxillary first molar relative to the palatal plane (U6-PP), and overbite change between T0 and T1 (Figure 1).

The secondary outcomes included changes in incisor position and inclination (U1-NA), anterior dental height (ADH), the distance from the maxillary incisor edge to the functional occlusal plane (U1-OP), the angle between the functional occlusal plane and the SN plane (OP-SN), and overjet (Figure 1). The functional occlusal plane was defined as the line connecting the midpoint of functional intercuspation of the first premolars and the midpoint of the first molars.

Power analysis and sample size

Sample size calculation was performed using G*Power (version 3.1.9.4; Franz Faul, Kiel University, Kiel, Germany) based on the primary outcome of maxillary molar intrusion (U6-PP).²² With a significance level of 0.05 ($\alpha = 0.05$) and statistical power of 80 % ($1 - \beta = 0.80$), 12 patients were required per group. Considering an estimated dropout rate of approximately 20 % per group, the final sample size was set at a minimum of 15 patients per group and a total sample size of at least 30 patients. The participants were recruited from patients attending the Department of Orthodontics, Faculty of Dentistry, Prince of Songkla University. Quota sampling was used, and recruitment continued until the required number of participants with predefined characteristics was reached. All participants were subsequently screened according to the inclusion and exclusion criteria, and only eligible individuals were included.

Treatment protocol in MT group

The protocol for the MT group was modified from Tassanapanont et al.¹⁵ A miniscrew, 2.0 mm in diameter and 6.0 mm in length (AbsoAnchor, Dentos, Daegu, Korea), was placed in the mid-palatal area in the mesial region of the maxillary first molar under local anesthesia. The TPA was fabricated with

a 3.0-mm offset from the palate to preserve vertical space for intrusion, and hooks were soldered to the molar bands on the palatal side to engage the nickel-titanium (NiTi) closed-coil springs during intrusion. Brackets and tubes (0.018-inch slot height; Roth™ system) were placed on the maxillary posterior teeth, and sectional 0.017 × 0.025-inch stainless steel wires were bent to be passively insert in the slots of the maxillary posterior teeth without force. The NiTi closed-coil springs were tied from

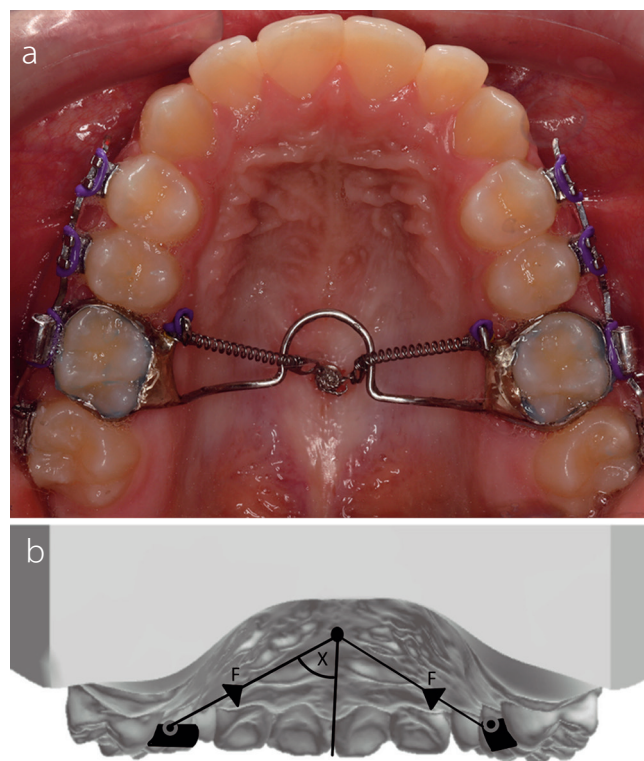


Figure 2 Image of a miniscrew-assisted transpalatal arch. (a) The posterior segment was consolidated to prevent tipping of the posterior teeth. Nickel-titanium (NiTi) closed-coil springs were engaged from the miniscrew to the hooks on the transpalatal arch to generate constant intrusive forces for maxillary posterior teeth intrusion. The protocol was modified from Tassanapanont et al.¹⁵ (b) The resultant intrusive force from each NiTi closed-coil spring was calculated using the formula $F(\sin x^\circ) = 150$ grams (F = the magnitude of force; x = the angle between NiTi closed-coil spring and the vertical line).

the miniscrew to the hooks on the TPA bilaterally to generate the intrusive forces. Premature contact at the anterior teeth that occurred during molar intrusion was corrected using an anterior segmented archwire with pre-adjusted edgewise Roth™ system appliance with 0.018-inch bracket slots on the maxillary anterior teeth.

The magnitude of the resultant intrusive force from each NiTi closed-coil spring was controlled at 150 grams/side with force calibration at 3-week interval. The force was calculated using the formula: $F(\sin x^\circ) = 150 \text{ grams}$ (F = magnitude of force; x = the angle between NiTi closed-coil spring and the vertical line) (Figures 2a, 2b).

Treatment protocol in CA group

A custom-made CA was fabricated entirely in-office using an intraoral scan. Stereolithography (STL) files from the intraoral scanner (TRIOS 3, 3Shape, Copenhagen, Denmark) were imported into the 3Shape OrthoAnalyzer program. The maxillary anterior teeth were set up to extrude 0.2 mm/aligner. A beveled horizontal rectangular attachment was designed on the maxillary anterior teeth from canine to canine (Figures 3a, 3b). A model was printed using a 3D printer (Asiga Pro 4K, Asiga, Sydney, Australia). The CA was fabricated from a 1-mm thick Duran thermoplastic sheet. Patients were instructed to wear the CA for at least 22 hours/day with a 3-week change interval, and to perform squeezing exercises while wearing the CA. The exercise protocol was modified from English and Olfert (2005); briefly, patients were asked to perform a series of six isometric clenches (clenching as hard as possible without pain) on the clear aligner for 5 seconds, followed by 5 seconds of rest, at least 5 times a day (or as often as possible throughout the day). During the 6-month observation period, no mandibular appliances or other active orthodontic interventions were applied to the mandibular arch in either group.

Cephalometric analysis

All lateral cephalograms were taken with the same cephalostat and cephalometric machine at

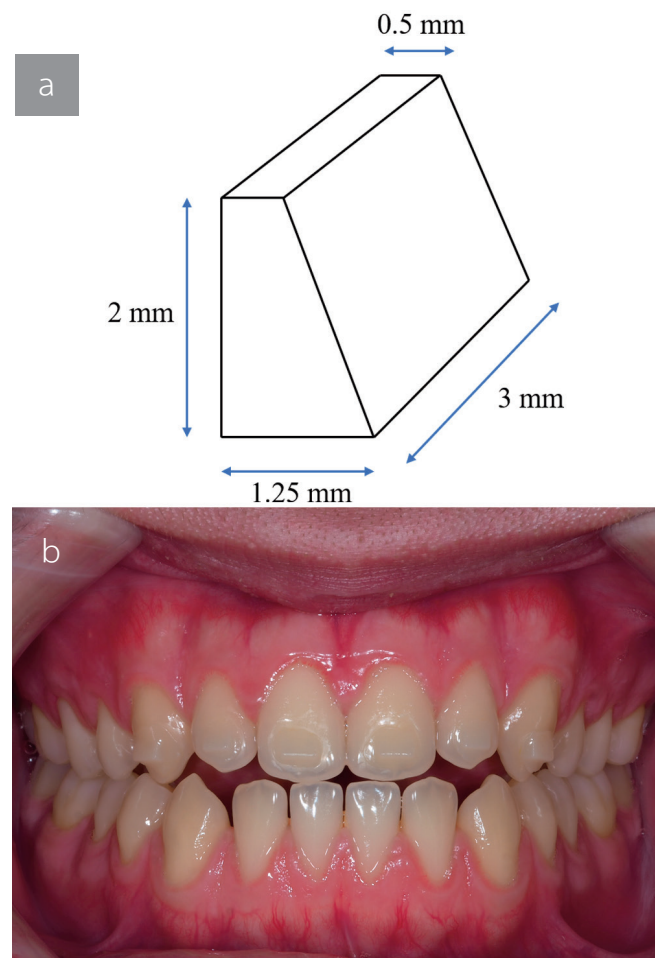


Figure 3 Images of beveled horizontal rectangular attachments placed on the maxillary anterior teeth. (a) The attachment design consisted of 0.5-mm thickness on the gingival side; 1.25-mm thick toward the occlusal surface; with dimensions of 3 × 2 mm (width and height). Reproduced from Withayanukonkij et al.²⁴ (b) An intraoral photograph showing the position and shape of the attachments.

T0 and T1 for all subjects. Natural head position was established for standardization. The cephalograms were digitized and analyzed using Dolphin Imaging software (Dolphin Imaging and Management Solutions, Chatsworth, CA, USA). All cephalometric landmarks were located and measured by one researcher after intra-observer reliability testing. Ten lateral cephalograms were randomly selected and remeasured by the same investigator after a 2-week interval to assess measurement errors. The measurement error was calculated by Dahlberg's

formula. The mean error was 0.13–0.18 mm for linear measurements and 0.11–0.16° for angular measurements. Intra-observer reliability, assessed using the intraclass correlation coefficient (ICC), was 0.94–0.97 for all cephalometric measurements, which indicated excellent reliability.

Statistical analysis

All data were analyzed with SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Means and standard deviations were calculated. The normality of the distributions of all variables was tested using the Shapiro-Wilk test; most data showed a normal distribution. Log transformation was applied to variables with a non-normal distribution prior to statistical comparison. The Chi-square test was used to determine the distribution of gender between the two groups. The independent *t*-tests were used to compare pretreatment data between groups at T0 and to compare the difference in cephalometric parameters (T1–T0) between the MT and CA groups. The paired *t*-tests were used to compare cephalometric parameters within each group between T0 and T1. The significance level adopted in this study was 5 % (P value < 0.05).

Results

Thirty-four subjects (9 males and 25 females) with a mean age of 24.97 ± 5.87 years were recruited for this study. The MT group consisted of 15 patients (2 males and 13 females) and the CA group consisted of 19 patients (7 males and 12 females). There was no significant difference in gender distribution between the MT and CA groups (P value = 0.12) (Table 1).

Comparisons of cephalometric parameters between the MT and CA groups were performed at pretreatment (T0), after 6 months of treatment (T1), and for the changes from T0 to T1 (Table 2). Significant maxillary molar intrusion (U6-PP) was observed in both groups: 2.01 ± 0.22 mm in the MT group and 0.82 ± 0.12 mm in the CA group. The MT group

demonstrated 1.19 mm greater molar intrusion than the CA group (P value < 0.001).

Overbite increased significantly in both groups. Mean overbite changes were 3.17 ± 0.44 mm in the MT group and 3.11 ± 0.42 mm in the CA group (P value < 0.001), with no significant difference between groups (P value > 0.05).

The position and inclination of the maxillary incisors, assessed by U1-NA angulation and U1-NA distance, changed significantly in both groups. In the CA group, U1-NA angulation and U1-NA distance decreased by $5.87 \pm 3.60^\circ$ and 1.98 ± 1.14 mm, respectively (P value < 0.001). In contrast, in the MT group, U1-NA angulation and U1-NA distance increased by $2.67 \pm 4.43^\circ$ (P value = 0.050) and 0.76 ± 1.19 mm (P value = 0.027), respectively. The between-group differences were 8.55° for U1-NA angulation and 2.74 mm for U1-NA distance (P value < 0.001).

In the CA group, anterior dental height (ADH) increased significantly by 1.93 ± 0.38 mm, which was 1.71 mm greater than that in the MT group (P value < 0.001).

The distance from the maxillary incisor edge to the functional occlusal plane (U1-OP) decreased in both groups (1.31 ± 0.51 mm in the MT and 2.01 ± 0.43 mm in the CA). The between-group difference was 0.69 mm and was statistically significant (P value < 0.001).

The OP-SN angle increased in both groups, with a greater increase in the MT group ($3.98 \pm 1.24^\circ$) than in the CA group ($1.09 \pm 0.53^\circ$). The between-group difference was 2.89° , which was statistically significant (P value < 0.001).

Overjet decreased significantly in the CA group by 0.76 ± 0.35 mm (P value < 0.001). Compared with the MT group, the reduction in overjet was significantly greater in the CA group by 0.58 mm (P value = 0.002).

The interincisal angle increased significantly in both groups, by $5.49 \pm 2.91^\circ$ in the CA group (P value < 0.001) and by $3.05 \pm 3.45^\circ$ in the MT group

(P value = 0.004). The increase was significantly greater in the CA group than in the MT group by 2.44° (P value < 0.001).

ANB showed a significant decrease only in the MT group ($-1.38 \pm 0.64^\circ$; P value < 0.001).

Wits appraisal, representing the maxillomandibular relationship relative to the functional occlusal plane, also decreased significantly only in the MT group (-2.26 ± 1.87 mm; P value < 0.001).

Table 1 Comparison of gender, and cephalometric parameters between the MT and CA groups at pretreatment (T0)

Cephalometric parameters	MT	CA	P value
	Mean $\pm$ SD	Mean $\pm$ SD	
FH-SN ($^\circ$)	8.55 ± 3.23	7.38 ± 2.99	0.289
SNA ($^\circ$)	81.43 ± 4.03	85.17 ± 5.22	0.029*
SNB ($^\circ$)	78.12 ± 4.60	82.38 ± 4.71	0.013*
ANB ($^\circ$)	3.31 ± 2.44	2.79 ± 1.73	0.493
Wits appraisal (mm)	-2.86 ± 4.05	-3.12 ± 2.14	0.827
A-Nperp (mm)	-0.19 ± 3.26	-2.63 ± 4.55	0.078
Pg-Nperp (mm)	-7.27 ± 8.06	-2.43 ± 8.22	0.095
SN-MP ($^\circ$)	35.57 ± 7.19	33.08 ± 5.74	0.284
OP-SN ($^\circ$)	19.67 ± 4.63	15.97 ± 6.15	0.054
Y-axis ($^\circ$)	67.72 ± 4.67	68.14 ± 4.21	0.789
U1-NA ($^\circ$)	25.05 ± 8.54	29.87 ± 7.31	0.093
U1-NA (mm)	6.51 ± 2.68	7.28 ± 2.73	0.415
L1-NB ($^\circ$)	38.25 ± 8.47	40.31 ± 6.48	0.443
L1-NB (mm)	8.79 ± 2.63	8.97 ± 2.20	0.832
L1-MP ($^\circ$)	97.69 ± 8.96	104.95 ± 8.22	0.021*
U1-L1 ($^\circ$)	114.01 ± 12.33	106.80 ± 10.56	0.083
U1-OP (mm)	-1.40 ± 2.66	-1.38 ± 1.65	0.984
ADH (mm)	27.65 ± 1.97	26.63 ± 2.41	0.181
U6-PP (mm)	20.08 ± 1.55	19.27 ± 2.23	0.223
L6-MPperp (mm)	28.46 ± 3.62	31.15 ± 2.99	0.028*
Overjet (mm)	2.67 ± 0.64	2.78 ± 0.53	0.587
Overbite (mm)	-1.93 ± 0.68	-1.85 ± 0.90	0.771
Pg-VRP (mm)	51.11 ± 10.17	54.02 ± 8.94	0.389
Me-HRP (mm)	106.27 ± 6.52	108.29 ± 7.03	0.391
LAFH (mm)	66.00 ± 3.83	65.71 ± 4.87	0.852
Gender, n (%)			
Male	2 (13.3)	7 (36.8)	0.123 ^a
Female	13 (86.7)	12 (63.2)	

Independent t -test; ^aChi-square test; * P value < 0.05

Pg-VRP, representing the anteroposterior position of the mandible, increased significantly in both groups, with values of 3.69 ± 0.12 mm in the MT group and 1.83 ± 0.71 mm in the CA group. The increase was significantly greater in the MT group than in the CA group, with a mean difference of 1.86 mm (P value < 0.001).

Lower anterior facial height (LAFH) decreased significantly in both groups, with reductions of

3.43 ± 0.25 mm in the MT group and 1.61 ± 0.25 mm in the CA group. The decrease was greater in the MT group by 1.82 mm (P value < 0.001).

The lower incisor position and inclination, including L1-NB angulation, L1-NB distance, and L1-MP, showed no significant changes in either group (P value > 0.05).

Table 2 Within-group comparisons of cephalometric parameters between pretreatment and 6 months of treatment (T0-T1)^a and between-group comparisons of cephalometric parameter changes (MT vs CA)^b.

Cephalometric parameters	MT				CA				Mean Difference MT-CA	P value
	T0 Mean $\pm$ SD	T1 Mean $\pm$ SD	T1-T0 Mean $\pm$ SD	P value	T0 Mean $\pm$ SD	T1 Mean $\pm$ SD	T1-T0 Mean $\pm$ SD	P value		
ANB (°)	3.31 $\pm$ 2.44	1.93 $\pm$ 2.31	-1.38 $\pm$ 0.64	$< 0.001^{***}$	2.79 $\pm$ 1.73	2.67 $\pm$ 1.77	-0.13 $\pm$ 0.35	0.127	1.25	$< 0.001^{***}$
Wits appraisal	-2.86 $\pm$ 4.05	-5.12 $\pm$ 2.95	-2.26 $\pm$ 1.87	$< 0.001^{***}$	-3.12 $\pm$ 2.14	-3.58 $\pm$ 2.72	-0.47 $\pm$ 1.82	0.276	-1.79	0.009**
OP-SN (°)	19.67 $\pm$ 4.63	23.65 $\pm$ 4.63	3.98 $\pm$ 1.24	$< 0.001^{***}$	15.97 $\pm$ 6.15	17.06 $\pm$ 6.17	1.09 $\pm$ 0.53	$< 0.001^{***}$	2.89	$< 0.001^{***}$
U1-NA (°)	25.05 $\pm$ 8.54	27.73 $\pm$ 7.67	2.67 $\pm$ 4.83	0.050	29.87 $\pm$ 7.31	23.99 $\pm$ 5.31	-5.87 $\pm$ 3.60	$< 0.001^{***}$	8.55	$< 0.001^{***}$
U1-NA (mm)	6.51 $\pm$ 2.68	7.27 $\pm$ 2.61	0.76 $\pm$ 1.19	0.027*	7.28 $\pm$ 2.73	5.30 $\pm$ 1.97	-1.98 $\pm$ 1.14	$< 0.001^{***}$	2.74	$< 0.001^{***}$
L1-NB (°)	38.25 $\pm$ 8.47	38.19 $\pm$ 8.52	-0.06 $\pm$ 0.21	0.294	40.31 $\pm$ 6.48	40.18 $\pm$ 6.57	-0.13 $\pm$ 0.22	0.024*	0.07	0.385
L1-NB (mm)	8.79 $\pm$ 2.63	8.78 $\pm$ 2.68	-0.01 $\pm$ 0.25	0.921	8.97 $\pm$ 2.20	8.83 $\pm$ 2.19	-0.14 $\pm$ 0.39	0.143	0.13	0.249
L1-MP (°)	97.69 $\pm$ 8.96	97.64 $\pm$ 8.85	-0.05 $\pm$ 0.34	0.601	104.95 $\pm$ 8.22	104.97 $\pm$ 8.24	0.02 $\pm$ 0.19	0.721	-0.06	0.529
U1-L1 (°)	114.01 $\pm$ 12.33	117.06 $\pm$ 10.72	3.05 $\pm$ 3.45	0.004**	106.80 $\pm$ 10.56	112.29 $\pm$ 10.49	5.49 $\pm$ 2.91	$< 0.001^{***}$	-2.44	0.037*
U1-OP (mm)	-1.40 $\pm$ 2.66	-0.09 $\pm$ 2.46	1.31 $\pm$ 0.51	$< 0.001^{***}$	-1.38 $\pm$ 1.65	0.62 $\pm$ 1.36	2.01 $\pm$ 0.43	$< 0.001^{***}$	-0.69	$< 0.001^{***}$
ADH (mm)	27.65 $\pm$ 1.97	27.87 $\pm$ 1.95	0.22 $\pm$ 0.72	0.258	26.63 $\pm$ 2.41	28.56 $\pm$ 2.43	1.93 $\pm$ 0.38	$< 0.001^{***}$	-1.71	$< 0.001^{***}$
U6-PP (mm)	20.08 $\pm$ 1.55	18.07 $\pm$ 1.46	-2.01 $\pm$ 0.22	$< 0.001^{***}$	19.27 $\pm$ 2.23	18.45 $\pm$ 2.20	-0.82 $\pm$ 0.12	$< 0.001^{***}$	-1.19	$< 0.001^{***}$
Overjet (mm)	2.67 $\pm$ 0.64	2.49 $\pm$ 0.71	-0.18 $\pm$ 0.56	0.234	2.78 $\pm$ 0.53	2.02 $\pm$ 0.38	-0.76 $\pm$ 0.35	$< 0.001^{***}$	0.58	0.002**
Overbite (mm)	-1.93 $\pm$ 0.68	1.24 $\pm$ 0.68	3.17 $\pm$ 0.44	$< 0.001^{***}$	-1.85 $\pm$ 0.90	1.26 $\pm$ 0.65	3.11 $\pm$ 0.42	$< 0.001^{***}$	0.14	0.683
Pg-VRP (mm)	51.11 $\pm$ 10.17	54.80 $\pm$ 10.15	3.69 $\pm$ 0.12	$< 0.001^{***}$	54.02 $\pm$ 8.94	55.85 $\pm$ 9.09	1.83 $\pm$ 0.71	$< 0.001^{***}$	-1.86	$< 0.001^{***}$
LAFH (mm)	66.00 $\pm$ 3.83	62.57 $\pm$ 3.96	-3.43 $\pm$ 0.25	$< 0.001^{***}$	65.71 $\pm$ 4.87	64.10 $\pm$ 4.95	-1.61 $\pm$ 0.25	$< 0.001^{***}$	1.82	$< 0.001^{***}$

^aPaired *t*-test; ^bIndependent *t*-test; * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$,

Discussion

Results showed no significant difference in open bite reduction between the two groups at 6 months. Open bite reductions were 3.17 mm in the MT group and 3.11 mm in the CA group. Previous studies have reported varying amounts of anterior open bite reduction through posterior teeth intrusion using skeletal anchorage, depending on the treatment protocol. Akbaydogan et al. reported 5.8 mm of open bite closure with 4.01 mm of molar intrusion,¹⁶ whereas Kim et al. reported 4.5 mm of open bite closure with 2.2 mm of molar intrusion.¹³

In the present study, the MT group showed greater molar intrusion, whereas the CA group relied more on maxillary incisor extrusion with limited posterior intrusion. This finding is consistent with previous reports showing relatively small amounts of molar intrusion with clear aligners, approximately 0.3–0.6 mm.¹⁹ Therefore, incisor extrusion appeared to contribute more substantially to open bite correction in the CA group. These findings support the concept that clear aligners primarily correct anterior open bite through anterior extrusion rather than predictable molar intrusion.²⁶ In contrast, molar intrusion mechanics have demonstrated more pronounced posterior intrusion and associated mandibular autorotation, supporting the findings observed in the MT group.^{13,16}

The cephalometric findings indicated improvements in overbite and overjet in both groups. In the MT group, overbite improvement was associated with a significant decrease in U6–PP. In the CA group, extrusion and retroclination of the maxillary incisors occurred to a greater extent than in the MT group. Decreases in U1-NA angulation and U1-NA distance were observed accompanied by extrusion of the maxillary incisor relative to the functional occlusal plane (U1-OP) and an increase in anterior dental height (ADH). These vertical and anteroposterior changes may be attributed to the extrusion and palatal crown tipping of the maxillary incisors during

clear aligner treatment. In contrast, in the MT group, alignment of the anterior teeth to prevent interference may have contributed to an increase in U1-NA angulation, whereas no significant vertical changes in the maxillary incisors were observed.

Factors contributing to anterior open bite correction in MT and CA

ANCOVA indicated that age differences between the groups did not affect the primary outcome. Moreover, the study duration was only 6 months. In the MT group, treatment was limited to maxillary molar intrusion, and no appliances were placed in the mandibular arch that could have influenced vertical dentoalveolar changes. Similarly, in the CA group, treatment protocols did not include mechanics aimed at altering mandibular vertical position during the observation period. No significant vertical changes were observed in the mandibular incisors in either group. Therefore, the correction of anterior open bite was primarily attributed to maxillary dentoalveolar changes, specifically maxillary incisor extrusion and maxillary molar intrusion.

Anterior dental height (ADH) was used to represent the vertical position of the maxillary incisors, whereas the vertical position of the maxillary molars was assessed using U6–PP. In the MT group, no significant change in ADH was observed. The use of a partial fixed appliance in the maxillary anterior segment may have acted as a confounding factor when interpreting changes in maxillary incisor position; therefore, the overbite change in the MT group cannot be attributed solely to molar intrusion. However, the absence of a significant change in ADH suggests that true maxillary incisor extrusion was minimal, supporting the interpretation that molar intrusion was the major contributor to overbite correction in the MT group.

In the MT group, the increase in overbite was primarily attributed to maxillary molar intrusion, which measured 2.01 mm and accounted for 93.06 % of the total overbite increase (3.17 mm), whereas incisor

extrusion of 0.22 mm contributed only 6.94 %. In the CA group, maxillary molar intrusion was 0.82 mm, accounting for 38 % of the overbite increase, whereas ADH increased by 1.93 mm, accounting for 62 % of overbite correction. A previous study reported that only 15 % of overbite correction was attributed to molar intrusion with clear aligners.²³ The difference in the percentage of molar intrusion may be related to variations in treatment protocols, including aligner thickness and material properties, which influence the bite-block effect. That study reported approximately 1 mm of unplanned molar intrusion with a 0.75-mm-thick clear aligner.²³ In the present study, the aligner thickness was 1 mm, and squeezing exercises were prescribed; therefore, the observed 0.82 mm of molar intrusion may be partly explained by these factors. Previous studies have shown that squeezing with clear aligners increases bite force in anterior open bite patients.²⁵ This increased force may have contributed to the amount of molar intrusion achieved. In addition, patient compliance with aligner wear and squeezing exercises may further influence the magnitude of intrusion.

Differences in magnitude and duration of force between MT and CA

In the MT group, the TPA helped prevent palatal crown tipping of the maxillary first molars, while sectional 0.017 × 0.025-inch stainless steel wires were placed bilaterally on the maxillary posterior teeth to consolidate the posterior segments. The vertical intrusive forces were controlled, and a light continuous force (150 grams/side, 37.5 grams/tooth) was applied for 6 months. In the CA group, the anterior teeth were programmed for extrusion, and patients were instructed to regularly clench on the clear aligner to promote posterior teeth intrusion. The occlusal force generated on the posterior teeth during squeezing exercises ranged from approximately 195.23–342.98 Newtons.²⁵ In addition, the force delivered by the aligner ranged from

0.18–2.91 Newtons (10.20–203.94 grams), depending on material properties, thermoplastic sheet thickness, amount of activation, and biomechanics.²⁷ However, in the CA group, the magnitude and duration of the intrusive force could not be directly measured. Moreover, the force generated by the clear aligner is intermittent and highly dependent on patient compliance with consistent aligner wear to achieve effective anterior open bite correction.

Differences in force systems and their effects to molars and incisors

In the MT group, the posterior segment was consolidated and intruded as a unit. The line of force passed through the CRe of the posterior segment to minimize occlusal plane tipping (Figures 4a, 4b). In the CA group, the occlusal force contributing to posterior

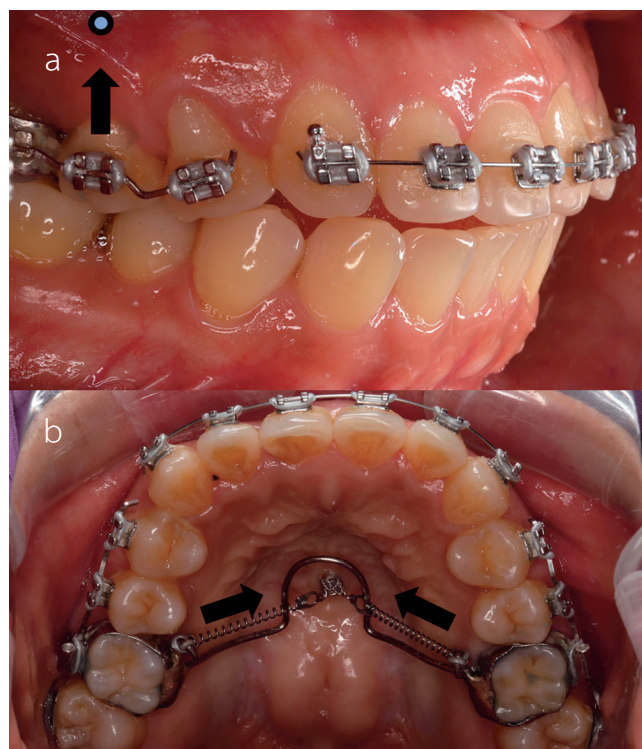


Figure 4 Schematic representation of dentoalveolar changes produced by miniscrew-assisted transpalatal arch mechanics. (a) Maxillary posterior intrusion in the vertical dimension. (b) In the transverse dimension, the TPA prevents posterior teeth from palatal tipping.

teeth intrusion depended on the factors mentioned above. Based on the study by Suh et al., the primary mechanics for correcting anterior open bite with clear aligner is the anterior teeth extrusion. Therefore, beveled attachments were designed on the maxillary incisors to facilitate controlled extrusion of the maxillary anterior teeth. Molar intrusion in clear aligner therapy is mainly influenced by the full-coverage design of the aligner and force distribution across the posterior segment, rather than by attachments on the molars. Thus, attachments were not placed on the maxillary first molars.

The results showed intrusion of the maxillary first molars. It was hypothesized that this intrusion may have occurred as a result of occlusal forces generated by the bite-block effect of clear aligners. This effect occurs when the posterior teeth are separated by the thickness of the aligner, which acts as a posterior bite block and may contribute to posterior teeth intrusion, open bite closure, and vertical control during treatment. When the aligner was fully seated, vertical force was applied primarily to the inclined surfaces of the attachments on the maxillary incisors. As the line of force passed anterior to the CRe (Figure 5), it likely contributed to both extrusion and palatal tipping of the incisors. Consistent with the CA mechanics, U1-NA angulation and distance in the CA group decreased significantly by 5.87° and 1.98 mm, respectively. Furthermore, the reductions in overjet, together with increases in overbite, interincisal angle, and ADH in the CA group, indicate extrusion and retroclination of the maxillary incisors, which contributed to anterior open bite correction (Figures 6a–d). Although clear aligners may result in incisor extrusion, the amount of extrusion was clinically controlled through the treatment protocol and participant selection criteria. Therefore, the inclusion of these participants was not expected to result in excessive incisor display.

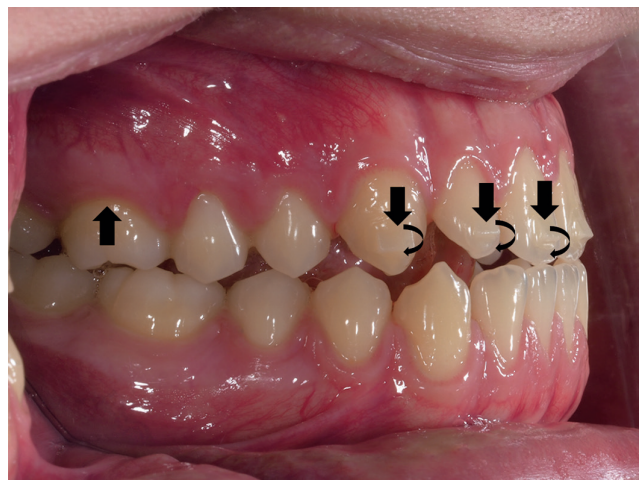


Figure 5 Schematic representation of dentoalveolar changes produced by clear aligners in anterior open bite correction. The extrusive force acting on the maxillary anterior teeth passes anterior to the CRe, generating a moment that may contribute to palatal tipping of the anterior teeth.

Occlusal plane changes

The OP-SN angle increased to a greater extent in the MT group than in the CA group, likely due to the greater amount of maxillary molar intrusion in the MT group, which directly influenced the orientation of the functional occlusal plane. Changes in U1-OP indicated a tendency toward maxillary incisor extrusion relative to the functional occlusal plane in both groups. In the CA group, this change was primarily attributable to extrusion of the maxillary incisors. In contrast, in the MT group, the changes in U1-OP were mainly related to posterior teeth intrusion accompanied by alterations in the functional occlusal plane. In addition, ADH showed no significant change in the MT group, further supporting the interpretation that true maxillary incisor extrusion was minimal, as discussed above.

Vertical control during and after treatment

Previous studies have reported an increase in bite force while wearing an acrylic splint or clear aligner, as these materials provide a more comfortable surface for biting than direct occlusal contact.^{28,30}

Squeezing exercises may further increase muscle activity and enhance bite force on the posterior teeth.²⁵ Increasing both the magnitude and duration of intrusive forces generated during occlusal contact while wearing a clear aligner may help control the vertical dimension.²⁸ In the present study, maxillary first molar intrusion was observed in the CA group, which may be partly attributed to the occlusal forces generated during aligner wear. Therefore, performing squeezing exercises while wearing clear aligners that cover all occlusal surfaces, as well as during the retention period, may contribute to posterior teeth intrusion and enhanced post-treatment stability.

Clinical relevance

In the MT group, maxillary molar intrusion was the major contributor to overbite increase, accounting for 93.06 % of the overbite increase, whereas maxillary incisor extrusion contributed only 6.94 %. In contrast, in the CA group, maxillary molar intrusion accounted for 38 % of overbite increase, whereas the extrusion of the maxillary incisors contributed 62 %. Within this initial phase, both treatment modalities demonstrated measurable vertical and sagittal changes. The decrease in ANB angle and increase in Pg-VRP indicate counterclockwise rotation of the mandible. Moreover, a decrease in lower anterior facial height was observed in both groups. These vertical and sagittal changes were more pronounced in the MT group.

This study demonstrates the early effects of anterior open bite correction using two different appliance mechanics. Maxillary molar intrusion was mainly observed in the MT group, whereas maxillary incisor changes were more pronounced in the CA group. Based on these initial findings, MT mechanics may be considered for patients with mild to moderate skeletal Class II anterior open bite with a hyperdivergent pattern. Posterior teeth intrusion followed by counterclockwise mandibular rotation may contribute to improvements in skeletal Class II discrepancy and vertical facial dimension. Conversely,

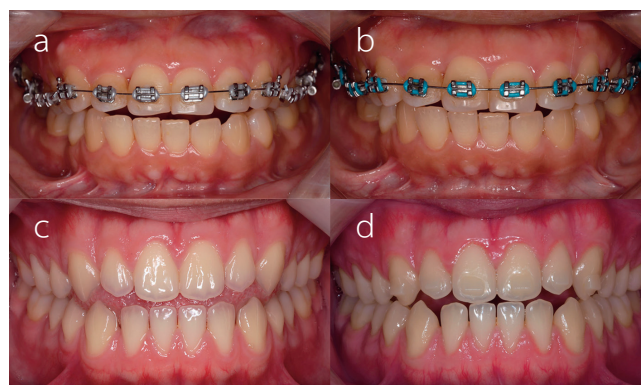


Figure 6 Intraoral photographs. (a) Pretreatment conditions in the MT group. (b) After 6 months of intrusion in the MT group. (c) Pretreatment conditions in the CA group. (d) After 6 months of treatment in the CA group.

in patients with a Class III open bite or hypodivergent pattern, MT mechanics should be used with caution, as they may adversely affect the facial profile and decrease lower facial height, which may be detrimental to facial esthetics. CA mechanics—the extrusion and retroclination of maxillary incisors—may be suitable for anterior open bite patients with a low smile line and mild incisor protrusion or proclination. These dentoalveolar changes may contribute to improvements in the smile line and in the inclination and position of maxillary incisors.

Addressing the etiology of anterior open bite, including parafunctional habits such as tongue thrusting, is essential for posttreatment stability, particularly in clear aligner treatment, in which maxillary incisors were primarily extruded and retroclined. Persistent tongue pressure may contribute to relapse of the maxillary incisors if such habits are not eliminated. In addition, posttreatment vertical control through squeezing exercises is recommended to reduce the risk of posterior teeth relapse.

Although statistically significant differences were observed between the MT and CA groups for certain variables, the clinical relevance of these differences should be interpreted with caution. For some parameters, the magnitude of between-group

differences was relatively small and may not translate into substantial clinical advantages. Therefore, these findings indicate early differences in dentoalveolar and skeletal responses rather than definitive superiority of one treatment modality over the other.

Limitations of the study

This study has several limitations. First, the 6-month follow-up period was insufficient to evaluate the long-term effects of treatment. Second, the study could not clearly differentiate between dental and skeletal contributions to open bite correction. Third, the biomechanical interpretations were based on theoretical considerations rather than direct force measurements. In addition, potential confounding factors such as patient compliance may have influenced the results. Therefore, further long-term, prospective studies are needed to validate these findings.

Further study

Further studies should evaluate the skeletal and soft tissue effects of these two mechanics in anterior open bite correction. Long-term outcomes and stability also require investigation. In addition, the magnitude and duration of forces generated during clear aligner treatment should be evaluated to better understand the underlying biomechanics.

Conclusion

1. Miniscrew-assisted transpalatal arch mainly intruded maxillary posterior teeth with minimal incisor changes.
2. Clear aligner treatment primarily resulted in maxillary incisor extrusion and retroclination, with limited posterior teeth intrusion.
3. Based on these initial findings, miniscrew-assisted transpalatal arch mechanics may be considered for patients with mild to moderate skeletal Class II anterior open bite with a hyperdivergent pattern, whereas clear aligner mechanics may be more suitable for patients with a low smile line and mild incisor protrusion or proclination.

Author contributions

Suthinun Suksutthiphan: Conceptualization, Investigation, Formal analysis, Writing – original draft, Writing – review & editing; **Angkana Thearnmontree:** Formal analysis, Writing – review & editing; **Chidchanok Leethanakul:** Conceptualization, Supervision, Project administration, Resources, Funding acquisition, Writing – review & editing.

Ethical statement

This study was approved by the Human Ethics Committee of the Faculty of Dentistry, Prince of Songkla University (Ethical approval number: EC6503-013).

Disclosure statement

The authors have no conflicts of interest.

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AI-assisted writing declaration

The authors used ChatGPT (OpenAI, GPT-5.5) solely for language editing and manuscript refinement. All scientific content was developed and verified by the authors, who take full responsibility for the accuracy and integrity of the manuscript.

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Correction of Class II Malocclusion Using a Resin Block Build up with Class II Elastic in an Adult Patient: A Case Report

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Abstract

Class II malocclusion is one of the most prevalent orthodontic problems that is commonly associated with mandibular retrognathia. Treatment in adults poses a challenge because growth modification is no longer possible, and most corrections rely on camouflage mechanics or orthognathic surgery. This report presents a 23-year-old female with a skeletal Class II normodivergent pattern, retrognathic mandible, and proclined maxillary incisors. A modified fixed twin block appliance was combined with fixed orthodontics as a non-extraction camouflage strategy. After 18 months, the patient achieved improved facial balance, normalized overjet and overbite, and Class I molar relationships. Skeletal change was minimal, while the effects were largely dentoalveolar; however, vertical control and occlusal stability were favorable. This case highlights the limited but valuable role of fixed twin block appliances in adults as a cost-effective camouflage option where surgery or extraction is not preferred.

Keywords: Adult orthodontics, Camouflage, Functional orthodontics, Skeletal Class II malocclusion, Twin block appliance

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Introduction

One of the most prevalent orthodontic problems worldwide is Class II malocclusion, which affects 15 % to 20 % of adolescents and persists into adulthood in untreated cases.^{1,2} In adults, treatment options are constrained because growth modification is no longer possible. Conventional strategies include premolar extractions, distalization with skeletal anchorage, or orthognathic surgery. Each of these treatments has distinct advantages and limitations regarding esthetics, invasiveness, treatment duration, and stability.³

Functional appliances, particularly the twin block technique that was introduced by Clark, remain one of the most effective methods for sagittal correction in growing patients with substantial evidence of skeletal and dentoalveolar improvements.^{4,5} However, in adults, true skeletal modification cannot be expected, and the evidence for functional appliances is limited to minor dentoalveolar adaptations and potential condylar remodeling.^{6,7}

To date, nearly all published reports on adult Class II camouflage with functional appliances have employed removable twin block devices in preliminary phases followed by fixed orthodontics.^{5,8} Reports of

fixed, non-removable twin block appliances used concurrently with comprehensive orthodontics in fully adult patients are virtually absent in the indexed literature.

The present case was an adult Class II patient who underwent treatment with a modified fixed twin block appliance that was integrated with fixed orthodontics from the outset. This approach not only addressed patient concerns about compliance and esthetics but also highlighted a practical, non-extraction, non-surgical camouflage strategy that expands the list of tools for orthodontists for managing adult Class II malocclusion.⁹

Case report

A 23-year-old Thai female presented to the Orthodontic Clinic, Dental Hospital, Faculty of Dentistry, Prince of Songkla University with the chief complaint of protrusive maxillary anterior teeth and crowding of the mandibular teeth. The patient reported no history of systemic disease, allergies, or medication use. Extraoral examination revealed normal facial development. The frontal view showed a mesofacial type with mild facial



Figure 1 Pretreatment extraoral examination



Figure 2 Pretreatment intraoral examination

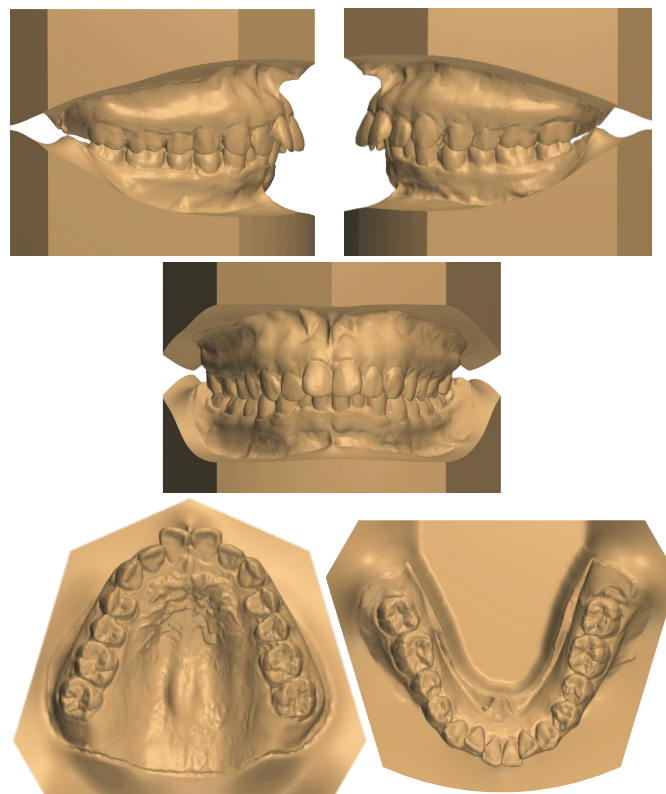


Figure 3 Pretreatment dental casts

asymmetry; the left cheek appeared slightly larger than the right. At rest, the patient exhibited incompetent lips with a 1-mm separation. The smile line was normal on smiling. The facial profile was convex with a normal nasolabial angle (Figure 1). No signs or symptoms of temporomandibular disorders were observed. The patient reported a history of thumb-sucking, which had ceased around the third to fourth grade of primary school.

Intraoral examination revealed asymmetrical arches with tapered maxillary and mandibular arch forms. Bolton's tooth size analysis revealed a discrepancy. The anterior ratio, calculated as $(34/44) \times 100 = 77.27\%$, exceeded the reported mean values of 75.50 – 77.20 – 78.90 %, ¹⁰ indicating that the size of upper and lower anterior teeth are consonant. The overall ratio, calculated as $(82/89) \times 100 = 92.13\%$, ¹⁰ fell within the reported mean range of 89.40 – 91.30 – 93.20 % (Bolton, 1958), suggesting consonance between the upper and lower posterior teeth. The overjet was 6.5 mm

and the overbite was 4 mm. According to Angle's classification, the molars were in a Class II relationship (3.5 mm on the right and 2.5 mm on the left), and the canines were also in a Class II relationship (5 mm on the right and 4 mm on the left) (Figures 2 and 3). The maxillary dental midline coincided with the facial midline, while the mandibular dental midline was deviated 1 mm to the right. Space analysis indicated mild crowding in both arches (Figures 2 and 3). No functional shift or occlusal interference was detected. Oral soft tissues and mucosa appeared normal with adequate attached gingiva. Tongue size and posture were within normal limits. The periodontium was diagnosed with gingivitis.

The mesiodistal tooth size measurements of both arches are presented in Table 1. The Korkhaus analysis indicated that the upper anterior arch width (AAW) was narrower than the lower AAW, while the upper and lower posterior arch widths (PAW) were equal. The upper and lower anterior arch widths (AAW) and posterior arch width (PAW) were within normal

Table 1 Pretreatment tooth size measurements

Tooth number	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
Size (mm)	-	10	9	6.5	7	7.5	7	7.5	8	6.5	7.5	7	6.5	9	10	-
Size (mm)	-	9	10	7	7	6.5	5.5	5	5	5.5	6.5	7	7	10	9	-
Tooth number	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38

Table 2 Pretreatment Korkhaus’s analysis

	Maxillary arch		Mandibular arch	
Type	Thai norm ¹¹	Pretreatment	Thai norm ¹¹	Pretreatment
Arch height (mm)	19.10 ± 2.40	23.50	17.3 ± 2.30	17.00
Anterior arch width (mm)	36.40 ± 1.90	35.50	36.2 ± 2.10	36.00
Posterior arch width (mm)	46.80 ± 2.20	46.50	45.7 ± 2.20	46.50



Figure 4 Pretreatment panoramic radiograph

limits. The upper arch height (AH) was greater than the lower AH. Compared with the standard values, the upper AH was larger, whereas the lower AH was within the normal range (Table 2). Space analysis revealed a space deficiency of 1 mm in the upper arch and 2.5 mm in the lower arch.

The panoramic radiograph demonstrated dental development at the permanent dentition stage. The maxillary nasal septum, bone density, and trabeculation appeared normal with no visible pathology. However, the mandibular condyles were asymmetrical with the left condyle being higher and larger than the right condyle (Figure 4).



Figure 5 Pretreatment lateral cephalogram

A lateral cephalometric analysis indicated a skeletal Class II normodivergent pattern with an orthognathic maxilla and a retrognathic mandible. Additional findings included proclined and protruded upper incisors, proclined and normally positioned lower incisors, an acute interincisal angle, a deep curve of Spee, increased overbite and overjet, a convex facial profile, decreased lower facial height (LFH), and lower lip trapping (Figure 5 and Table 3).

Table 3 Pretreatment cephalometric analysis

Area		Measurement	Norm Mean $\pm$ SD	Pre-treatment	Interpretation
Skeletal	Reference line	FH-SN ($^{\circ}$) ¹²	6 $\pm$ 3	9.5	Steep SN plane
	Maxilla to cranial base	SNA ($^{\circ}$) ¹³	84 $\pm$ 4	76.5	Retrognathic maxilla
		A-Nperp (mm) ¹⁴	5 $\pm$ 4	-3.5	Orthognathic maxilla
		SN-PP ($^{\circ}$) ¹⁴	9 $\pm$ 3	10	Normodivergent pattern
	Mandible to cranial base	SNB ($^{\circ}$) ¹³	81 $\pm$ 4	71	Retrognathic mandible
		Pg-Nperp (mm) ¹⁴	0 $\pm$ 6	-13.5	Retrognathic mandible
		SN-Pg ($^{\circ}$) ¹³	82 $\pm$ 3	74	Retrognathic mandible
		SN-MP ($^{\circ}$) ¹³	29 $\pm$ 6	33	Normodivergent pattern
		NS-Gn ($^{\circ}$) ¹³	68 $\pm$ 3	70	Normodivergent pattern
	Maxillo-mandibular	ANB ($^{\circ}$) ¹³	3 $\pm$ 2	5.5	Skeletal Class II
		Wits (mm) ¹²	-3 $\pm$ 2	4.5	Skeletal Class II
		FMA ($^{\circ}$) ¹⁴	23 $\pm$ 5	22	Normodivergent pattern
		MP-PP ($^{\circ}$) ¹³	21 $\pm$ 5	23	Normodivergent pattern
Dental	Maxillary dentition	$\perp$ to NA ($^{\circ}$) ¹³	22 $\pm$ 6	32	Proclined upper incisors
		$\perp$ to NA (mm) ¹³	5 $\pm$ 2	8	Protruded upper incisors
		$\perp$ to SN ($^{\circ}$) ¹³	108 $\pm$ 6	115	Proclined upper incisors
		ADH (mm) ¹⁵	27.23 $\pm$ 2.79	27	Normal ADH
		PDH (mm) ¹⁵	22.24 $\pm$ 2.23	18.5	Decreased PDH
	Mandibular dentition	$\bar{\perp}$ to NB ($^{\circ}$) ¹³	30 $\pm$ 6	35.5	Normally inclined lower incisors
		$\bar{\perp}$ to NB (mm) ¹³	7 $\pm$ 2	8	Normally positioned lower incisors
		$\bar{\perp}$ to MP ($^{\circ}$) ¹²	99 $\pm$ 5	109.5	Proclined lower incisors
	Maxillo-mandibular	$\perp$ to ($^{\circ}$) ¹³	125 $\pm$ 8	108	Acute interincisal angle
Soft tissue	Soft tissue	E line U. lip (mm) ¹⁴	-1 $\pm$ 2	1	Normally positioned upper lip
		E line L. lip (mm) ¹⁴	2 $\pm$ 2	2	Normally positioned lower lip
		NLA ($^{\circ}$) ¹²	91 $\pm$ 8	91	Normal nasolabial angle
		H-angle ($^{\circ}$) ¹³	14 $\pm$ 4	19	Protruded upper lip

Pretreatment facial analysis revealed decreased lower facial height (LFH) measuring 62 mm compared with the Thai normative value of 69 $\pm$ 3 mm, indicating a reduced vertical dimension. Upper facial height (UFH) was also slightly decreased at 45 mm (norm 48 $\pm$ 3 mm). Soft tissue evaluation demonstrated decreased upper lip length (ULL) of 21 mm (norm 23 $\pm$ 2 mm) and

decreased lower lip length (LLL) of 40 mm (norm 46 $\pm$ 3 mm), contributing to an imbalanced vertical facial proportion and chin-lip relationship.

The patient presented with protrusive upper incisors and lower anterior crowding with a history of childhood thumb sucking that had been discontinued. Clinical and radiographic evaluations revealed Skeletal

Class II normodivergent pattern with orthognathic maxilla, retrognathic mandible, dental Class II malocclusion, proclined and protruded upper incisors, mild crowding, large overjet, deep overbite, and a convex profile. The cervical vertebral maturation analysis indicated stage 6, which is beyond the growth spurt that rendered mandibular growth modification inappropriate. As the skeletal discrepancy was mild, orthodontic treatment alone was sufficient.

Three treatment options were considered: 1) conventional orthodontics (non-extraction) with fixed twin block, 2) conventional orthodontics (non-extraction) with whole arch distalization, and 3) conventional orthodontics with extraction of maxillary first premolars (teeth 14 and 24). The fixed twin block option normally provided advantages of avoiding extractions, correcting the deep bite and posturing the mandible forward to allow occlusal seating and potential condylar adaptation rather than true skeletal advancement. Although not inducing true growth in adults, evidence from Prof. Gang Shen and others suggests mandibular repositioning can promote adaptive condylar remodeling that has been supported by animal studies, clinical reports, and case evidence.^{6,7,16} Whole arch distalization also avoids extractions and corrects deep bite, but causes mandibular retrusion and requires longer treatment times and higher costs. Extractions of teeth 14 and 24 shortens treatment and reduces overjet efficiently but risks worsening the deep bite. Therefore, non-extraction treatment with fixed twin block was selected as a balanced approach that offered overjet and deep bite correction, profile improvement, and potential condylar adaptation. Close monitoring was emphasized due to relapse risk and initial discomfort.

After leveling and alignment were achieved, the treatment entered the movement phase. Stiff stainless steel archwires (0.016 × 0.016-inch) were inserted in both the maxillary and mandibular arches to maintain arch form and provide adequate rigidity for mandibular repositioning. Resin block

buildups (Band-Lok) were constructed on both the maxillary and mandibular premolars in the form of inclined planes to posture the mandible forward into a more favorable position. In this protocol, the resin block buildups served as the primary mechanism for mandibular posturing, while short Class II elastics were used adjunctively to facilitate vertical occlusal seating rather than sagittal mandibular advancement. The mandible was guided to a position corresponding to a normal overjet with approximately 30 % overcorrection, resulting in an almost edge-to-edge incisal relationship. This procedure created a posterior open bite, which was managed by applying intermaxillary elastics to seat the occlusion into the new mandibular position. Short Class II elastics (¼-inch, 4.5 oz) were worn full-time while the Band-Lok were in place to provide a vertical seating force, promote posterior interdigitation, and serve as a mandibular positional reminder. As occlusal stops gradually developed, the Band-Lok were selectively reduced to allow for progressive intercuspation



Figure 6 Fixed twin block

while monitoring for any mandibular relapse (Figure 6). During the maintenance phase, short Class II elastics were prescribed for night-time wear only to function as a mandibular positional reminder and to maintain the advanced mandibular position during neuromuscular adaptation. Following the establishment of stable posterior occlusal contacts, elastic wear was limited to nighttime only during the maintenance phase. The forward mandibular position was maintained for approximately six months to permit adaptation and stabilization.¹⁷ Once the Band-Lok were completely removed, finishing mechanics were carried out to refine tooth positions. During this phase, slight tooth mobility was observed in the premolars supporting the resin block buildups; however, the patient did not report pain or discomfort. The resin blocks did not function as definitive occlusal rests but acted as diagonal guiding planes to posture the mandible forward, and the observed mobility resolved spontaneously after their removal. No radiographic evidence of root resorption was detected. Throughout the use of the resin block buildups, the patient was instructed to avoid hard or sticky foods and to maintain a soft diet to minimize excessive occlusal loading and reduce the risk of appliance-related complications. Retention was subsequently applied to monitor stability prior to appliance removal.

After 18 months, the patient demonstrated normalized vertical proportions, improved lower facial height, aligned dental and facial midlines, proper arch coordination, and satisfactory occlusion with a slight Class II canine relationship bilaterally (Figures 7–9, Table 4). Lower lip trapping observed pretreatment was eliminated following normalization of overjet and overbite.

The posttreatment lateral cephalometric radiograph revealed 1) skeletal Class II normodivergent pattern with orthognathic maxilla and rethognathic mandible, 2) normally inclined and positioned upper incisors, but proclined lower incisors, 3) normal



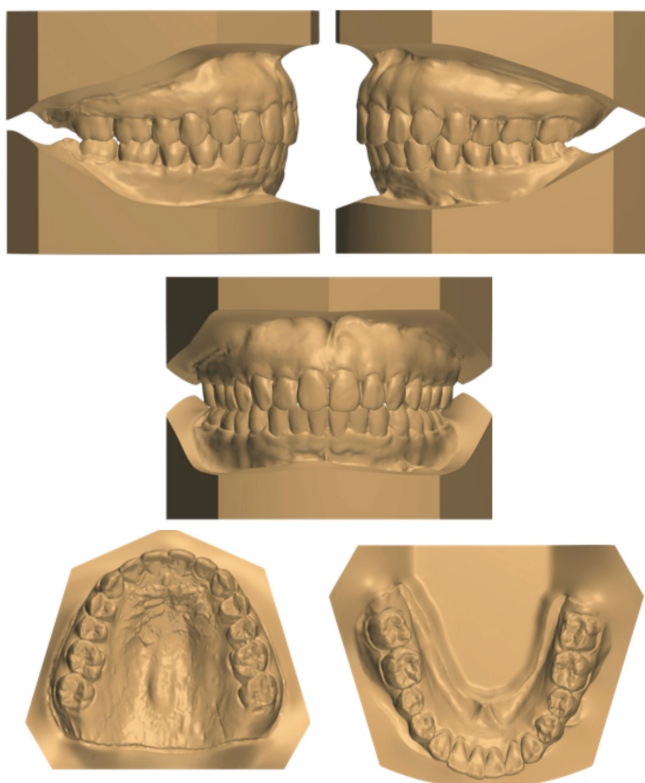
Figure 7 Posttreatment extraoral examination



Figure 8 Posttreatment intraoral examination

Table 4 Comparison of the pretreatment and post-treatment dental cast analysis

Parameters		Pretreatment	Posttreatment
Overjet		6.5 mm	1.5 mm
Overbite		4 mm	1.5 mm
Canine relationships	Right	Class II 5 mm	Class II 1 mm
	Left	Class II 4 mm	Class II 1 mm
Molar relationships	Right	Class II 3.5 mm	Class I
	Left	Class II 2.5 mm	Class I
Upper	Midline	Center	Center
	Arch form	Taper	Paraboloid
	Arch height	23.5 mm	17 mm
	Anterior arch width	35.5 mm	36.5 mm
	Posterior arch width	46.5 mm	47 mm
Lower	Midline	Shift to the right 1 mm	Center
	Arch form	Taper	Paraboloid
	Arch height	20 mm	18 mm
	Anterior arch width	36 mm	37 mm
	Posterior arch width	46.5 mm	47 mm

**Figure 9** Posttreatment dental casts**Figure 10** Posttreatment lateral cephalogram.

interincisal angle, 4) normal posterior dental height, 5) convex soft tissue profile, 6) normally positioned upper and lower lips, and 7) improved LFH (Figure 10 and Table 5).

Table 5 Posttreatment cephalometric analysis

Area		Measurement	Norm Mean $\pm$ SD	Pretreatment	Posttreatment	Difference
Skeletal	Reference line	FH-SN ($^{\circ}$) ¹²	6 $\pm$ 3	9.5	9.5	0
	Maxilla to cranial base	SNA ($^{\circ}$) ¹³	84 $\pm$ 4	76.5	76.5	0
		A-Nperp (mm) ¹⁴	5 $\pm$ 4	-3.5	-4	-0.5
		SN-PP ($^{\circ}$) ¹⁴	9 $\pm$ 3	10	10	0
	Mandible to cranial base	SNB ($^{\circ}$) ¹³	81 $\pm$ 4	71	70.5	-0.5
		Pg-Nperp (mm) ¹⁴	0 $\pm$ 6	-13.5	-14	-0.5
		SN-Pg ($^{\circ}$) ¹³	82 $\pm$ 3	74	76	+2
		SN-MP ($^{\circ}$) ¹³	29 $\pm$ 6	33	35	+2
		NS-Gn ($^{\circ}$) ¹³	68 $\pm$ 3	70	72	+2
	Maxillo- mandibular	ANB ($^{\circ}$) ¹³	3 $\pm$ 2	5.5	6	+0.5
		Wits (mm) ¹²	-3 $\pm$ 2	4.5	4	-0.5
		FMA ($^{\circ}$) ¹⁴	23 $\pm$ 5	22	24	+2
		MP-PP ($^{\circ}$) ¹³	21 $\pm$ 5	23	25	+2
Dental	Maxillary dentition	$\perp$ to NA ($^{\circ}$) ¹³	22 $\pm$ 6	32	18	-14
		$\perp$ to NA (mm) ¹³	5 $\pm$ 2	9	4	-5
		$\perp$ to SN ($^{\circ}$) ¹³	108 $\pm$ 6	115	101	-14
		ADH (mm) ¹⁵	27.23 $\pm$ 2.79	27	29	+2
		PDH (mm) ¹⁵	22.24 $\pm$ 2.23	18.5	20.5	+2
	Mandibular dentition	$\bar{I}$ to NB ($^{\circ}$) ¹³	30 $\pm$ 6	35.5	39.5	+4
		$\bar{I}$ to NB (mm) ¹³	7 $\pm$ 2	8	8.5	+0.5
		$\bar{I}$ to MP ($^{\circ}$) ¹²	99 $\pm$ 5	109.5	113.5	+4
	Maxillo- mandibular	$\perp$ to ($^{\circ}$) ¹³	125 $\pm$ 8	108	118	+10
Soft tissue	Soft tissue	E line U. lip (mm) ¹⁴	-1 $\pm$ 2	1	0	-1
		E line L. lip (mm) ¹⁴	2 $\pm$ 2	2	2.5	+0.5
		NLA ($^{\circ}$) ¹²	91 $\pm$ 8	91	100	+9
		H-angle ($^{\circ}$) ¹³	14 $\pm$ 4	19	18	-1

Posttreatment evaluation showed improvement in vertical facial proportions. Lower facial height (LFH) increased to 66 mm, reaching within normal limits, while upper facial height (UFH) remained within the normal range at 45 mm. Soft tissue parameters also improved, with upper lip length (ULL)

increasing to 22 mm and lower lip length (LLL) to 44 mm, both of which were within normal limits. These changes reflected enhanced vertical facial balance and improved soft tissue support of the chin and lips.

The panoramic radiograph demonstrated nearly parallel roots, except for teeth 13 and 44. Clinically, the alignment of the incisal edges and marginal ridges had already been achieved; however, tooth 13 presented with root prominence, and therefore no additional mesial root torque was applied. No external root resorption was observed (Figure 11). A cranial base superimposition revealed no further growth at either the nasion or basion points, as well as no maxillary growth, whereas slight condylar growth and evidence of adaptive condylar remodeling of the

mandible were detected. The mandible exhibited a clockwise rotation. Maxillary superimposition indicated that the upper incisors were retruded, retroclined, and extruded, along with extrusion of the upper molars. Moreover, mandibular superimposition demonstrated proclination of the lower incisors, with extrusion and mesial movement of the lower molars (Figure 12).

Retention consisted of an upper wraparound retainer without a passive anterior bite plane since the initial deep bite was not severe and overcorrection had already been achieved. Also, a lower wraparound retainer was employed to avoid occlusal interference. The patient was instructed to gradually reduce the duration and frequency of retainer wear until stable occlusion was established. After debonding, the patient was referred for restorative management of tooth 11, which was in progress. Follow-up appointments were scheduled at 1, 3, and 6 months, and annually thereafter (Figure 13).



Figure 11 Posttreatment panoramic radiograph

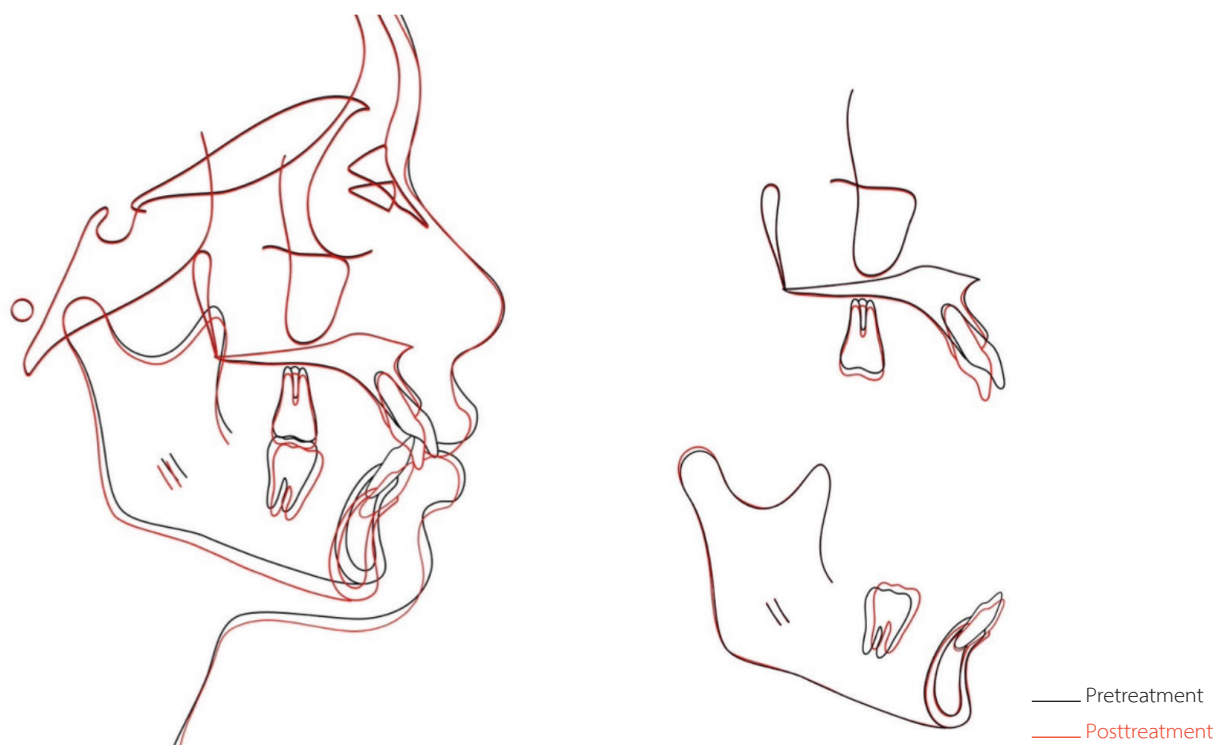


Figure 12 Cephalometric superimposition of pretreatment (black) and posttreatment (red) tracings



Figure 13 Posttreatment with retention appliances

The treatment outcomes were satisfactory. The patient's upper incisor protrusion and lower anterior crowding were corrected, lower facial height increased moderately, and the facial profile improved. The patient was highly satisfied with the esthetic and functional results.

Discussion

This case highlights the management of a borderline adult Class II malocclusion using a novel fixed twin block appliance in combination with comprehensive orthodontics. While the treatment outcomes—reduction of overjet, improvement of overbite, and establishment of Class I occlusion—were comparable to those reported with other functional and camouflage approaches, the main distinction lies in the use of a fixed, non-removable twin block appliance in a fully grown adult. Most previous reports have involved removable twin block therapy in adolescents followed by fixed appliances. However, applications in adults using a concurrent fixed twin block remain very limited in the literature.^{5,9}

A critical aspect of this report is the treatment planning process. Three alternatives were carefully

considered: 1) premolar extractions, which would reduce overjet efficiently but at the cost of possible profile flattening and deep bite worsening, 2) whole-arch distalization with skeletal anchorage, which avoids extractions but increases cost, invasiveness, and treatment time, and 3) camouflage with a fixed twin block. The patient's preference for a non-surgical, non-extraction solution, coupled with the clinician's concern about maintaining vertical control, supported the selection of option three.³ This structured decision-making framework illustrates the importance of patient-centered care and individualized biomechanics in adult Class II treatment.

From a biomechanical standpoint, the fixed twin block produced mandibular advancement through inclined plane mechanics that generated a posterior open bite and thereby facilitated vertical control. This mechanism differs from Class II elastics, which often produce mandibular incisor proclination and molar extrusion.¹⁸ Compared with Herbst or Forsus appliances, which also posture the mandible forward but require anchorage from miniscrews or rigid attachments, the fixed twin block offers a simpler force system with fewer side effects, albeit with more reliance on dentoalveolar compensation.⁹ In this adult patient, a fixed Twin-block-type approach was selected to allow mandibular posturing while maintaining continuous three-dimensional control within an ongoing fixed appliance system. Although removable Twin-block appliances have been more extensively studied, particularly in growing patients, their skeletal effects in fully mature adults remain limited. In the present case, the fixed approach provided a practical and biomechanically integrated solution consistent with the treatment stage and objectives. The present case still demonstrated lower incisor proclination that was consistent with previous findings but within a clinically acceptable range.⁵ Although lower incisor proclination was observed in the present case, this finding cannot be attributed solely to the fixed twin block phase. Lower incisor inclination may have been influenced by

multiple stages of treatment, including initial leveling and alignment, resolution of anterior crowding, and intrusion of the lower anterior teeth during deep-bite correction prior to the application of the fixed twin block. Because no intermediate cephalometric records were obtained before fixed twin block insertion, the precise contribution of each treatment phase to lower incisor proclination cannot be determined.

In the present case, the treatment outcome was achieved through a combination of two complementary biomechanical components. Resin block buildups functioned as the primary mechanism for forward mandibular posturing via inclined plane mechanics, while short Class II elastics were used adjunctively to facilitate vertical occlusal seating and posterior intercuspation. Importantly, during the maintenance phase, short Class II elastics were prescribed for night-time wear only to serve as a mandibular positional reminder rather than as a sagittal force system. This combined approach allowed stabilization of the advanced mandibular position while minimizing unwanted dentoalveolar compensation. To further minimize excessive occlusal loading and appliance-related complications, patients were instructed to avoid hard or sticky foods and to maintain a soft diet during the period of resin block use.

It is important to note that skeletal effects in adults remain minimal. Functional appliances at this stage cannot stimulate true mandibular growth.⁶ While cephalograms suggested minor condylar positional change, such findings must be interpreted cautiously. Advanced three-dimensional imaging, such as CBCT, has been shown to more accurately capture condylar remodeling.¹⁹ Therefore, any skeletal changes in this case should be attributed primarily to dental-alveolar adaptation rather than true growth modification.

Another consideration is the risk of relapse since camouflage corrections often have lower long-term stability compared with orthognathic solutions.¹ Evidence-based protocols emphasize the role of tailored retention strategies in maintaining

alignment and bite correction.²⁰ In this case, retention was designed with wraparound retainers, but clinicians should anticipate long-term monitoring, particularly for vertical stability and lower incisor position.

This case illustrates that a fixed twin block appliance, when used in adults, should not be viewed as a growth modification tool but rather as a biomechanical adjunct for dentoalveolar camouflage. Its value lies in enabling non-extraction correction, enhancing vertical control, and aligning with patient-centered preferences. When appropriately selected, this approach expands the orthodontist's armamentarium for managing borderline Class II adults that offers a balance between effectiveness, patient comfort, and clinical practicality.

Conclusion

The treatment of an adult patient with skeletal Class II malocclusion using a modified fixed twin block appliance combined with fixed orthodontics achieved satisfactory esthetic and functional results. The improvements were primarily dentoalveolar, with minimal skeletal correction. This outcome confirms the role of the approach as orthodontic camouflage rather than true skeletal modification. In adult patients with mild Class II discrepancies who refuse orthognathic surgery, functional appliances may be considered as part of a non-extraction camouflage plan to improve occlusion and facial balance. However, clinicians must emphasize the limitations of skeletal correction, the reliance on dental compensation, and the necessity for long-term retention to maintain stability.

Author contributions

Nicha Kukongviriyapan: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization;

Pornpimon Kamchai: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization; **Bancha Samruajbenjakun:** Conceptualization, Methodology, Software, Validation, Investigation, Resources, Writing - Review & Editing, Visualization, Supervision, Project administration.

Ethical statement

The patient's consent was obtained before publication.

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