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Original Article

Comparison of Maxillary Posterior Root Volume Changes After 6 Months of Intrusion with Fixed Appliances and Clear Aligners in Adults with Anterior Open Bite: A Secondary Analysis of a Randomized Clinical Trial

Kanwara Vilamas* Udom Thongudomporn** Chidchanok Leethanakul**

Abstract

Background: Treatment of anterior open bite using posterior teeth intrusion may result in root volume loss, which can be detected using cone beam computed tomography (CBCT). However, no studies have compared fixed appliances with miniscrews (FA) and clear aligners (CA). **Objective:** To compare three-dimensional root volume (RV) changes of maxillary second premolars (U5) and first and second molars (U6, U7) after 6 months of posterior intrusion with FA versus CA in adults with anterior open bite. **Materials and methods:** A secondary analysis of a two-arm randomized clinical trial was conducted in 29 adults (FA = 15, CA = 14) with 0–4 mm anterior open bite. CBCT scans before intrusion and after 6 months were used to segment and measure RV of U5, U6, and U7. Within-group changes were assessed with paired t-tests, and between-group differences with independent t-tests ($P < 0.05$). **Results:** FA produced significantly greater intrusion than CA at all posterior teeth. All roots in both groups showed significant RV loss with mean percentage reductions of approximately 3–11 %. Intergroup comparisons showed greater RV loss with FA at U6 palatal and mesiobuccal roots with no significant differences for U5 buccal, U6 distobuccal, or U7 roots. **Conclusion:** Six months of posterior intrusion produced significant RV loss in all maxillary posterior roots with both appliances. FA caused greater RV loss at the palatal and mesiobuccal roots of U6 than CA. Although changes were small and likely of limited clinical relevance, root morphology should be monitored during posterior intrusion.

Keywords: Anterior open bite, Clear aligners, Cone beam computed tomography, Miniscrews, Root volume

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Introduction

Treatment of mild to moderate anterior open bite in adults can be achieved by anterior teeth extrusion, posterior teeth intrusion, or a combination of both approaches.[1] Posterior intrusion with fixed appliances commonly uses temporary anchorage devices to achieve molar intrusion, promote counterclockwise mandibular rotation, and reduce lower facial height in long-faced patients.[2,3] Clear aligners are increasingly used for open bite correction and can produce spontaneous or planned molar intrusion,[4] possibly through posterior occlusal coverage and altered neuromuscular function.[5,6]

Intrusive movement is strongly associated with external apical root resorption and carries a higher risk than extrusion.[7,8] A recent cone beam computed tomography (CBCT) randomized clinical trial in adults with anterior open bite compared maxillary first molar intrusion with fixed appliances and miniscrews (FA) versus clear aligners (CA).[9] The trial found greater root length reduction with FA, which was consistent with a larger amount of intrusion, but assessed resorption only via root length changes of the maxillary first molar.

Root resorption is a three-dimensional phenomenon that may involve apical, mid-root, and cervical regions. Two-dimensional root length measurements may therefore underestimate true root loss. Volumetric CBCT assessment with three-dimensional segmentation provides a more comprehensive evaluation and has been increasingly applied in orthodontic research.[10-12] Posterior intrusion for open bite correction usually involves several posterior teeth with different root morphologies, and the force systems differ substantially between FA and CA. In FA, posterior teeth are consolidated and subjected to continuous, palatally directed intrusive forces, whereas CA deliver more intermittent and more widely distributed occlusal forces through individual occlusal coverage.[13,14]

Evidence on three-dimensional posterior root volume (RV) changes that compare FA and CA during molar intrusion in adults with anterior open bite is scarce, and no previous study has comprehensively evaluated volume changes in multiple posterior teeth and individual roots.

Therefore, this secondary analysis aimed to evaluate and compare RV changes of the maxillary second premolar (U5), first molar (U6), and second molar (U7), including their individual roots, after 6 months of posterior intrusion with FA and miniscrews versus CA in adults with anterior open bite. The null hypothesis was there would be no difference in posterior RV loss between FA and CA.

Materials and methods

Participants, eligibility criteria, and setting

This study is a secondary analysis of a single-center, two-arm, parallel-group randomized clinical trial that evaluated maxillary first molar intrusion, root length changes, dentoskeletal effects, and maximum bite force in adults with anterior open bite treated with FA or CA.[9] The trial was approved by the Human Research Ethics Committee of the Faculty of Dentistry, Prince of Songkla University (Approval No. EC6703-016) and registered in the Thai Clinical Trial Registry (TCTR20201218004). All participants provided written informed consent. For the present analysis, only subjects with CBCT scans covering all maxillary posterior teeth (U5-U7) at the two time points were included.

The sample size for RV analysis was calculated with G*Power (version 3.1) that assumed α = 0.05, power = 0.95, and effect size f = 1.55 based on volumetric root resorption data by Leonardi et al.[15] A minimum of 12 subjects per group was required. Twenty-nine participants (FA = 15, CA = 14) from the original trial met the additional criterion of complete CBCT coverage of all maxillary posterior teeth and were included.

Adults aged 18-35 years with anterior open bite who participated in the original trial were eligible. All were treated at the Orthodontic Clinic, Faculty of Dentistry, Prince of Songkla University. The inclusion and exclusion criteria were as follows:

Inclusion/Exclusion criteria

Inclusion: (1) Dental anterior open bite 0–4 mm. (2) Angle Class I or mild Class II malocclusion. (3) Skeletal Class I or mild Class II (ANB 0-5°). (4) Normodivergent to hyperdivergent facial pattern (mandibular plane angle 23–39°). (5) Good periodontal health and oral hygiene and (6) CBCT volumes encompassing all maxillary posterior teeth at pretreatment (T0) and 6 months (T1). Exclusion: (1) Moderate or severe crowding. (2) Missing posterior teeth. (3) History of posterior dental trauma. (4) Systemic metabolic bone disease. (5) Previous root canal treatment of maxillary posterior teeth. (6) Use of drugs affecting bone metabolism or tooth movement (e.g., bisphosphonates, long-term corticosteroids, immunosuppressants). (7) Neuromuscular disorders and (8) Previous comprehensive orthodontic treatment.

Randomization and blinding

Participants were randomly assigned (1:1) to FA or CA using computer-generated block randomization with allocation concealment via opaque, sequentially numbered, sealed envelopes prepared by an independent researcher. All treatments were performed by a single orthodontist.

A two-stage protocol was used for the volumetric analysis. The first examiner processed and segmented the CBCT data and exported anonymized STL files. A second examiner, blinded to treatment group, performed all RV measurements.

Interventions

Clear aligners (CA)

In the CA group, clear aligners were fabricated from 1-mm Duran thermoplastic sheets (SCHEU-DENTAL GmbH, Iserlohn, Germany). Maxillary anterior teeth were programmed for 0.2 mm of extrusion per aligner at 3-week intervals to achieve relative posterior intrusion. All maxillary teeth were fully covered by the aligners, while no treatment was performed on the mandibular teeth. Patients were instructed to wear the aligners for at least 22 hours per day and to perform isometric clenching exercises while wearing them. The exercise protocol consisted of 1-minute sessions of alternating 5 seconds of clenching and 5 seconds of relaxation for six cycles to be performed at least five times daily. These isometric clenching exercises were incorporated to enhance posterior intrusion through the bite-block effect generated by the clear aligners. Patient compliance with the isometric clenching exercises was monitored through follow-up interviews at each appointment, and maximum bite force (MBF) was evaluated in the main study as an indirect indicator of functional loading and patient cooperation from Withayanukonkij 2023.

Fixed appliances with miniscrews (FA)

In the FA group, 0.022 × 0.028-inch Roth prescription brackets were bonded, and maxillary posterior teeth were consolidated with passive 0.018 × 0.025-inch stainless steel segmental archwires. A midpalatal miniscrew and a transpalatal arch with palatal hooks (TPA) were used. Two nickel-titanium closed coil springs were attached from the miniscrew to the transpalatal arch hooks to deliver approximately 150 grams of continuous intrusive force per side. Force levels were verified at 3-week intervals, and the closed-coil springs were adjusted as needed to maintain a consistent 150 grams intrusive force from Withayanukonkij 2023.

CBCT acquisition and intrusion measurement

CBCT scans were obtained at T0 and T1 of posterior intrusion using the same machine (Veraviewepocs; J Morita MPG, Kyoto, Japan) with standardized settings: 80 kV, 5 mA, 9.2 second exposure, 0.125 mm

voxel size, and 80 × 80 mm field of view. Patients were scanned in maximum intercuspation.

The palatal plane (PP) was defined from the anterior nasal spine to the posterior nasal spine in the midsagittal plane and used as a skeletal reference. The deepest points of the central pits of U5, U6, and U7 were identified, and the perpendicular distance from each pit to the PP (U5PP, U6PP, U7PP) was measured at T0 and T1 using One Volume Viewer software (J. Morita MPG, Kyoto, Japan). Intrusion was calculated as T1 minus T0; negative values indicated intrusion. The right and left values were averaged.

Types of tooth movement

The types of tooth movement were assessed using Mimics Medical software (Materialise, Leuven, Belgium) as follows. The PP was defined, and the long axis of the tooth was set as a line from the central pit to the deepest point of the furcation. The U6 was selected for evaluation because it was directly connected to the TPA and located closest to the intrusive force in the FA, making it the most representative tooth to assess posterior intrusion mechanics. Therefore, U6 was evaluated in both groups for consistency.

Buccolingual (BL) movement was measured on the coronal section. The angle between the long axis of U6 and the PP was recorded. The difference in BL inclination between T0 and T1 represented BL tooth movement of U6. The angle was defined as negative (–) when the crown was lingual to the roots and positive (+) when the crown was buccal to the roots.

Mesiodistal (MD) movement was measured on the sagittal section. The angle between the long axis of U6 and the PP was recorded, and MD movement between T0 and T1 was calculated using the same approach as for BL movement. The angle was defined as negative (–) when the crown was mesial to the roots and positive (+) when the crown was distal to the roots (Figure 1).

Root volume segmentation and measurement

Maxillary U5, U6, and U7 were segmented from CBCT volumes at T0 and T1 using Mimics Medical (Materialise, Leuven, Belgium) with a consistent Hounsfield unit threshold to isolate dental hard tissues. Semi-automated segmentation combined with repeated slice-by-slice manual refinement was performed to improve accuracy. The segmentation

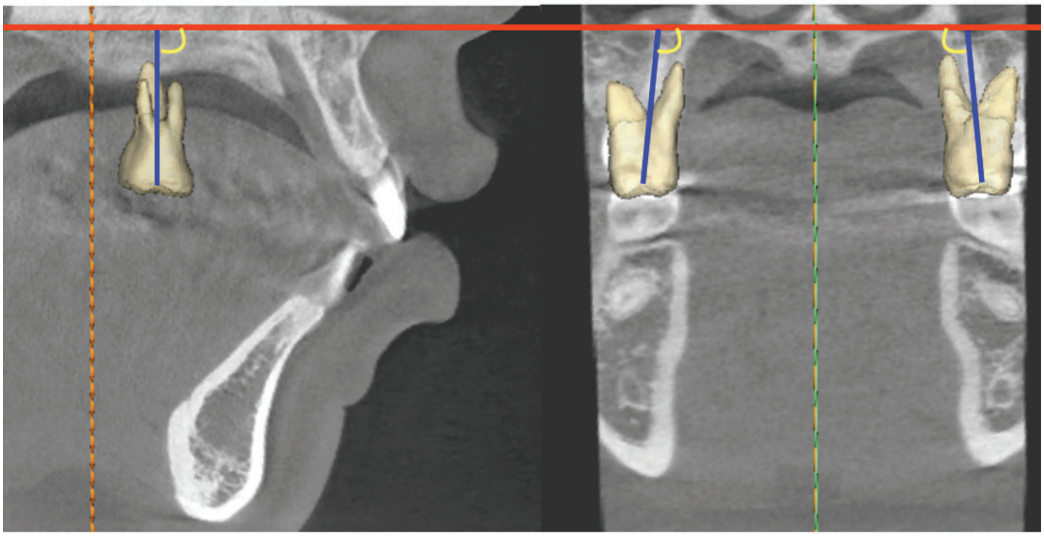


Figure 1 Buccolingual and mesiodistal movement measurements.

process was reviewed in multiple planes to minimize distortion from beam hardening and scatter artifacts and to improve tooth boundary identification before exporting the 3D models as STL files. [13]

In Geomagic Control X (Hexagon AB, Stockholm, Sweden), each tooth was oriented with mesial and distal cusp tips parallel to the horizontal plane. T0 and T1 models of each tooth were aligned by point-based superimposition and then global surface-based registration (best fit algorithm). For U5, the root was separated from the crown using a plane at the highest buccopalatal cementoenamel junction. In cases where the U5 presented with two roots, the same reference approach used for multirooted molars was applied, with segmentation performed at the furcation area to ensure consistency and accuracy of root volume measurements. The roots of U6 and U7 were separated using a plane parallel to the cementoenamel junction passing through the deepest point of the furcation (Figure 2). Reference planes defined at T0 were applied to T1 models. Volumes (mm^3) of the buccal root of U5 (U5B) and the mesiobuccal (U6MB, U7MB), distobuccal (U6DB, U7DB), and palatal roots (U6Pa, U7Pa) were calculated. Root volume loss was defined as T1 minus T0, and percentage loss was calculated using the following formula: (T1 – T0)/T0 × 100.[15]

To validate the segmentation and reference planes, crown volumes at T0 and T1 were also measured. Mean crown volume differences that were < 1 mm^3 were considered clinically negligible and indicated satisfactory methodological precision.

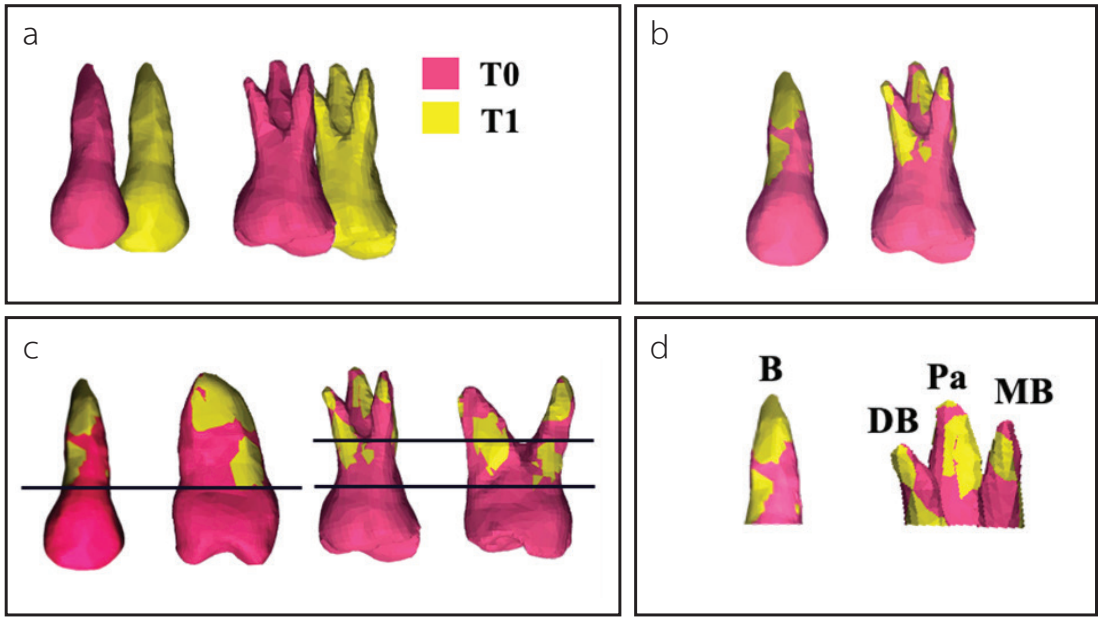


Figure 2 Root segmentation for volume measurement.
(a) 3D model of T0 (pink) and T1 (yellow) orientation of a maxillary second premolar (U5) and a maxillary molar. A similar method was used for the maxillary first molar (U6) and second molar (U7). (b) Point-based superimposition between T0 and T1 was followed by global surface-based registration. (c) Root separation was performed using the highest point of the buccal-palatal cementoenamel junction in U5. In the maxillary molars, the roots were separated using a plane parallel to the cementoenamel junction and passing through the deepest point of the furcation. The reference plane was defined at T0 and applied consistently to both T0 and T1. (d) Root segmentation of T0 and T1 after separation resulted in the buccal root (B) of U5, and the mesiobuccal (MB), distobuccal (DB), and palatal (Pa) roots of the maxillary molars.

Reliability

After the initial assessment, 20 % of the sample was re-segmented and re-measured after 4 weeks to assess intra-examiner reliability. Intraclass correlation coefficients for RV and intrusion measurements were 0.91.

Statistical analysis

Normality was tested with the Shapiro–Wilk test. Within-group changes from T0 to T1 were assessed with paired t-tests. Between-group differences in intrusion and RV loss were analyzed with independent t-tests. The significance level was set at $P < 0.05$. Descriptive statistics included means, standard deviations, and percentage changes.

Results

The study included 29 subjects (6 males, 23 females) with a mean age of 25.03 ± 5.89 years. The FA group was comprised of 15 subjects (2 males, 13 females; mean age, 27.0 ± 7.51 years), and the CA group included 14 subjects (4 males, 10 females; mean age, 23.2 ± 3.10 years). There were no significant differences between groups in age, gender distribution, SNMP, ANB, or overbite at baseline ($P > 0.05$).

After 6 months of intrusion, the FA group showed mean intrusion values of -1.90 ± 0.23 mm (U5), -2.01 ± 0.22 mm (U6), and -2.02 ± 0.23 mm (U7). The CA group exhibited significantly less intrusion: -0.81 ± 0.14 mm (U5), -0.81 ± 0.13 mm (U6), and -0.83 ± 0.15 mm (U7). All between-group differences were statistically significant ($P < 0.01$) (Table 1).

Buccolingual and mesiodistal inclination changes of U6 were significant within both groups ($P < 0.001$), which indicated that intrusion was accompanied by minor tipping components. The mean changes in the FA group were 0.17 ± 1.73° (mesiodistal) and 0.33 ± 0.35° (buccolingual), and in the CA group 0.33 ± 0.57° and 0.17 ± 2.02°, respectively. No significant differences were observed between the groups.

Crown volume differences before and after treatment were assessed to validate the accuracy of the reference planes used for root segmentation. Even though the difference was statistically significant ($P < 0.001$), the mean change was less than 1 mm³, which represented acceptable measurement precision and confirmed the reliability of the volumetric methodology.

Table 1 Mean and standard deviation of root volume change in fixed appliances with miniscrews (FA) and clear aligners (CA)

Root volume (mm^3)	FA (Mean ± SD)					CA (Mean ± SD)					Mean difference FA − CA	*P* value[b]
	T0	T1	T1 − T0	*P* value[a] T1 − T0	T1 − T0 (%)	T0	T1	T1 − T0	*P* value[a] T1 − T0	T1 − T0 (%)		
U5-B	254.93 ± 43.63	246.54 ± 44.21	-8.38 ± 2.91	< 0.001***	-3.42 ± 1.46	203.57 ± 24.62	196.97 ± 23.05	-6.6 ± 3.16	< 0.001***	-3.19 ± 1.39	-1.78	0.126
U6-MB	78.58 ± 29.45	71.76 ± 28.23	-6.82 ± 2.2	< 0.001***	-9.17 ± 2.63	67.28 ± 16.22	62.57 ± 15.82	-4.71 ± 1.41	< 0.001***	-7.26 ± 2.31	-2.11	0.005**
U6-DB	69.73 ± 22.28	63.5 ± 20.09	-6.23 ± 3.86	< 0.001***	-8.66 ± 4.43	55.83 ± 16.97	51.09 ± 16	-4.74 ± 2.00	< 0.001***	-8.74 ± 3.15	-1.49	0.212
U6-Pa	93.4 ± 30.01	83.34 ± 28.6	-10.07 ± 5.77	< 0.001***	-11.14 ± 6.31	72.65 ± 21.78	68 ± 21.44	-4.66 ± 1.86	< 0.001***	-6.72 ± 3.07	-5.41	0.004**
U7-MB	57.62 ± 17.8	52.63 ± 16.67	-4.99 ± 2.75	< 0.001***	-8.73 ± 4.16	55.52 ± 18.06	51.46 ± 17.35	-4.06 ± 1.78	< 0.001***	-7.57 ± 2.95	-0.93	0.239
U7-DB	61.0 ± 16.79	56.54 ± 17.32	-4.46 ± 1.93	< 0.001***	-7.47 ± 3.05	46.16 ± 9.37	42.54 ± 9.38	-3.63 ± 1.73	< 0.001***	-7.64 ± 4.44	-0.83	0.231
U7-Pa	75.86 ± 18.07	69.24 ± 17.24	-6.61 ± 2.68	< 0.001***	-8.82 ± 3.25	59.87 ± 12.9	54.46 ± 12.64	-5.41 ± 2.47	< 0.001***	-9.28 ± 4.42	-1.19	0.219

[a]Data analysis using paired t-test; [b]Data analysis using independent t-test; * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

FA = fixed appliances with miniscrews, CA = clear aligners, T0 = pretreatment, T1 = after 6 months, B = buccal, MB = mesiobuccal, DB = distobuccal, Pa = palatal

All RVs in both FA and CA groups showed statistically significant reductions from T0 to T1 ($P < 0.001$ for all roots). In the FA group, the greatest mean volume loss was observed at U6Pa (-10.07 ± 5.77 mm³, -11.14 %), followed by U5B (-8.38 ± 2.91 mm³, -3.42 %) and U6MB (-6.82 ± 2.2 mm³, -9.17 %). In the CA group, the greatest reduction was found at U7Pa (-5.41 ± 2.47 mm³, -9.28 %), followed by U6DB (-4.74 ± 2.00 mm³, -8.74 %) and U7DB (-3.63 ± 1.73 mm³, -7.64 %). Intergroup comparisons revealed significantly greater volume loss in the FA group at U6Pa ($P = 0.004$) and U6MB ($P = 0.005$). No significant differences were found between groups for U5B, U6DB, or any U7 roots ($P > 0.05$). In both groups, percentage reductions ranged from approximately 3 % to 11 %. The greatest mean percentage loss was observed at U6Pa (Table 1).

Discussion

This secondary analysis showed that 6 months of posterior intrusion in adults with anterior open bite led to statistically significant RV loss in all evaluated maxillary posterior roots in both treatment groups. Mean percentage volume reductions ranged from about 3 % to 11 %, which indicated generally mild to moderate resorptive changes.[14,16] These results agree with previous CBCT-based studies that reported volumetric root resorption after intrusive forces[13] and extend prior work by assessing multiple posterior teeth and individual roots in a randomized clinical setting.

In the FA group, the greatest volume loss occurred at the palatal root of the maxillary first molar (U6Pa), followed by the buccal root of U5 and the mesiobuccal root of U6. Although some earlier studies reported the mesiobuccal root as the most susceptible[13] the predominance of resorption at U6Pa in this study may reflect the biomechanics of the intrusion system. Posterior teeth were splinted and subjected to continuous intrusive forces delivered primarily from the palatal side through the midpalatal miniscrew and TPA. These forces placed the palatal root closer to the line of force and potentially resulted in greater stress concentration at this root during posterior intrusion.

In contrast, the CA group showed a more uniform distribution of RV loss. The largest reductions were U7Pa and U6DB, and generally smaller absolute changes were observed. The amount of intrusion in the CA group was approximately half that in the FA group, which is consistent with the well-recognized relationship between the magnitude of intrusive displacement and resorption.[5,7,17] Based on previous studies,[4] clear aligners can produce posterior tooth intrusion even without planned intrusion mechanics because of the bite block effect. Molar intrusion results from the interposition of the plastic material between the maxillary and mandibular occlusal surfaces. When isometric clenching is performed, the generated occlusal forces may further enhance posterior tooth intrusion. In addition, clear aligners provide intermittent force through individual occlusal coverage. Furthermore, the posterior teeth are not rigidly splinted together, which may result in greater distributed loading and less concentrated stress on specific roots. These intermittent occlusal forces may facilitate posterior tooth movement while allowing periods of stress relief within the periodontal ligament. These forces potentially reduce sustained compressive stress on the root surface and contribute to less root volume reduction compared with continuous force systems.[4,5]

Between-group comparisons revealed significantly greater RV loss with FA at U6Pa and U6MB, while no significant differences were observed for the U5B, U6DB, or U7 roots. These findings agree with previous reports that fixed appliances were associated with a higher prevalence and severity of root resorption than clear aligners,[18] and experimental data indicated that continuous forces induced more resorption than intermittent forces.[17,19] However, the

FA group also exhibited significantly greater intrusion of all posterior teeth. Thus, part of the greater resorption with FA may be attributable to the larger amount of intrusion rather than the appliance system alone. Future studies using multivariable analyses are needed to clarify the relative contributions of intrusion magnitude, force characteristics, and appliance type to posterior RV loss.

From a clinical perspective, the RV loss observed in both groups, although statistically significant, was small and is unlikely to compromise tooth prognosis in healthy adults over the short term. Nonetheless, clinicians should exercise caution when applying intrusive forces to posterior teeth, particularly with fixed appliances and skeletal anchorage, and consider monitoring root status in patients with known risk factors for root resorption. Interpretation of volumetric changes should be interpreted cautiously because CBCT assessment should also consider the location and extent of the resorption defect, as localized loss in critical areas may be more clinically relevant than total volumetric reduction alone. Despite these considerations, the FA achieved a greater amount of posterior intrusion than the CA. Therefore, FA may be more clinically relevant for cases requiring substantial posterior intrusion, such as patients with increased posterior dentoalveolar height (PDH), whereas CA may be more appropriate for cases requiring less posterior intrusion.

Limitations

This study has several limitations. First, the follow-up period was limited to 6 months and does not reflect long-term resorptive and reparative processes over the entire course of treatment or after appliance removal. Second, as a secondary analysis, the study was constrained by the original trial design and may be subject to residual confounding. In particular, the greater posterior intrusion observed in the FA group complicated interpretation of the independent effect of appliance type on RV loss. Therefore, longer-term prospective studies are needed to clarify the independent effects of appliance type, magnitude of intrusion, and other contributing factors on RV loss. Third, the sample size was modest and derived from a single center, which may limit generalizability. Fourth, even though CBCT-based volumetric assessment provides three-dimensional information superior to conventional radiography, its resolution is lower than micro-CT, and segmentation is operator dependent despite high intra-examiner reliability. Finally, no additional CBCT scans were taken beyond those required in the primary trial; however, radiation exposure remains an important consideration when planning similar studies.

Conclusion

(1) Six months of posterior intrusion in adults with anterior open bite resulted in statistically significant RV loss in all maxillary posterior roots (U5, U6, U7) in both the fixed appliance with miniscrews group and the clear aligner group. (2) The fixed appliance group exhibited significantly greater RV loss at the palatal and mesiobuccal roots of the maxillary first molar compared with the clear aligner group and (3) The overall magnitude of RV loss was small and likely of limited clinical significance; however, root morphology should be monitored during posterior intrusion, particularly when using continuous intrusive forces with fixed appliances and skeletal anchorage.

Author contributions

Kanwara Vilamas: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, and Writing-Original draft; **Udom Thongudomporn:** Methodology, Data curation, Formal analysis, and Writing-Review and Editing; **Chidchanok Leethanakul:** Conceptualization, supervision, and Writing-Review and Editing; All authors have read and approved the final manuscript.

Ethical statement

The trial was approved by the Human Research Ethics Committee of the Faculty of Dentistry, Prince of Songkla University (Approval No. EC6703-016) and registered in the Thai Clinical Trial Registry (TCTR20201218004). All participants provided written informed consent.

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) for language editing and proofreading. The authors reviewed and revised all AI-assisted content and take full responsibility for the final content.

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Original Article

Stability of Nasal Morphology Following Post-Surgical Nasal Stent in Patients with Unilateral Cleft Lip and Palate

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Abstract

Background: Despite advances in cleft treatment, postoperative nasal relapse remains a challenge in patients with unilateral cleft lip and palate (UCLP). Nasal stents are widely used to maintain nasal symmetry; however, the optimal duration of postoperative stenting remains unclear. **Objective:** To compare the stability of nasal morphology one year after three versus six months of postoperative nasal stent use in patients with UCLP. **Materials and methods:** This retrospective cohort study included 12 patients with UCLP (n = 6 per group). Three-dimensional photogrammetric analysis was performed at five time points: immediately after cheiloplasty (T0), at stent termination (T1), and 3 (T2), 6 (T3), and 12 months (T4) after discontinuation. Within-group comparisons were performed using paired t-tests or Wilcoxon signed-rank tests, and between-group comparisons using independent t-tests or Mann–Whitney U-tests. **Results:** Alar base width and nostril width increased, whereas nostril height and lip-columella crease to soft triangle distance decreased in both groups. Columella deviation remained stable throughout the observation period. No significant between-group differences were detected for any measurement, and symmetry ratios remained relatively high throughout the observation period. **Conclusion:** Gradual postoperative changes in nasal morphology were observed. No significant differences were detected between the three- and six-month groups. These findings suggest that extending postoperative nasal stent use beyond three months may provide limited additional benefit. Larger prospective studies are needed to determine the optimal duration of postoperative nasal stenting.

Keywords: Cleft lip and palate, Nasal morphology, Nasal stent, Postoperative stability

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Introduction

Nasal deformity represents one of the most significant aesthetic concerns among patients with unilateral cleft lip and palate (UCLP). Investigations evaluating patient satisfaction with treatment outcomes have demonstrated that nasal appearance constitutes the least satisfactory aspect, followed closely by lip aesthetics.[1,2] Nasal asymmetry arises from aberrant muscle insertion, resulting in a depressed nasal dome, shortened columella, and widened alar base on the affected side.[3-5] To address these anatomical abnormalities, presurgical nasal molding in conjunction with primary lip and nasal surgery is performed to optimize nasal morphology. However, inherent tissue memory and scar contracture following primary lip and nasal repair may precipitate surgical relapse.[6,7]

To preserve nasal symmetry following surgical correction, nasal stents are employed to minimize nasal deformity relapse by externally molding the surrounding alar cartilage and counteracting the forces of scar contracture.[6,8-11] Various nasal stent designs exist, designated by different nomenclature, including "nostril retainer",[12] "nasal splint",[7] and "nostril splint".[13,14] Nevertheless, a standardized protocol for the optimal duration of nasal stent wear has not been established. Recommended durations vary considerably, with suggestions ranging from full-time utilization for 3 to 12 months post-surgery.[7,9,13,15,16]

The present institution recommended full-time post-surgical nasal stent utilization for six months. However, clinical observations revealed that patient tolerance varied over time; certain patients experienced difficulty with stent compliance, while others demonstrated adequate tolerance. Typically, at approximately 7 to 8 months of age, or following approximately three months of utilization, some patients began exhibiting behaviors such as nasal rubbing or stent removal. Consequently, caregivers frequently discontinued stent use earlier than initially recommended, resulting in abbreviated utilization duration.

Although various postoperative nasal stent protocols have been reported, evidence directly comparing different stent durations remains limited. If a shorter postoperative nasal stent wear period yields comparable stability in postoperative nasal morphology, reducing the recommended wear period could lessen the burden on caregivers and improve treatment adherence. It was hypothesized that three months of postoperative nasal stent use would provide nasal morphology stability comparable to that of six months of use. Given the absence of a standardized protocol regarding postoperative nasal stent wear duration, this investigation aimed to evaluate the stability of nasal morphology one year following post-surgical nasal stent discontinuation in patients with unilateral cleft lip and palate by comparing three-month and six-month postoperative nasal stent use.

Materials and methods

This retrospective cohort study received ethical approval from the Khon Kaen University Ethics Committee for Human Research (HE651588).

Three-dimensional photographic records and operative data were retrieved from the database of the Center of Cleft Lip-Cleft Palate and Craniofacial Deformities at Khon Kaen University. This retrospective investigation included 12 patients who underwent primary surgical repair of cleft lip and nasal deformity between 2021 and 2022. All patients received comprehensive treatment at this center. Patient selection was based on the following inclusion criteria: (1) non-syndromic unilateral cleft lip and palate; (2) age at the time of surgery between 3 and 6 months; and (3) surgical intervention performed at Srinagarind Hospital, Khon Kaen University. The exclusion criteria were (1) patients with systemic diseases that may interfere with soft tissue healing, and (2) patients who declined to utilize post-surgical nasal stents. All patients had non-syndromic unilateral complete

clefts of primary and secondary palate and received the same treatment protocol at the cleft center. The protocol consisted of presurgical nasoalveolar molding (NAM), primary cheiloplasty using the modified rotational advancement technique (with or without primary rhinoplasty) between 3 and 6 months of age, followed by the same postoperative nasal stent protocol. Following the surgical procedure, an appropriately sized Nasal Creator Device (Neo Plastomer Co; Ltd; Bangkok, Thailand), a specific nasal stent variant employed at this institution, was applied immediately in the operating room and retained within the patient's nostrils.

Each patient attended a follow-up appointment with a plastic and reconstructive surgeon at two weeks post-surgery to evaluate wound healing and monitor for signs of infection. Following this initial assessment, patients were referred to the Orthodontic Clinic for subsequent follow-up appointments throughout the duration of Nasal Creator Device utilization. During follow-up visits, device retention and size were routinely assessed. The device size was changed when clinically indicated according to nasal growth to ensure an appropriate fit throughout the treatment period. The Nasal Creator Device was available in the following sizes: XS, S, M, L, XL, XXL, EM, and EL. Instructions regarding Nasal Creator Device utilization and maintenance were provided to caregivers in accordance with the institution's standard protocol, which mandated full-time wear for six months. Caregivers were also advised to notify the orthodontist immediately if the patient experienced difficulty tolerating the device. Following discontinuation of Nasal Creator Device utilization, patients were scheduled for follow-up appointments at 3, 6, and 12 months. During each visit, both two-dimensional and three-dimensional photographs were obtained to monitor outcomes and document changes in nasal morphology.

Patient data were stratified into two cohorts based on postoperative nasal stent utilization. Group 1 comprised patients who utilized the Nasal Creator Device for approximately three months prior to discontinuation, while Group 2 included patients who adhered to the institutional protocol and utilized the device for six months. Although the institutional protocol recommended full-time nasal stent use for six months, the actual duration of stent utilization varied among patients and was consistently documented during follow-up visits. Accordingly, patients were grouped retrospectively based on their actual duration of nasal stent use. Patients who discontinued nasal stent use at approximately three months because of reduced tolerance were classified into the three-month group. Patients who were unable to tolerate the nasal stent from the first postoperative month and formally declined its use were classified as non-compliant and were therefore excluded from the analysis. In contrast, patients who demonstrated good compliance and were able to continuously use the nasal stent for approximately five to six months were classified into the six-month group.

Three-dimensional photographs were acquired using the H3 Lumio 3D Face Scanner (LUMIO 3D Co; Ltd; Bangkok, Thailand), with calibration performed in accordance with the manufacturer's guidelines. During image acquisition, each infant was gently supported in an upright position by the caregiver and directed to look forward. Because this was a retrospective study, photographs were obtained by the treating dentists during routine clinical follow-up. The three-dimensional images were subsequently imported into (Dolphin Imaging software; Chatsworth; CA, USA). Before landmark identification, all three-dimensional images were reoriented by aligning the interpupillary line parallel to the horizontal plane. The model was then adjusted to obtain a basilar view in which both nostrils and nasal tip were clearly visible. All measurements were subsequently performed using the same viewing orientation. A set of three-dimensional photographs for each patient was selected from five distinct time points: immediately

Table 1 The description of 14 landmark points

Landmarks	Point	Location
RAl	Right alare	The most infero-lateral point on the right alar contour
LAl	Left alare	The most infero-lateral point on the left alar contour
RUIN	Right upper inner rim of the nostril	The midpoint on the upper inner rim of the nostril on the right side
LUIN	Left upper inner rim of the nostril	The midpoint on the upper inner rim of the nostril on the left side
RLIN	Right lower inner rim of the nostril	The midpoint on the lower inner rim of the nostril on the right side
LLIN	Left lower inner rim of the nostril	The midpoint on the lower inner rim of the nostril on the left side
RMNM	Right medial nostril margin	The most medial nostril margin on the right side
LMNM	Left medial nostril margin	The most medial nostril margin on the left side
RLNM	Right lateral nostril margin	The most lateral nostril margin on the right side
LLNM	Left lateral nostril margin	The most lateral nostril margin on the left side
RSMN	Right superior-medial of the nostril	The most superior-medial point of the right nostril margin
LSMN	Left superior-medial of the nostril	The most superior-medial point of the left nostril margin
RIMN	Right inferior-medial of the nostril	The most inferior-medial point of the right nostril margin
LIMN	Left inferior-medial of the nostril	The most inferior-medial point of the left nostril margin

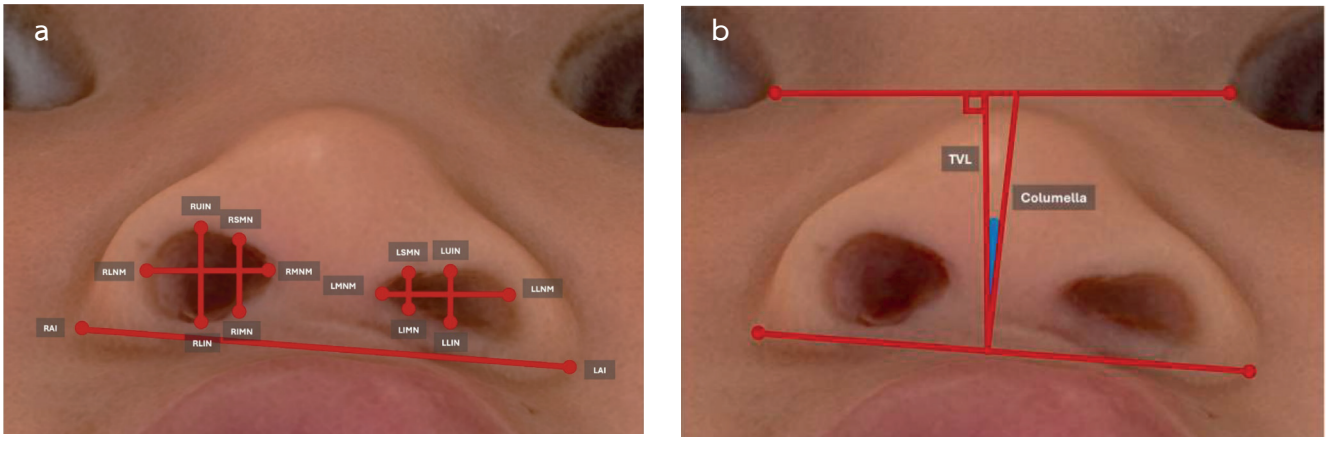


Figure 1 Nasal measurements used to evaluate nasal morphology in basilar view.
(a) Alar base width (RAl-LAl), nostril height (RUIN-RLIN, LUIN-LLIN), nostril width (RMNM-RLNM, LMNM-LLNM), lip-columella crease to soft triangle distance (RSMN-RIMN, LSMN-LIMN). (b) Columella deviation: The angle between the columella and the true vertical line (TVL). The true vertical line is perpendicular to the line formed by connecting the medial canthi.

post-cheiloplasty (T0), upon termination of Nasal Creator Device utilization (regardless of three-month or six-month duration) (T1), three months following device discontinuation (T2), six months following device discontinuation (T3), and one year following device discontinuation (T4). Each photograph was analyzed from the basilar view.

Measurements encompassed four linear dimensions and one angular measurement—alar base width, nostril height, nostril width, lip-columella crease to soft triangle distance, and columella deviation—derived from 14 anatomical landmarks (Table 1). All measurements were performed on three-dimensional surface images, as illustrated in Figure 1.

Definition of measurements

(1) Alar base width: The distance between the most inferolateral points of the alae. (RAl-LAl) (2) Nostril height: The distance from the upper inner rim of the nostril to the lower inner rim of the nostril. (RUIN-RLIN, LUIN-LLIN) (3) Nostril width: The horizontal distance between the most medial nostril margin and the most lateral nostril margin (RMNM-RLNM, LMNM-LLNM) (4) Lip-columella crease to soft triangle distance: The distance between the most superior-medial and the most inferior-medial of the nostril. (RSMN-RIMN, LSMN-LIMN) (5) Columella deviation: The angle between the columella and the true vertical line (TVL). The true vertical line is perpendicular to the line formed by connecting the medial canthi.

All measurements were performed by a single examiner, who was calibrated with an experienced cleft orthodontist before data collection. To assess inter-examiner reliability, 15 three-dimensional images from three randomly selected patients (all five time points per patient) were independently measured by both examiners. To assess intra-examiner reliability, the same 15 images were remeasured by the primary examiner after a one-month interval. Patient identifiers were replaced with study identification numbers during image analysis. Examiner blinding was not performed because the primary examiner was responsible for image preparation, including reorientation by aligning the interpupillary line before landmark identification.

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 28.0.1.1 (IBM Corp; Armonk; NY, USA). Data normality was assessed using the Shapiro–Wilk test. Baseline comparisons between the two groups were performed using the independent t-test. Within-group comparisons between T1 and T4 were performed using the paired t-test for normally distributed data and the Wilcoxon signed-rank test for non-normally distributed data. Between-group comparisons of nasal morphology changes were performed using the independent t-test for normally distributed data and the Mann–Whitney U-test for non-normally distributed data. Statistical significance was set at $P < 0.05$. Intra- and inter-examiner reliability were assessed using intraclass correlation coefficients (ICC).

Nasal symmetry was evaluated using the nostril height ratio, nostril width ratio, and lip-columella crease to soft triangle distance ratio. Each ratio was calculated as the measurement on the cleft side divided by the corresponding measurement on the non-cleft side.

Results

This investigation included 12 patients (7 males and 5 females) with a mean age of 4.50 ± 0.20 months at the time of surgery. Patients were stratified into two cohorts based on the duration of post-surgical Nasal Creator Device utilization. Group 1 (n = 6) utilized the device for three months post-surgery, with a mean age at surgery of 4.70 ± 0.30 months. Group 2 (n = 6) utilized the device for six months post-surgery, with a mean age at surgery of 4.20 ± 0.10 months. Regarding laterality of the condition, nine cases presented with left unilateral cleft lip and palate, while three cases presented with right unilateral cleft lip and palate. Ten patients completed the presurgical nasoalveolar

molding (NAM) protocol before primary cheiloplasty, and primary rhinoplasty was performed in four patients (Table 2). Baseline nasal morphology at T0 was comparable between the three-month and six-month groups, with no statistically significant differences observed for any measurement (Table 3).

Intra- and inter-examiner reliability were high, with ICC values ranging from 0.993 to 0.999.

Table 2 Baseline characteristics of the patients

Measurements	3-month group	6-month group	All patients
Number of patients (n)	6	6	12
Gender (n)			
Female	1	4	5
Male	5	2	7
Age at T0 (Mean ± SD, month)	4.68 ± 0.33	4.23 ± 0.12	4.45 ± 0.19
Side (n)			
Left	3	6	9
Right	3	0	3
Completed presurgical NAM (n)	5	5	10
Primary rhinoplasty (n)	2	2	4

Table 3 Baseline nasal morphology at T0

Measurements	3-month group (Mean ± SD)	6-month group (Mean ± SD)	*P* value
Alar base width (mm)	27.58 ± 2.14	25.95 ± 2.42	0.244
Nostril height (mm)			
Cleft side	4.81 ± 0.88	4.33 ± 1.16	0.434
Non-cleft side	5.72 ± 0.26	5.78 ± 0.35	0.717
Nostril width (mm)			
Cleft side	6.03 ± 0.71	6.08 ± 1.33	0.937
Non-cleft side	6.03 ± 0.71	5.56 ± 0.85	0.310
Lip-columella crease to soft triangle distance (mm)			
Cleft side	3.06 ± 0.56	3.20 ± 0.83	0.751
Non-cleft side	3.12 ± 0.63	3.42 ± 0.26	0.310
Columella deviation (degree)	7.15 ± 2.89	7.25 ± 2.39	0.949

Statistical significance was determined using the independent t-test.

Table 4 Comparison of nasal morphology at T1

Measurements	Mean ± SD		*P* value	Difference between T1 and T4 (Mean ± SD)
	T1	T4		
Alar base width (mm)				
3-month group	29.42 ± 1.94	31.48 ± 1.69	<0.001[a***]	2.07 ± 0.68
6-month group	27.60 ± 1.66	29.63 ± 1.76	0.004[a**]	2.03 ± 0.99
Nostril height (mm)				
Cleft side				
3-month group	4.15 ± 0.44	3.53 ± 0.47	<0.001[a***]	-0.62 ± 0.19
6-month group	3.82 ± 0.62	3.30 ± 0.36	0.21[a*]	-0.52 ± 0.38
Non-cleft side				
3-month group	5.28 ± 0.81	4.80 ± 0.95	0.20[b*]	-0.48 ± 0.31
6-month group	5.63 ± 0.73	5.22 ± 0.28	0.44[b*]	-0.42 ± 0.48
Nostril width (mm)				
Cleft side				
3-month group	7.67 ± 1.47	8.17 ± 1.53	0.005[a**]	0.50 ± 0.26
6-month group	7.07 ± 0.68	7.77 ± 0.35	0.006[a**]	0.70 ± 0.37
Non-cleft side				
3-month group	6.55 ± 0.70	6.73 ± 0.78	0.020[a*]	0.18 ± 0.13
6-month group	5.98 ± 0.65	6.42 ± 0.55	0.017[a*]	0.43 ± 0.30
Lip-columella crease to soft triangle distance (mm)				
Cleft side				
3-month group	2.85 ± 0.45	2.48 ± 0.46	0.004[a**]	-0.37 ± 0.18
6-month group	2.98 ± 0.56	2.58 ± 0.55	0.029[a*]	-0.40 ± 0.32
Non-cleft side				
3-month group	3.00 ± 0.62	2.90 ± 0.57	0.041[a*]	-0.10 ± 0.09
6-month group	3.30 ± 0.25	3.20 ± 0.28	0.011[a]	-0.10 ± 0.13
Columella deviation (degree)				
3-month group	7.45 ± 2.91	7.45 ± 2.81	1.00[a]	0.00 ± 0.33
6-month group	7.62 ± 2.38	7.80 ± 2.45	0.026[a]	0.18 ± 0.36

[a]Statistically significant (Paired t-test, $P < 0.05$.)

[b]Statistically significant (Wilcoxan Signed Rank Test, $P < 0.05$.)

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

Nasal morphology at one year following discontinuation of Nasal Creator Device utilization (T4) demonstrated significant changes from the time of device termination. Specifically, alar base width increased significantly in both cohorts. The three-month cohort exhibited an increase of 2.1 ± 0.7 mm, while the six-month cohort demonstrated an increase of 2.0 ± 1.0 mm.

Nostril height decreased significantly on both the cleft and non-cleft sides. On the cleft side, the three-month cohort demonstrated a reduction of 0.6 ± 0.2 mm, whereas the six-month cohort displayed a decrease of 0.5 ± 0.4 mm. On the non-cleft side, the three-month cohort exhibited a reduction of 0.5 ± 0.3 mm, while the six-month cohort demonstrated a reduction of 0.4 ± 0.5 mm.

Nostril width increased significantly in both cohorts on both the cleft and non-cleft sides. On the cleft side, the three-month cohort demonstrated an increase of 0.5 ± 0.3 mm, while the six-month cohort exhibited an increase of 0.7 ± 0.4 mm. On the non-cleft side, the three-month cohort demonstrated an increase of 0.2 ± 0.1 mm, and the six-month cohort exhibited an increase of 0.4 ± 0.3 mm.

Lip-columella crease to soft triangle distance decreased, particularly on the cleft side. The three-month cohort exhibited a significant reduction of 0.4 ± 0.2 mm on the cleft side, while the non-cleft side demonstrated

Table 5 Comparison of nasal morphology changes between the 3-month group and the 6-month group

Measurements	Differences between T1 and T4			
	3-month group (Mean ± SD)	6-month group (Mean ± SD)	Mean difference (95 % CI)	*P* value
Alar base width (mm)	2.07 ± 0.68	2.03 ± 0.99	0.03 (-1.06, 1.13)	0.947
Nostril height (mm)				
Cleft side	-0.62 ± 0.19	-0.52 ± 0.38	-0.10 (-0.49, 0.29)	0.290
Non-cleft side	-0.48 ± 0.31	-0.42 ± 0.48	-0.07 (-0.59, 0.46)	0.391
Nostril width (mm)				
Cleft side	0.50 ± 0.26	0.70 ± 0.37	-0.20 (-0.61, 0.21)	0.308
Non-cleft side	0.18 ± 0.13	0.43 ± 0.30	-0.25 (-0.57, 0.07)	0.106
Lip-columella crease to soft triangle distance (mm)				
Cleft side	-0.37 ± 0.18	-0.40 ± 0.32	0.03 (-0.30, 0.37)	0.828
Non-cleft side	-0.10 ± 0.09	-0.10 ± 0.13	0.00 (-0.14, 0.14)	1.000
Columella deviation (degree)	0.00 ± 0.33	0.18 ± 0.36	-0.18 (-0.63, 0.26)	0.379

Values are presented as difference between T1 and T4 (mean ± SD). Mean difference represents the between-group difference (3-month group minus 6-month group) with 95 % confidence intervals. T1 = at the cessation of nasal stent use; T4 = one year following the cessation of nasal stents. Statistical significance was determined using the independent t-test ($P < 0.05$).

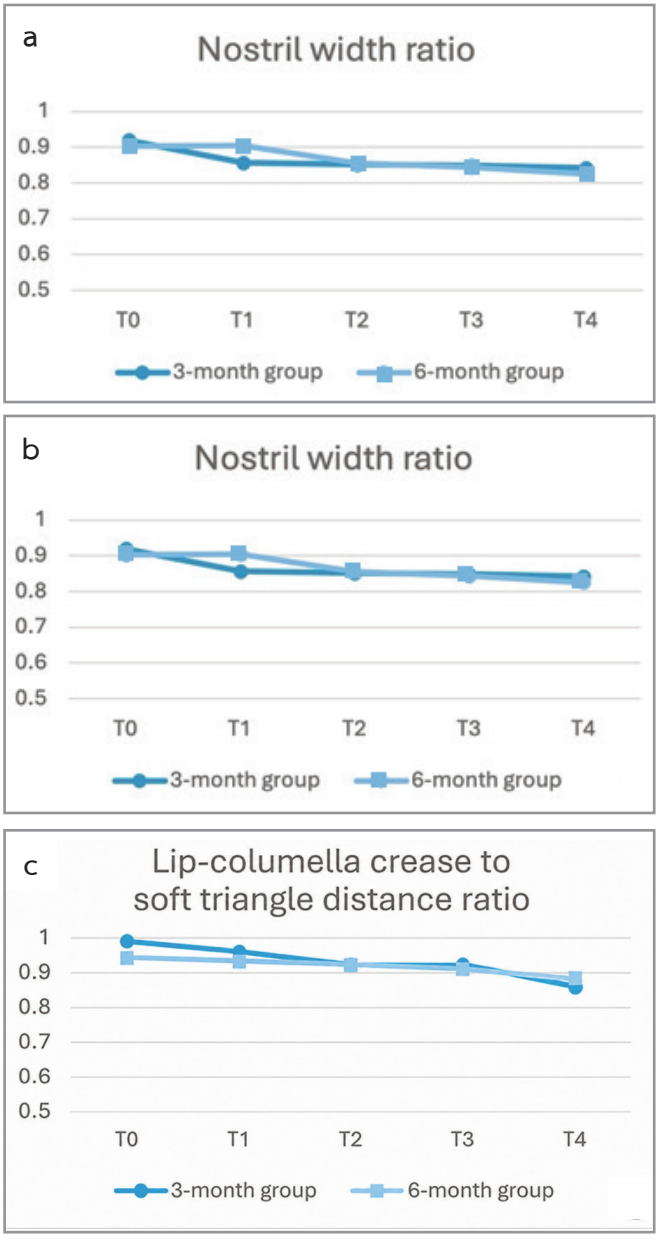


Figure 2 Comparison of nasal symmetry at each time point.
(a) Nostril height ratio.
(b) Nostril width ratio.
(c) Lip-columella crease to soft triangle distance ratio.

a reduction of 0.1 ± 0.1 mm. The six-month cohort revealed significant reductions exclusively on the cleft side, with a reduction of 0.4 ± 0.3 mm.

No significant changes were observed in columella deviation in either cohort (Table 4).

Although significant changes in nasal morphology were observed from T1 to T4, no statistically significant differences in these changes were identified when comparing the two cohorts (Table 5).

Nasal morphology symmetry was quantitatively evaluated using the nostril height ratio, nostril width ratio, and lip-columella crease to soft triangle distance ratio. A gradual decrease in symmetry was observed across all parameters within both study cohorts. Despite this gradual decline, relatively high symmetry ratios were maintained throughout the follow-up period (Figure 2).

Discussion

The institutional protocol for record acquisition incorporated both two-dimensional and three-dimensional (3D) photography. In this investigation, 3D photographs were employed for nasal morphology evaluation owing to their superior accuracy compared with two-dimensional methods. Furthermore, 3D facial scanning enables standardized magnification and precise measurement.

Post-surgical management and challenges

Post-surgical relapse of nasal morphology represents a recognized phenomenon in cleft care. Consequently, craniofacial centers employ diverse pre-surgical, surgical, and post-surgical management protocols to mitigate these undesirable sequelae. Pre-surgical management frequently involves nasoalveolar molding (NAM), which leverages the neonatal estrogen surge to non-surgically enhance nasal morphology.[17,18] Surgical overcorrection represents another technique employed to optimize outcomes. Surgical approaches prioritize minimizing scarring to prevent contracture forces, with surgeon experience being crucial for optimal results.[6,19]

Postoperative management frequently includes nasal stents, which are instrumental in preserving nasal form and function.[9] A common protocol for full-time nasal stent utilization ranges from three to six months.[6,7,12,18,20] Several authors have described suturing nasal stents, augmented with moldable

silicone rubber, to the nasal dorsum for two weeks, in addition to a three- to four-month wear period.[14] At the present institution, the current standard protocol for post-surgical nasal stent utilization is six months, as a previous investigation demonstrated improved nasal morphology following six months of utilization compared with a three-month duration.[21] The timing of device initiation is also crucial. Some centers commence nasal stent application immediately post-surgery,[14,18,20] while others initiate placement one to two weeks following surgery.[10,13] The present institution initiates nasal stent application immediately post-operatively to circumvent the increased difficulty of stent placement due to nostril constriction following surgical intervention.

Practical observations indicate a wide range of patient cooperation. As patients mature, their tolerance for nasal stent utilization decreases, often resulting in premature discontinuation of device usage. The primary reason for non-compliance with the institutional protocol was patients attempting to remove the self-retaining nasal stents. Taping techniques were employed to reinforce stent positioning, with two methods recommended to caregivers. The first technique involved wrapping tape around the bridge of the nasal stents, securing it to the nasal dorsum, and reinforcing it with additional horizontal tape. The second technique involved positioning the nasal stents with an elastic band and securing them to both sides of the cheeks. While some patients demonstrated improved tolerance with taping reinforcement, others remained completely intolerant.

Observed relapse and literature review

Routine follow-up after the termination of nasal stent usage revealed morphological relapse in all patients. Among the observed changes, a reduction in nostril height was noted on both the cleft and non-cleft sides. In the present study, this finding may be explained by postoperative soft-tissue remodeling. Scar maturation within the nasolabial region and reorientation of the orbicularis oris muscle can lead to downward rotation of the columella and nasal tip, thereby reducing the vertical dimension of the nostril bilaterally during the healing process. A previous study suggested that postoperative scar contracture following cleft lip repair may contribute to secondary nasal deformity.[22]

In addition to postoperative tissue remodeling, normal nasal growth may also contribute to changes in nasal morphology over time. A previous study reported that nasal morphology may continue to change during growth following primary cleft repair, and residual asymmetry may persist despite an initially satisfactory surgical outcome.[23] Therefore, long-term postoperative changes are likely influenced by both healing-related remodeling and normal craniofacial growth.

From a clinical perspective, the magnitude of the observed changes should also be considered. Although statistically significant changes were observed in several nasal measurements, the magnitude of these changes was relatively small and nasal symmetry remained within an acceptable range throughout the observation period. Whether these dimensional changes are clinically meaningful requires further investigation in larger prospective studies.

In the present investigation, significant changes in various nasal measurements were observed following the cessation of nasal stent utilization in both cohorts, with only columella deviation remaining stable. The observed widening of alar base width may be attributed to a combination of normal growth and morphological relapse. Furthermore, reductions in vertical dimensions, such as nostril height and lip-columella crease to soft triangle distance, suggest a greater degree of relapse relative to growth in these directions.

During follow-up visits, the considerable burden on caregivers for maintaining nasal stents for extended durations became evident. Adherence to the institutional protocol of full-time nasal stent utilization for six months often posed challenges for caregivers.

Previous studies have demonstrated favorable outcomes with postoperative nasal stenting. Yeow et al.[7] compared two cohorts of three-month-old infants following unilateral complete cleft lip repair with primary rhinoplasty—one cohort received nasal stents for six months, while the other received no stenting (NAM was not utilized). Follow-up assessments at 5 to 8 years of age demonstrated improved nasal appearance, symmetry, alar cartilage position, alar base level, and columella tilt in the nasal stented cohort compared with controls. Similarly, Al-Qatami et al.[12] randomized 50 infants undergoing unilateral cleft lip repair into stenting and non-stenting cohorts. All participants underwent preoperative NAM followed by primary lip repair and rhinoplasty at three months of age, with follow-up occurring three months later during palatoplasty. Most specific nasal measurements and nasal symmetry demonstrated improvement in the nasal stenting cohort. A recent systematic review by Nguyen et al.[9] reported that postoperative nasal stent protocols varied across studies, including differences in stent design, timing of application, and duration of wear. Although favorable outcomes have generally been reported with postoperative nasal stenting, the optimal duration of postoperative nasal stent use remains uncertain. The present study focused on a different aspect of postoperative nasal stenting by comparing different durations of postoperative nasal stent use, whereas these previous studies evaluated the effectiveness of postoperative nasal stenting by comparing stented and non-stented patients.

The present investigation demonstrated relapses of nasal morphology in both cohorts. However, comparison of nasal morphology changes at the one-year follow-up between the two cohorts revealed no statistically significant differences, and nasal morphology symmetry remained within an acceptable range in both cohorts. The present study could not detect a significant advantage of extending postoperative nasal stent use from three to six months, although larger prospective studies are needed to determine the optimal duration of postoperative nasal stenting.

Because of variability in primary rhinoplasty performance based on surgeon preference at the present institution, a reduction in symmetry was noted from T0 (post-cheiloplasty period) to T1 (at the termination of Nasal Creator Device utilization). Primary rhinoplasty may be a contributing factor to achieving nasal symmetry; however, its practice in conjunction with primary cheiloplasty remains a topic of controversy. Given that cleft rhinoplasty is a technique-sensitive procedure, some surgeons refrain from undertaking primary rhinoplasty due to concerns regarding potential growth retardation resulting from early intervention on the nasal structures.[24] Conversely, numerous investigations have reported favorable outcomes following primary rhinoplasty.[25-27] A study by Anderl[28] evaluated patients who underwent simultaneous lip and nose repair and followed them for 15 years, concluding that primary rhinoplasty does not inhibit growth. Regardless of the decision to perform primary rhinoplasty, the judicious utilization of nasal stents should be considered in post-surgical management to maintain nasal shape and mitigate potential future relapse.[9]

Limitations

Owing to the retrospective design of this investigation, completion of presurgical nasoalveolar molding (NAM), the performance of primary rhinoplasty, and the operating surgeon could not be fully standardized and may have influenced the study outcomes. In addition, the absence of randomization and a non-stented control group may have introduced selection bias and limited the ability to distinguish postoperative relapse from normal growth-related changes. Furthermore, the small sample size likely limited the statistical power to detect clinically meaningful differences between the two groups. Future prospective longitudinal studies with larger sample sizes and standardized treatment protocols

are needed to further clarify the relative contributions of postoperative remodeling and normal nasal growth to long-term changes in nasal morphology.

Conclusion

In this investigation, both the three-month and six-month nasal stent groups exhibited mild changes in nasal morphology during the one-year follow-up period after stent discontinuation. No significant differences in nasal morphology changes or nasal symmetry were observed between the two groups, and nasal symmetry ratios remained relatively high throughout the observation period. These findings suggest that extending postoperative nasal stent use beyond three months may provide limited additional benefit. Further prospective studies with larger sample sizes are needed to determine the optimal duration of postoperative nasal stenting.

Author contributions

Nounprang Boonpongsathian: Methodology, Validation, Formal analysis, Investigation, Data curation, Writing-original draft preparation, Visualization; **Buddhathida Wangsrimongkol:** Methodology, Validation, Investigation, Writing-review & editing; **Araya Pisek:** Formal analysis, Writing-review & editing; **Palakorn Surakunprapha:** Investigation, Resources; **Poonsak Pisek:** Conceptualization, Writing-review & editing, Supervision, Project administration.

Ethical statement

This study was approved by the Khon Kaen University Ethics Committee for Human Research (Approval No. HE651588).

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 English language editing only, comprising grammar correction, sentence-level clarity, and consistency of academic style. All AI-assisted text was reviewed, verified, and where necessary revised by the authors, who take full responsibility for the accuracy and integrity of the final manuscript.

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Original Article

Patient-Reported Adverse Conditions and Acceptance During Fixed Orthodontic Treatment

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Abstract

Background: Orthodontic treatment is associated with a range of adverse conditions. Understanding the occurrence of these conditions, patient acceptance, and their interrelationships is necessary to optimize patient experience and to inform clinical communication during fixed orthodontic treatment. **Objective:** This study aimed to investigate patient-reported adverse conditions experienced during fixed orthodontic treatment, evaluate patient acceptance of these conditions, and examine the associations between condition occurrence, patient characteristics, and acceptance. **Materials and methods:** A descriptive cross-sectional study was conducted among 219 patients who had completed fixed orthodontic treatment at the Orthodontic Clinic, Prince of Songkla University. Respondents reported adverse conditions experienced during treatment and whether they accepted each condition, using an online questionnaire. Descriptive statistics summarized the proportion of patients reporting adverse conditions and acceptance. Associations between demographic variables, adverse conditions, and acceptance were analyzed using the Mann-Whitney U-test and chi-square test. **Results:** All respondents reported experiencing pain during treatment. Appliance or wire detachment was the most common condition (73.52 %), while dental caries was the least reported (28.31 %). Most respondents indicated acceptance of the adverse conditions encountered during treatment. Acceptance differed significantly according to occurrence status for dental caries, halitosis, increased calculus formation, preauricular pain/tightness/fatigue, and poking from appliances or wires (P = 0.001–0.015). **Conclusion:** Patients reported multiple adverse conditions during fixed orthodontic treatment, and acceptance was generally high. Acceptance differed according to occurrence status for five adverse conditions; however, the distinction between experienced and hypothetical acceptance should be considered when interpreting these associations.

Keywords: Acceptance, Adverse condition, Orthodontic treatment, Questionnaire, Survey

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Introduction

Orthodontic treatment is recognized for its ability to improve occlusion, dental esthetics, and overall quality of life.[1] Although these benefits are well established, many patients experience temporary adverse effects during treatment that may affect comfort and the overall treatment experience.[2]

Adverse conditions may arise during fixed orthodontic treatment as a result of mechanical forces, irritation from appliance components, and challenges in maintaining oral hygiene.[3] Pain is the most frequently reported condition, typically beginning within 24 hours after appliance activation.[4] Pain and discomfort are common during orthodontic procedures and may persist for several days.[5]

Other adverse conditions include dental caries and enamel demineralization. Early demineralization, often presenting as white spot lesions, is well documented.[6] Chapman et al. reported that 36 % of patients developed at least one white spot lesion on the labial surfaces of the anterior maxillary teeth during fixed orthodontic treatment.[7] Halitosis is another potential adverse condition during fixed orthodontic treatment. Fixed orthodontic appliances may increase oral malodor, partly because appliance components facilitate plaque retention and make oral hygiene more challenging.[8,9] Fixed orthodontic appliances may also be associated with increased plaque and calculus accumulation.[10] Bracket placement can alter subgingival microbiota and increase plaque accumulation, gingival inflammation, and bleeding.[11]

Some patients experience temporomandibular symptoms, including joint pain, clicking, or limited mouth opening during treatment.[12] Although available evidence does not support a simple causal relationship between orthodontic treatment and temporomandibular disorders, TMD signs and symptoms may occur independently of orthodontic treatment.[13]

Soft-tissue irritation caused by protruding wires or appliance components is another frequently observed condition and may result in ulcerations of the cheeks, lips, or gingiva.[14,15] Appliance or wire detachment can prolong treatment and contribute to discomfort.[16,17]

Although numerous adverse conditions during orthodontic treatment have been described in the literature, studies examining the frequency of these conditions and patient perceptions of their acceptability remain limited. Most existing research focuses on prevalence, with few studies assessing whether patients consider each condition acceptable or unacceptable. It also remains unclear whether acceptance differs between patients who have actually experienced a condition and those evaluating it hypothetically. This gap limits orthodontists' ability to anticipate patient concerns and provide appropriate guidance. The present study aimed to investigate patient-reported adverse conditions experienced during fixed orthodontic treatment, evaluate patient acceptance of these conditions, and examine the associations between condition occurrence, patient characteristics, and acceptance.

Materials and methods

Because no existing instrument comprehensively assessed both adverse conditions and their acceptance during fixed orthodontic treatment, a self-administered questionnaire was developed through a multistep process. The initial draft was prepared using information from previous studies describing orthodontic treatment–related pain, white spot lesions, halitosis, calculus formation, temporomandibular symptoms, soft-tissue irritation, and appliance failure[4–17] together with informal interviews. Content validity was evaluated by three experts, comprising two orthodontists and one research methodology specialist. The questionnaire achieved a Content Validity Index (CVI) of 0.98. After receiving approval from the Human Research Ethics Committee of the Faculty of Dentistry, Prince of Songkla University, the questionnaire was pilot tested with individuals whose characteristics were similar to those of the target population. The pilot test assessed

language clarity, item comprehension, and overall reliability. Based on the pilot data, the questionnaire demonstrated acceptable internal consistency, with a Cronbach's alpha coefficient of 0.78. Feedback from the pilot phase was used to revise the instrument before final use.

The final questionnaire consisted of three components. The first component collected demographic information, including gender, age at the start of treatment, educational level, and the primary reason for seeking orthodontic care. Respondents who selected both esthetic and functional reasons were asked to identify the main reason. The second component addressed adverse conditions experienced during treatment. Respondents indicated whether they had experienced specific conditions, including pain, dental caries, halitosis, increased calculus formation, discomfort or tightness around the preauricular area, poking from appliances or wires, and appliance or wire detachment. Pain was rated on a numeric scale from 0 to 10, while the remaining conditions were assessed using binary response options. The third component focused on acceptance. For each condition that respondents had experienced, they reported whether they accepted the condition based on their actual experience. For conditions they had not experienced, they reported whether they would hypothetically accept the condition if it occurred.

The study population included patients who completed fixed orthodontic treatment between July 2021 and July 2022 at the Dental Hospital, Faculty of Dentistry, Prince of Songkla University. Eligible participants were patients who had completed treatment primarily with fixed orthodontic appliances, had complete treatment records, were contactable by telephone, and were at least 18 years old at the time of questionnaire completion. Patients who temporarily used adjunct removable appliances during conventional fixed orthodontic treatment were not excluded, because fixed appliances remained the primary treatment modality throughout the overall treatment course. Exclusion criteria included patients who received combined orthodontic and orthognathic treatment, had cleft lip and/or palate, or underwent repeat orthodontic treatment. A total of 578 patient records were screened. After applying the eligibility criteria, all 465 eligible patients were contacted and invited to participate. Because the study attempted to recruit the entire accessible eligible population rather than a predetermined sample, no prospective sample-size calculation was performed. A total of 219 patients completed the questionnaire, corresponding to a response rate of 47.10 %. Data collection was carried out between February and March 2023. The mean interval between treatment completion and questionnaire completion was 11.0 months (range, 7–20 months). The questionnaire was administered online through Google Forms, and the survey link was sent to the respondent via the LINE application. A total of 219 respondents completed the questionnaire and were included in the analysis.

Descriptive statistics were used to summarize demographic characteristics, the self-reported occurrence of adverse conditions, experienced acceptance, and hypothetical acceptance. For each condition other than pain, the proportions of respondents who accepted the condition were compared between those who had and had not experienced it using the chi-square test. Associations of condition-specific acceptance with gender, educational level, and primary treatment motivation were also examined using the chi-square test. Because all respondents reported experiencing pain, pain scores were compared between respondents who accepted and did not accept pain using the Mann–Whitney U test. Statistical significance was set at $P < 0.05$.

Results

General data

A total of 219 respondents were included in the analysis. As shown in Table 1, the majority of respondents were female. The mean age at the start of treatment was 20.66 years, with a range of 11 to

56 years. When categorized by age group, most respondents were younger than 20 years. More than half of the respondents were studying for or had completed a bachelor's degree or higher. Esthetic concerns were the primary reason for seeking orthodontic treatment.

Table 1 General demographic data of the respondents

General data	Respondents (n(%))
Gender	
Male	47 (21.46)
Female	172 (78.54)
Age at the start of treatment	
Younger than 20 years	126 (57.53)
20 – 29 years	65 (29.68)
30 – 39 years	19 (8.68)
40 years or older	9 (4.11)
Education at the start of treatment	
Below bachelor's degree	99 (45.21)
Bachelor's degree or higher	120 (54.79)
Main reason for seeking treatment	
Esthetic concerns	167 (76.26)
Functional concerns	52 (23.74)

Adverse Conditions During Treatment

All respondents reported experiencing pain during treatment. Severe pain (scores 7–10) was the most frequently reported category, accounting for 47.49 % of respondents, as presented in Table 2. The occurrence of other adverse conditions is summarized in Table 3. The reported adverse conditions included dental caries (28.31 %), halitosis (36.53 %), increased calculus formation (61.64 %), preauricular pain, tightness, or fatigue, including worsening of pre-existing symptoms (31.51 %), poking from orthodontic appliances or wires (70.32 %), and appliance or wire detachment (73.52 %).

Table 2 Pain level during treatment reported by respondents

Level of pain	Respondents (n(%))
Mild pain (Score 1-3)	25 (11.42)
Moderate pain (Score 4-6)	90 (41.10)
Severe pain (Score 7-10)	104 (47.49)

* Percentages may not total 100 % due to rounding.

Acceptance of Adverse Conditions

As shown in Table 4, acceptance among respondents who experienced each adverse condition was high: pain (99.09 %), dental caries (85.48 %), halitosis (91.25 %), increased calculus formation (91.85 %), preauricular symptoms (88.41 %), poking from appliances or wires (88.96 %), and appliance or wire detachment (93.79 %). In comparison, acceptance

Table 3 Self-reported occurrence of adverse conditions during fixed orthodontic treatment

Adverse conditions during treatment	Respondents (n(%))	
	Occurrence	No occurrence
Pain	219 (100.00)	0 (0.00)
Dental caries	62 (28.31)	157 (71.69)
Halitosis	80 (36.53)	139 (63.47)
Increased calculus formation	135 (61.64)	84 (38.36)
Preauricular pain/tightness/fatigue	69 (31.51)	150 (68.49)
Poking from appliances or wires	154 (70.32)	65 (29.68)
Appliance or wire detachment	161 (73.52)	58 (26.48)

Table 4 Experiential acceptance among respondents who reported experiencing each adverse condition

Acceptance of adverse conditions reported by respondents who experienced those adverse conditions	Respondents (n(%))	
	Accept	Do not accept
Pain	217 (99.09)	2 (0.91)
Dental caries	53 (85.48)	9 (14.52)
Halitosis	73 (91.25)	7 (8.75)
Increased calculus formation	124 (91.85)	11 (8.15)
Preauricular pain/tightness/fatigue	61 (88.41)	8 (11.59)
Poking from appliances or wires	137 (88.96)	17 (11.04)
Appliance or wire detachment	151 (93.79)	10 (6.21)

Table 5 Hypothetical acceptance among respondents who did not report experiencing each adverse condition

Acceptance of adverse conditions reported by respondents who did not experience those adverse conditions	Respondents (n(%))	
	Accept	Do not accept
Dental caries	109 (69.43)	48 (30.57)
Halitosis	102 (73.38)	37 (26.62)
Increased calculus formation	67 (79.76)	17 (20.24)
Preauricular pain/tightness/fatigue	110 (73.33)	40 (26.67)
Poking from appliances or wires	49 (75.38)	16 (24.62)
Appliance or wire detachment	52 (89.66)	6 (10.34)

among respondents who did not experience the adverse condition, as presented in Table 5, was lower: dental caries (69.43 %), halitosis (73.38 %), increased calculus formation (79.76 %), preauricular symptoms (73.33 %), poking from appliances or wires (75.38 %), and appliance or wire detachment (89.66 %).

Relationships Between Factors and Acceptance

As shown in Table 6, no significant associations were found between acceptance and gender, educational level, or the primary reason for seeking treatment. However, significant associations were observed between acceptance and five adverse conditions: dental caries (P = 0.015), halitosis (P = 0.001), increased calculus formation (P = 0.009), preauricular pain/tightness/fatigue (P = 0.012), and poking from appliances or wires (P = 0.010). These findings indicate that condition-specific acceptance differed according to occurrence status for these five adverse conditions.

Discussion

Significant associations between occurrence status and condition-specific acceptance were observed for five adverse conditions. These findings should not be interpreted as evidence that the occurrence of adverse conditions determined patients' overall treatment experiences, because treatment continuation,

Table 6 *P* values for associations between acceptance of adverse conditions and condition occurrence or pain score and participant characteristics

Acceptance of adverse condition	Condition occurrence / pain score	Gender	Education	Main reason for seeking treatment
Pain	0.224[a]	0.323[b]*	0.891[b]*	1.000[b]
Dental caries	0.015[b]	0.507[b]	0.190[b]	0.847[b]
Halitosis	0.001[b]	0.522[b]	0.083[b]	0.859[b]
Increased calculus formation	0.009[b]	0.326[b]	0.174[b]	0.486[b]
Preauricular pain/tightness/fatigue	0.012[b]	0.605[b]	0.669[b]	0.567[b]
Poking from appliances or wires	0.010[b]	0.378[b]	0.121[b]	0.376[b]
Appliance or wire detachment	0.300[b]*	0.507[b]	0.149[b]	0.768[b]

[a] Mann–Whitney U-test

[b] chi-square test.

* For values marked with an asterisk, at least one expected cell count was less than 5; therefore, the chi-square result should be interpreted with caution.

For pain, the first *P* value column represents the association between acceptance and pain score. For all other adverse conditions, it represents the association between condition-specific acceptance and occurrence status.

satisfaction, and adherence were not directly assessed. Acceptance-based frameworks suggest that willingness to experience discomfort can coexist with continued pursuit of valued treatment goals.[18] Experimental evidence also suggests that treatment-related side effects can influence expectations regarding treatment efficacy.[19] However, these psychological mechanisms were not directly assessed in the present study.

When considering the self-reported occurrence of adverse conditions in this study, pain was the side effect experienced by all respondents. Previous studies have likewise shown that pain is common during the early stages of orthodontic treatment. Bergius et al. reported that 48 of 55 patients (87.27 %) experienced pain on the first evening after placement of molar separators, with pain intensity reaching its highest level the following day.[5] Ngan et al. found a significant increase in discomfort at 4 and 24 hours after placement of separators or initial archwires, whereas discomfort was no longer significantly elevated at 7 days.[20] These findings indicate that pain is an almost unavoidable side effect of fixed orthodontic treatment. Despite the high occurrence of pain, acceptance remained high among respondents. Pain may have been widely accepted because it is commonly anticipated as an unavoidable part of orthodontic treatment and is generally perceived as temporary.

Dental caries was self-reported by 28.31 % of respondents in the present study. Direct comparison with previous studies should be made cautiously because most previous studies assessed white spot lesions, which represent early enamel demineralization rather than cavitated dental caries. Gorelick et al. reported that 49.60 % of orthodontic patients developed at least one white spot lesion during treatment.[21] Øgaard found that orthodontically treated individuals had significantly more teeth with white spot lesions than untreated individuals more than five years after treatment.[6] Julien et al. reported that 23.40 % of patients developed at least one white spot lesion during orthodontic treatment.[22] In a meta-analysis, Sundararaj et al. reported pooled incidence and prevalence rates of 45.80 % and 68.40 %, respectively.[23] The lower self-reported occurrence in the present study may therefore reflect

differences in outcome definition and assessment method, as well as possible under-recognition by patients.

Soft-tissue irritation and oral mucosal lesions are recognized complications of fixed orthodontic appliances.[14,15] Baričević et al. also reported a higher occurrence of oral mucosal lesions among patients receiving orthodontic treatment.[24] These findings are consistent with the high proportion of respondents in the present study who reported poking or irritation from orthodontic appliances or wires.

Acceptance among respondents who had experienced an adverse condition reflects an evaluation based on lived experience. In contrast, responses from participants who had not experienced the condition represent hypothetical acceptance based on expectations. These two forms of acceptance are conceptually different and should not be interpreted as directly equivalent. Experiential acceptance is likely to be influenced by symptom severity, familiarity, coping strategies, and clinical management, whereas hypothetical acceptance primarily reflects expectations, uncertainty, or fear of an unfamiliar condition.

Five conditions demonstrated significant relationships with acceptance, specifically dental caries, halitosis, increased calculus formation, preauricular pain/tightness/fatigue, and poking from appliances or wires. In each of these conditions, respondents who had actually experienced the condition showed higher acceptance than those who had not. For example, respondents who experienced increased calculus formation had an acceptance rate of 91.85 %, while those who did not experience it had an acceptance rate of only 79.76 %. A similar pattern was found for poking from appliances or wires.

The significant associations observed for dental caries, halitosis, increased calculus formation, preauricular pain/tightness/fatigue, and poking from appliances or wires may reflect differences between actual and anticipated perceptions of these conditions. Respondents who had experienced these conditions may have become more familiar with their severity, duration, and manageability, whereas those without prior experience may have anticipated greater discomfort or disruption. For conditions such as increased calculus formation and poking from appliances or wires, familiarity with practical management strategies, including improved oral hygiene, professional removal, orthodontic wax, or minor chairside adjustment, may also have contributed to greater acceptance. However, the present study did not directly assess perceived severity, controllability, symptom duration, coping strategies, or the type of management received. These explanations should therefore be considered hypothesis-generating rather than causal.

Acceptance was also higher among respondents who experienced appliance or wire detachment, but the difference was not statistically significant. This may reflect the smaller between-group difference, unequal numbers of respondents across categories, or variation in unmeasured factors such as severity, duration, impact on daily activities, expectations, and individual coping ability. Because no prospective sample-size calculation was performed, the absence of statistical significance should not be interpreted as evidence of no association.

Taken together, these findings suggest that prior experience with certain adverse conditions may be associated with greater acceptance. This observation should be interpreted with caution because the study design does not permit conclusions about causality. Future research is needed to clarify whether familiarity with a condition, perceived controllability, expectations, or other psychological factors contribute to patient acceptance.

Despite these findings, orthodontists should continue to provide oral-health care and patient education to reduce the self-reported occurrence of adverse conditions during treatment and to reduce patient anxiety, which may affect satisfaction after treatment.

Several limitations of this study should be considered when interpreting the findings. Data were collected after completion of orthodontic treatment, with a mean recall interval of 11 months and a range of 7–20 months. Participants with longer recall intervals may have remembered the occurrence, severity, or duration of adverse conditions less accurately. In addition, satisfaction with the final esthetic outcome may have led some participants to evaluate previous discomfort more favorably, resulting in retrospective glorification. Conversely, particularly unpleasant experiences may have been more readily recalled. As a result, both the reported occurrence and acceptance of adverse conditions may have been affected. In addition, because this study invited all eligible patients during the study period rather than recruiting a predetermined sample size, the final sample depended on voluntary participation and may not fully represent all eligible patients. Although all eligible patients were invited, only 219 of 465 individuals completed the questionnaire, corresponding to a response rate of 47.10 %. Nonrespondents may have differed from respondents in their treatment experiences or acceptance, resulting in potential nonresponse bias. Because no prospective sample-size calculation was performed, some comparisons may have had limited statistical precision, particularly when the number of respondents who did not accept a condition was small. Therefore, nonsignificant results should not be interpreted as evidence of no association. The study was conducted at a single institution, and the findings may not be directly applicable to patients treated in different clinical settings. Another limitation is that the severity of adverse conditions was not evaluated, although severity may influence patient acceptance. In addition, dental caries and increased calculus formation were assessed using self-reported responses rather than clinical examinations. Participants may have misidentified dental caries, white spot lesions, plaque accumulation, or calculus, which may have reduced diagnostic accuracy. This limitation may partly explain why the self-reported occurrence of dental caries in the present study was lower than the prevalence reported in clinical studies.

Further studies involving patients during active orthodontic treatment may provide a more accurate assessment of acceptance at different stages of treatment. Investigation of additional factors that may influence acceptance would also be valuable, including psychological and behavioral variables.

Conclusion

Patients reported multiple adverse conditions during fixed orthodontic treatment, and overall acceptance of these conditions was high. Acceptance differed according to occurrence status for dental caries, halitosis, increased calculus formation, preauricular pain/tightness/fatigue, and poking from appliances or wires. Because acceptance among respondents without prior experience was hypothetical rather than experience-based, these associations should be interpreted cautiously. Clinicians can provide condition-specific anticipatory guidance and practical management instructions to support patients during treatment, although prospective studies are needed to confirm their effects on acceptance.

Author contributions

Kantakawee Ruankaeo: Software, Investigation, Resources, Data Curation, Writing – Original Draft, Visualization; **Nattaporn Youravong:** Conceptualization, Methodology, Validation, Formal analysis, Writing – Review & Editing; **Supanee Suntornlohanakul:** Conceptualization, Writing – Review & Editing, Supervision, Project administration, Funding acquisition.

Ethical statement

The study was approved by the Human Research Ethics Committee of the Faculty of Dentistry, Prince of Songkla University (EC6407-049). All participants

provided informed consent prior to participation.

Disclosure statement

The authors have no conflicts of interest.

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AI-assisted writing declaration

The authors used Microsoft Copilot solely for language editing and grammar refinement to improve the clarity and readability of the manuscript. All AI-assisted content was reviewed, edited, and verified by the authors to ensure accuracy and integrity.

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Case Report

Combination of Removable and Fixed Appliances to Correct Anterior and Unilateral Posterior Crossbite Associated with a Functional Mandibular Shift in a Late Adolescent Patient: A Case Report

Ornjira Wiriyapongsukit* Chairat Charoemratrote**

Abstract

Various methods have been proposed to correct anterior and posterior crossbites in the permanent dentition. This case report presents the orthodontic management of a 15-year-old female with partial anterior and unilateral posterior crossbites. The maxillary right and left lateral incisors, left canine, and posterior teeth on the left side, except first premolar and second molar—were in crossbite, accompanied by a functional shift in the transverse dimension. Treatment consisted of a removable posterior bite plane with unilateral expansion screw followed by fixed edgewise appliances using a bidimensional bracket system. The total treatment duration was 25 months. At the end of treatment, both anterior and posterior crossbites were successfully corrected, which resulted in a stable occlusion, centered dental midlines, and improved facial symmetry.

Keywords: Anterior crossbite, Functional shift, Orthodontic treatment, Posterior crossbite

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Introduction

Crossbite is a relatively frequent malocclusion that can involve either the anterior or posterior segments of the dental arches. It is characterized by an abnormal buccolingual relationship between maxillary and mandibular teeth and may originate from dental, skeletal, or functional discrepancies.[1] Crossbite has been reported in approximately 56 % of malocclusion cases, with a prevalence of 10 % in primary dentition, 11 % in the mixed dentition, and 5 % in permanent dentition.[2] The etiology of crossbite is multifactorial[3] and may include hereditary influences, discrepancies in dental arch, retained deciduous or supernumerary teeth, mouth-breathing patterns, sucking habits, or occlusal interferences originating from premature contacts.[4,5]

Untreated crossbite in adolescents and adults can lead to asymmetric mandibular movement, occlusal trauma, gingival recession, or temporomandibular-joint dysfunction.[6-8] Anterior crossbite, in particular, may cause labial displacement of mandibular incisors, gingival margin discrepancy, and thinning of alveolar bone,[9] whereas posterior crossbite often produces a functional mandibular shift and midline deviation.[10] Because the potential for spontaneous correction in permanent dentition is minimal, active orthodontic intervention is recommended.[11]

Numerous treatment approaches have been reported for crossbite correction depending on its extent and etiology.[12,13] Removable expansion plates with jackscrews are effective for mild transverse deficiencies and allow convenient oral-hygiene maintenance,[14,15] whereas fixed appliances offer precise three-dimensional control for alignment and finishing.[16] In cases with functional posterior crossbite accompanied by anterior crossbite, a staged removable–fixed treatment approach may be advantageous, that allows initial transverse correction with removable appliances followed by fixed appliances for alignment while minimizing unwanted side effects.

This case report aims to present a simple and effective technique for managing posterior and anterior crossbites using a removable posterior bite plane with unilateral expansion screw, followed by fixed edgewise appliances. Illustrations of treatment progress and appliance design are provided to serve as clinical guidance.

Case report

A 15-year-old female was brought to the the Orthodontic Clinic of Prince of Songkla University by her mother due to concerns about dental crowding and chin deviation. There was no family history of chin deviation, and her parents reported no any premature loss of primary teeth. The patient had no known underlying disease, allergies, or regular medication. Menarche had occurred approximately three years earlier. Cervical vertebral maturation



Figure 1 Pretreatment extraoral and intraoral photographs.

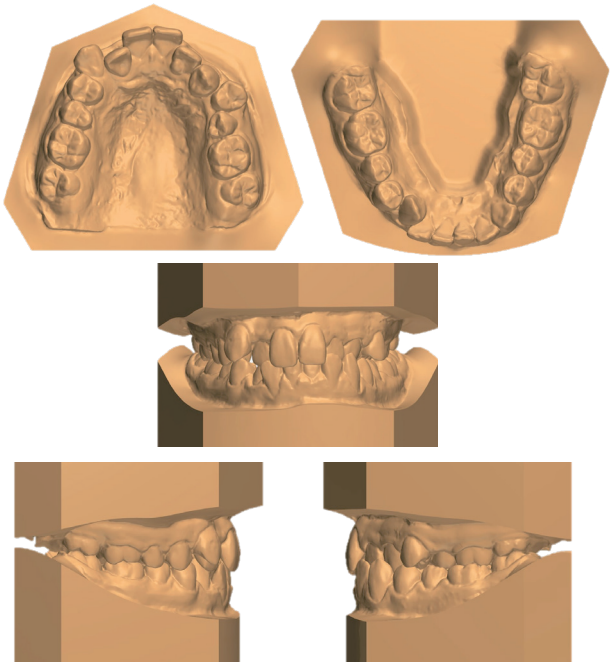


Figure 2 Pretreatment dental casts.

analysis showed CS5, which indicated that most craniofacial growth had been completed.[17]

Extraoral examination in the frontal view revealed a mesofacial type with chin deviation to the left side by 3 mm from the facial midline. Although the patient had competent lips, lip redundancy was observed due to mandibular overclosure in maximum intercuspation. In the lateral profile view, the patient exhibited a straight facial profile with chin prominence (Figure 1).

The intraoral examination revealed anterior crossbite that involved teeth 12/42-43, 22/32, and 23/33, as well as posterior crossbite on 25/35 and 26/36. The overjet and overbite measured 2 mm and 4 mm, respectively. According to Angle's classification, both canine and molar relationships were Class I. Upper dental midline coincided with facial midline, whereas the lower dental midline deviated from facial midline to the left by 3 mm. Moyer's analysis indicated severe crowding in the upper arch and mild crowding in the lower arch (Figures 1 and 2).

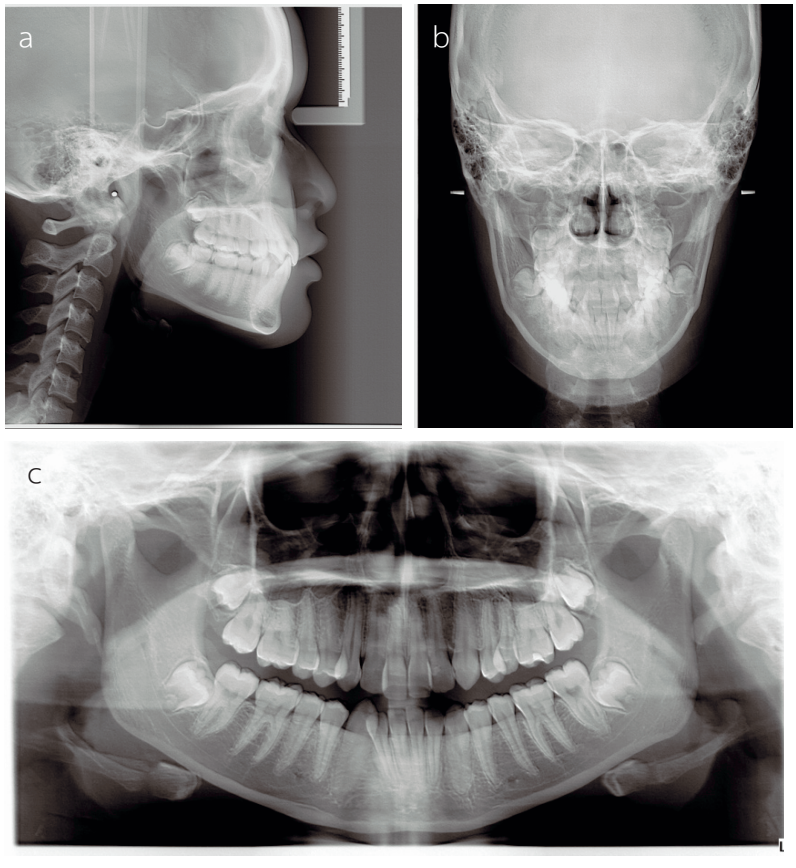


Figure 3 Pretreatment lateral cephalometric
(a) posteroanterior cephalometric
(b) panoramic
(c) radiographs.

A functional shift was detected. Bimanual manipulation was performed to identify the condylar position in centric relation.[18] The first contact in centric occlusion occurred between 12/43, and a 3 mm transversal discrepancy between the centric occlusion and maximum intercuspation positions was observed during clinical examination.

Panoramic radiography demonstrated fully developed permanent dentition with developing third molars and no pathology. Lateral cephalometric analysis revealed a skeletal Class I normodivergent pattern with orthognathic maxilla and mandible, normally inclined and positioned upper incisors, retroclined and retruded lower incisors, obtuse interincisal angle, normally positioned upper and lower lips, and obtuse nasolabial angle. The posteroanterior cephalogram also showed a 3 mm chin deviation to the left. (Figure 3 and Table 1)

Table 1 Pretreatment, treatment progression, and posttreatment cephalometric analysis

Area		Measurement	Norm Mean ± SD	Pre treatment	Progression	Post treatment
Skeletal	Maxilla to Cranial base	SN-FH (°)	6 ± 3	8	8	8
		SNA (°)	84 ± 4	87	87.50	87
		SN-PP (°)	9 ± 3	5	5	5
	Mandible to Cranial base	SNB (°)	81 ± 4	83	82	83
		SN-MP (°)	29 ± 6	28	29	29
		SN-Pg (°)	82 ± 3	83	82	83
		NS-Gn (°)	68 ± 3	66	67	67
	Maxillo-Mandibular	ANB (°)	3 ± 2	3	5	4
		Wits (mm)	-3 ± 2	-2	-2	-2
		MP-PP (°)	21 ± 5	23	24	24
		FMA (°)	23 ± 5	20	21	21
Dental	Maxillary dentition	UI-NA (°)	22 ± 6	18.50	19	22
		UI-NA (mm)	5 ± 2	4	4	4
		UI-SN (°)	108 ± 6	105	105	108
	Mandibular dentition	LI-NB (°)	30 ± 6	20	26	26
		LI-NB (mm)	7 ± 2	4	6	6
		LI-MP (°)	99 ± 5	88	92	94
	Maxillo-Mandibular	UI-LI (°)	125 ± 8	137	131	127
Soft tissue	Soft tissue	E line-UL (mm)	-1 ± 2	0	0	0
		E line-LL (mm)	2 ± 2	1	2	2
		NLA (°)	91 ± 8	111	111	108
		H-angle (°)	14 ± 4	15	16	17

Abbreviations: FH, Frankfurt horizontal plane; PP, palatal plane; MP, mandibular plane; FMA, Frankfort mandibular plane angle; UI, upper incisor; LI, lower incisor; UL, upper lip; LL, lower lip; NLA, Naso-labial angle; H, Holdaway



Figure 4 Intraoral photographs of the bilateral posterior bite plane with unilateral expansion screw.

Based on the diagnostic information, the treatment objectives were: (1) eliminate the functional shift and improve facial asymmetry (2) relieve crowding and achieve proper alignment (3) correct both anterior and posterior crossbite and (4) obtain normal overjet, overbite, stable intercuspation, and centered dental midlines.

Two treatment approaches were considered: (1) a removable appliance consisting of a posterior bite plane with unilateral expansion screw and (2) fixed bi-dimensional preadjusted edgewise appliances with 0.018-inch slots for incisors and 0.022-inch slots for canines, premolars, and molars.

Treatment was initiated with a bilateral posterior bite plane incorporating a unilateral jackscrew oriented buccolingually to tip teeth 25-27 buccally. Two Adams clasps, one triangular clasp, and four C-clasps were used for retention. The patient was instructed to wear the appliance full time, including during meals except for toothbrushing, and to activate the jackscrew by one quarter turn per week. (Figure4)

After the posterior crossbites were corrected, C-clasps on teeth 13 and 23 were removed. Brackets were then bonded to teeth 14-24 to correct the anterior crossbite, and to the mandibular teeth to relieve crowding. Leveling was carried out using sequential 0.012-inch and 0.014-inch nickel–titanium (NiTi) archwires with bends[19] on both upper and lower arches.



Figure 5 Intraoral photographs after three months of leveling and alignment that showed coincidence of the upper and lower dental midlines.



Figure 6 Treatment progress extraoral and intraoral photographs showing complete correction of the anterior and posterior crossbites at 11 months.

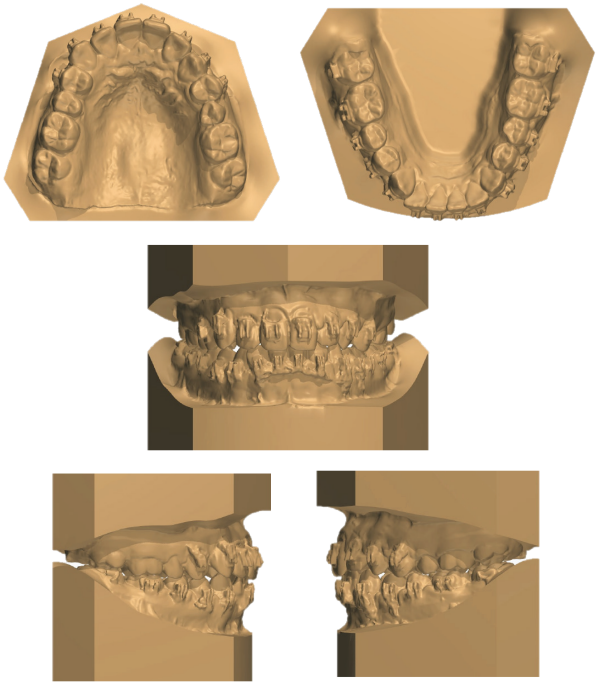


Figure 7 Treatment progress dental casts.

After three months of leveling and alignment and relieving the acrylic interference that impeded normal tooth alignment, the functional shift was corrected, as demonstrated in Figure 5, with coincidence of the upper and lower dental midlines. Since the anterior crossbite had not yet been fully resolved, the patient was instructed to continue wearing and activating the posterior bite plane until the jackscrew reached its maximum advancement. The total activation time was seven months.

After 11 months of treatment, both the anterior and posterior crossbites were fully corrected, and treatment-progress records were obtained (Figures 6 and 7). The treatment-progress radiographs, cephalometric analysis (Figure 8 and Table 1) and superimposition tracing between pretreatment and progress stages (Figure 9) demonstrated the changes in skeletal, dental, soft-tissue aspects. Cranial base superimposition revealed slight forward and downward displacement of the maxilla, downward displacement of the mandible, and a clockwise rotation of the mandible. Maxillary superimposition showed that the upper incisors were slightly proclined, protruded, and extruded, while the upper molars were mesialized. Mandibular superimposition showed that the lower incisors were proclined, protruded, and extruded and the lower molars were extruded and mesialized. Upward growth of the mandibular condyle and ramus were also observed. At the same time, the soft-tissue profile became more convex, and an increase in the lower anterior facial height was observed. The upper lip was more retruded whereas the lower lip position remained stable, and the nasolabial angle was maintained.

No traumatic occlusion was observed even without the removable appliance. Furthermore, since activation of the expansion screw resulted in proper posterior occlusion, the removable appliance was discontinued. Subsequently, fixed appliances were placed, and brackets were bonded to teeth 15-17 and 25-27. Leveling and alignment were carried

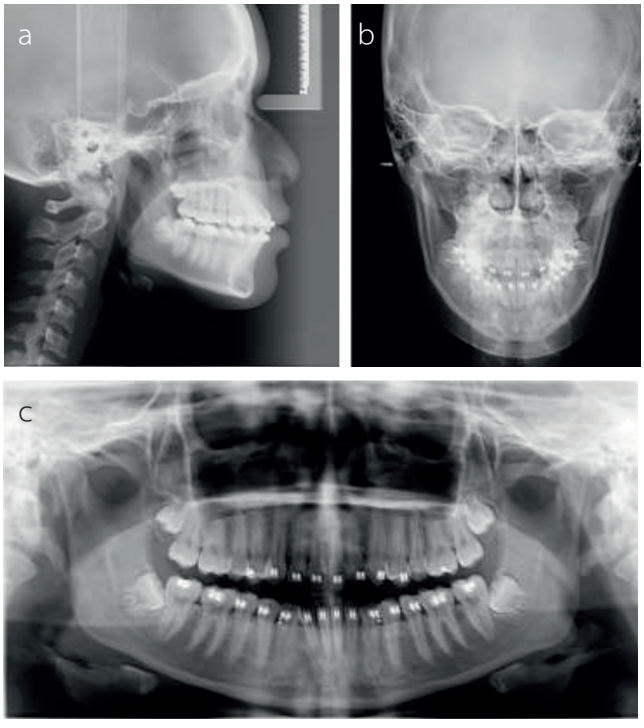


Figure 8 Treatment progress lateral cephalometric (a) posteroanterior cephalometric (b) panoramic and (c) radiographs.

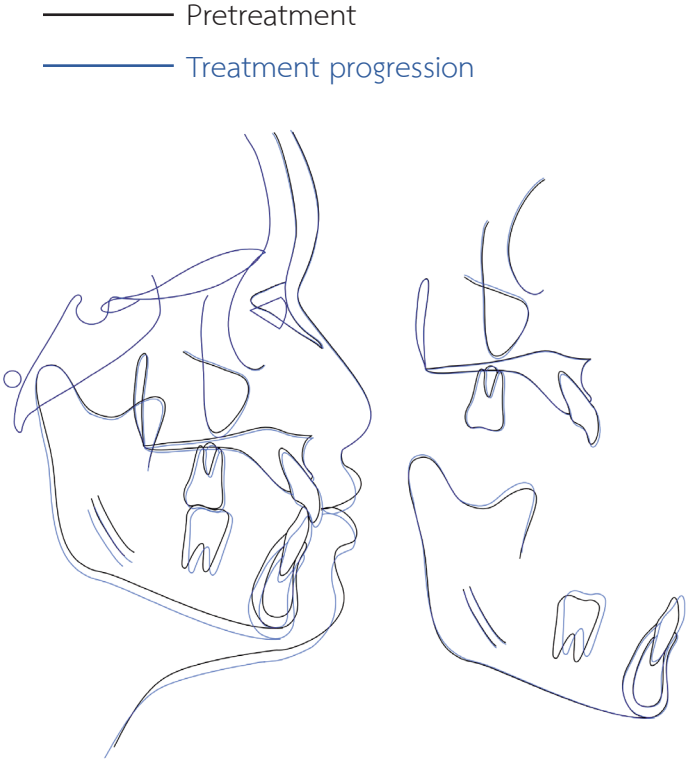


Figure 9 Cephalometric superimposition of the pretreatment (black lines) and treatment progress (blue lines) tracings.

out using sequential 0.012-inch, 0.014-inch, 0.016-inch, and 0.016 × 0.016-inch nickel–titanium (NiTi) archwires on both the upper and lower arches. Finishing was performed with 0.016 × 0.016-inch and 0.016 × 0.022-inch stainless steel wires, incorporating torque, artistic bends, open coil spring, and chains to close residual spaces.

A satisfactory facial appearance was achieved, with improvement of the facial asymmetry and normal upper and lower lip positions (Figure 10). Normal occlusion was established, as the anterior and posterior crossbites and upper and lower arch crowding were corrected, and the dental midlines were centered. Normal overjet and overbite were achieved, along with a well-interdigitated and stable occlusion. (Figures 10 and 11). Posttreatment radiographs are shown in Figure 12, and the posteroanterior cephalogram demonstrated coincidence of the chin and facial midlines. The posttreatment cephalometric analysis is summarized in Table 1.



Figure 10 Posttreatment extraoral and intraoral photographs.

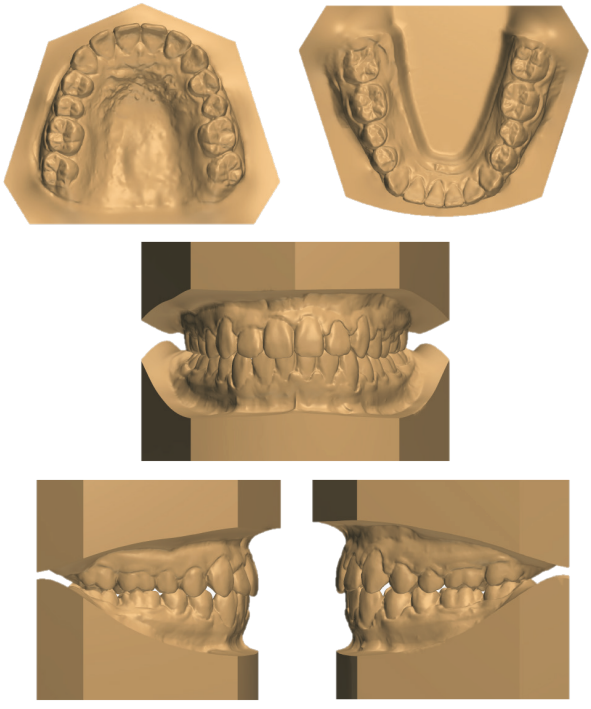


Figure 11 Posttreatment dental casts.

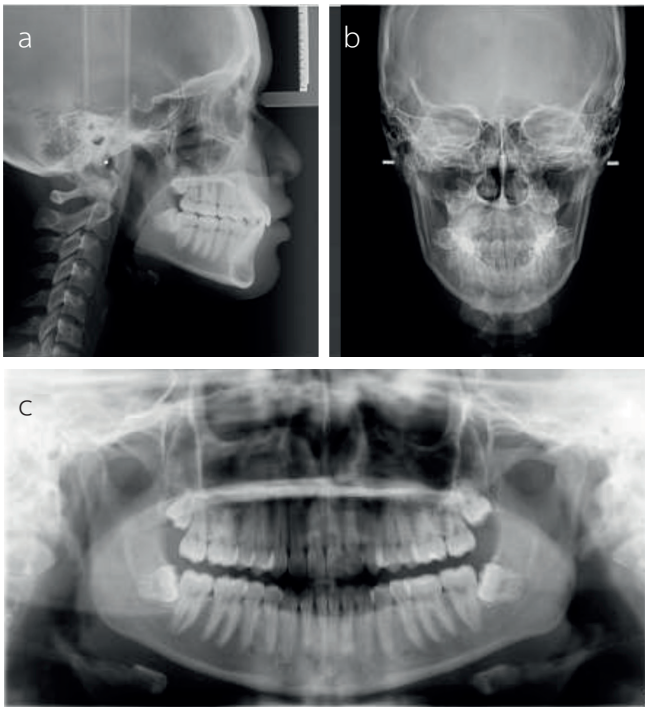


Figure 12 Posttreatment lateral cephalometric
(a) posteroanterior cephalometric
(b) panoramic
(c) radiographs.

Pretreatment, treatment progress, and posttreatment cephalometric tracings were superimposed to analyze the change after treatment (Figure 13). Only minor changes were observed following

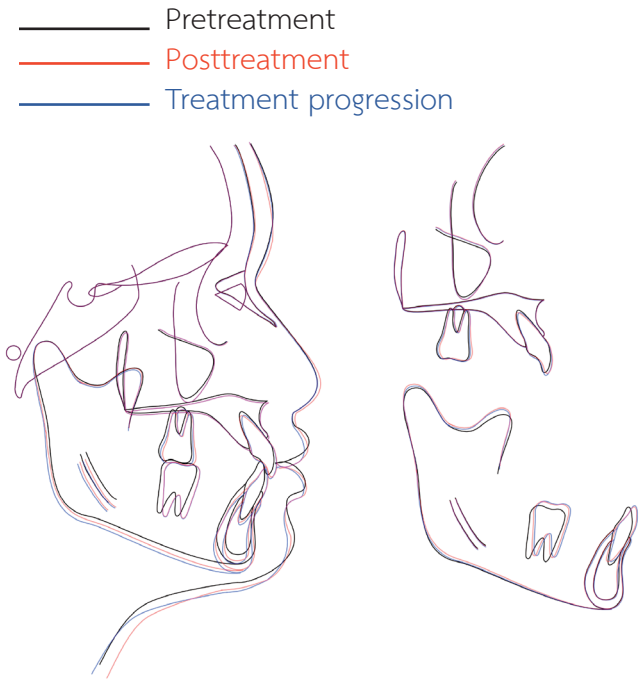


Figure 13 Cephalometric superimposition of pretreatment (black lines), treatment progress (blue lines) and posttreatment (red lines) tracings.

the placement of full fixed edgewise appliances for re-leveling and finishing. The primary differences were limited to dental inclination, which was adjusted toward a more normal orientation.

The treatment was completed in 25 months, after which all appliances were removed. Retention consisted of wearing a maxillary wraparound retainer full time with a passive anterior bite plane, and a mandibular wraparound retainer.

Follow-up records were obtained at 1, 3, and 6 months, and at 1 year after appliance removal. During the follow-up period, the corrected anterior and posterior occlusal relationships remained unchanged, and no re-establishment of crossbite was observed. Clinical examination did not reveal any apparent increase in facial asymmetry.

Discussion

Crossbite correction requires a comprehensive understanding of the dental, skeletal, soft-tissue, and functional components that together determine

the patient's occlusal and facial presentation. Although anterior crossbite may be the most obvious clinical finding, the underlying cause of functional mandibular shift is often related to posterior transverse discrepancy rather than the anterior teeth themselves. Functional mandibular shifts commonly originate from posterior occlusal interferences, even when the first occlusal contact is observed in the anterior region. For this reason, correction of the transverse discrepancy—particularly posterior crossbite—is recommended before attempting anterior correction.[7,20] Several authors have emphasized that addressing posterior crossbite with functional shift first helps re-establish a stable and unstrained closure path and prevents persistent anterior locking.[7]

Beyond the presence of a functional mandibular shift, additional diagnostic findings supported the diagnosis of a functional posterior crossbite rather than a true skeletal posterior crossbite. Posteroanterior cephalometric analysis did not demonstrate a significant maxillary transverse deficiency or skeletal asymmetry, and the maxillary and mandibular basal relationships were within normal transverse limits. In addition, coincidence of the maxillary and mandibular dental midlines was observed when the patient was instructed to open the mouth to maximum opening, which is a clinical feature consistent with functional deviation rather than a true skeletal discrepancy.[21] Furthermore, elimination of the posterior crossbite resulted in immediate coincidence of the maxillary and mandibular dental midlines, which indicated resolution of the functional shift rather than correction of a fixed skeletal transverse discrepancy.

Based on the diagnostic findings, posterior crossbite correction was prioritized in this patient to eliminate the functional shift. A removable posterior bite plane with unilateral expansion screw was designed to correct the posterior crossbite while simultaneously providing posterior disocclusion to allow the incisors to move freely without anterior interference. The acrylic plate also provided additional anchorage from multiple teeth and palatal support that improved appliance stability. Although removable expansion appliances primarily produce uncontrolled buccal crown tipping, careful monitoring in this case—through extraoral examination and posteroanterior cephalometry—confirmed the absence of maxillary canting or clinically significant vertical discrepancies after transverse correction.

An alternative approach using fixed appliances alone with cross-elastics was also considered. However, this method would have required additional disocclusion, most commonly through the use of bite turbos. Because bite turbos are typically placed from the early stage of treatment, they have been reported to interfere with mastication and cause patient discomfort during the initial treatment period.[11] Therefore, a posterior bite plane was selected as a more appropriate initial treatment modality in this patient.

Prior to fabrication of the removable appliance, bite registration was performed in a position that eliminated both anterior and posterior occlusal interferences. The vertical dimension of the bite construction was determined with reference to the incisal edges of the upper and lower anterior teeth, approximately 5 mm of anterior separation was created while ensuring that the vertical opening did not exceed the patient's physiologic freeway space.

In addition to occlusal correction, other treatment options were discussed with the patient. Since the patient exhibited an asymmetric smile line at baseline, she was counseled regarding smile training. Adjunctive esthetic procedures, which included botulinum toxin injections, were also discussed as optional treatments for further improvement of smile symmetry, if she desired.

Elimination of the posterior crossbite resulted in the disappearance of the functional mandibular shift, as demonstrated by the coincidence of the upper and lower dental midlines during closure (Figure 5). Once the functional shift was resolved and anchorage

from the removable appliance was no longer required, brackets were bonded to teeth 14-24 to proceed with anterior correction. Following correction of both posterior and anterior crossbites, full bonding was performed, and re-leveling was initiated.

In cases with large palatal displacement of the maxillary lateral incisors, mild proclination may remain after alignment because the tooth travels a long path into the arch. This occurred in the present patient, where slight proclination of the lateral incisors was noted. Various techniques, such as upside-down bracketing or applying additional palatal crown torque, have been described to refine incisor inclination when needed.[20,22] However, further torque adjustment was not performed in this case because gingival recession was observed on the maxillary lateral incisors, and the incisors already exhibited light, stable contact with the mandibular teeth. Although acceptable esthetic outcomes were achieved, the gingival margin heights did not fully follow the ideal pattern in which the maxillary central incisors and canines share a similar gingival level, with the lateral incisors positioned approximately 0.5 mm lower.[23] If the patient desires further esthetic enhancement, periodontal surgery may be recommended.[24] Overall, the staged removable–fixed protocol used in this case allowed efficient correction of both transverse and anterior discrepancies while minimizing unwanted effects. The elimination of the functional shift, the coordinated alignment of the incisors, and the improvement in occlusal and soft-tissue balance demonstrate the effectiveness of prioritizing transverse correction before comprehensive fixed appliance therapy in patients with combined anterior and posterior crossbite.

Although the short-term follow-up up of 1 year demonstrated maintenance of the corrected occlusal relationships and facial appearance, longer-term observation would be beneficial to further assess treatment stability.

Conclusion

This case demonstrates that a staged approach using a removable posterior bite plane with unilateral expansion screw followed by fixed appliances is effective for correcting both posterior and anterior crossbites associated with a functional mandibular shift. Priority correction of the transverse discrepancy restored a stable mandibular closure pathway, eliminated the functional shift, and facilitated subsequent anterior alignment. At the end of treatment, the patient achieved a stable Class I occlusion, corrected crossbites, centered midlines, improved facial symmetry, and acceptable soft-tissue balance. This approach highlights the value of combining removable and fixed appliances in managing complex crossbite cases in late adolescents.

Author Contributions

Ornjira Wiriyapongsukit: Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Visualization, Project administration; **Chairat Charoemratrote:** Conceptualization, Writing - Review & Editing, Supervision

Ethical statement

The patient's consent was obtained before publication.

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Review Article

Digital and Cone Beam Computed Tomography-Guided Miniscrew-Assisted Rapid Palatal Expansion: Workflows, Accuracy, and Clinical Outcomes: A Review of Literature

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Abstract

Background: Miniscrew-assisted rapid palatal expansion (MARPE) enables nonsurgical maxillary expansion in skeletally mature patients but is highly technique-sensitive. Inaccurate miniscrew placement and suboptimal planning may compromise skeletal outcomes. Digital and cone beam computed tomography (CBCT)–guided workflows have been introduced to improve anatomical assessment, placement accuracy, and treatment predictability. **Objective:** To provide a comprehensive and clinically relevant overview of digital and CBCT-guided MARPE workflows, with emphasis on planning protocols, miniscrew placement accuracy, anchorage strategies, and treatment outcomes. **Materials and methods:** A focused literature search was conducted to identify studies on digitally planned and CBCT-guided MARPE. Given heterogeneity in study designs and outcome measures, a narrative synthesis was performed in accordance with the principles of the Scale for the Assessment of Narrative Review Articles (SANRA). **Results:** Digital and CBCT-guided workflows enable three-dimensional, anatomy-driven planning and are associated with improved miniscrew placement accuracy and reproducibility, particularly regarding angular control and bicortical engagement. CBCT-based studies report predominantly skeletal expansion with limited dentoalveolar side effects. However, treatment response remains strongly influenced by patient age and midpalatal suture maturation. **Conclusion:** Digital and CBCT-guided MARPE enhance planning precision, anchorage stability, and clinical predictability. Nevertheless, lack of standardized protocols and limited high-quality clinical evidence highlight the need for well-designed trials to establish evidence-based guidelines.

Keywords: Cone beam computed tomography, Digital orthodontic workflow, Guided miniscrew placement, MARPE, Maxillary skeletal expansion

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Introduction

Maxillary transverse deficiency is a common dentofacial discrepancy associated with posterior crossbite, dental crowding, compromised occlusal function, and altered nasal airway dimensions, affecting approximately 8–18 % of referred orthodontic patients.[1] Conventional rapid palatal expansion (RPE) is effective in growing patients; however, increased midpalatal suture maturation in late adolescents and adults limits skeletal response and often results in predominantly dentoalveolar changes.[2,3] Surgically assisted rapid palatal expansion (SARPE) may overcome these limitations but is associated with increased invasiveness, cost, and morbidity.[4]

To achieve skeletal expansion while avoiding surgery, miniscrew-assisted rapid palatal expansion (MARPE) was developed.[5,6] MARPE delivers expansion forces directly to the maxillary basal bone through palatal miniscrews, producing greater skeletal expansion than conventional RPE.[7]

However, MARPE remains highly technique-sensitive, with treatment success dependent on accurate miniscrew placement, anchorage depth, and appliance positioning. The integration of cone beam computed tomography (CBCT) and intraoral scanning has enabled three-dimensional, anatomy-driven planning, virtual miniscrew positioning, and guided or appliance-integrated insertion techniques aimed at improving placement accuracy and reproducibility.[8,9]

Despite these advances, evidence supporting digital and CBCT-guided MARPE remains fragmented and methodologically heterogeneous, with limited prospective data and scarce long-term outcomes. Given the rapid evolution of digital technologies, a narrative synthesis is warranted to critically integrate current evidence, identify limitations, and outline directions for future research.

The aim of this narrative review is to provide a comprehensive and clinically relevant overview of CBCT-guided and digitally planned MARPE, with emphasis on clinical workflows, placement accuracy, treatment outcomes, and future perspectives.

Materials and methods

A focused literature search was conducted using PubMed, Scopus, and Google Scholar to identify publications related to digital workflows, CBCT-guided planning, and miniscrew-assisted rapid palatal expansion (MARPE). The search strategy combined keywords using Boolean operators as follows: (“MARPE” or “maxillary skeletal expander”) and (“CBCT” or “cone beam computed tomography”) and (“digital workflow” or “guided miniscrew placement”). The search was adapted for each database. Studies published between January 2017 and December 2025 and written in English were included to capture recent developments. The selected time frame (2017–2025) was chosen because significant developments in digital planning, CBCT-guided workflows, and guided miniscrew placement in MARPE have predominantly emerged during this period. Earlier studies predominantly described conventional MARPE without digital integration; the year 2017 marks the appearance of foundational CBCT-based anatomical quantification and early digital workflow descriptions in the MARPE literature,[8,9] making it an appropriate starting point for a review focused on digitally guided approaches.

This review is narrative in nature and does not follow PRISMA guidelines. Studies were selected based on thematic relevance to digital workflows, CBCT-guided miniscrew placement, anatomical assessments, and clinical outcomes of MARPE, while those focusing solely on conventional tooth-borne expansion were excluded. Reference lists of selected studies were also manually reviewed.

Following title and abstract review and full-text assessment, 24 studies were ultimately selected based on their relevance to the review topic. This review is a traditional narrative review guided by SANRA principles and does not represent a systematic or semi-systematic review. To enhance transparency and methodological rigor, the review framework was guided by the Scale for the Assessment of Narrative Review Articles (SANRA).[10] The SANRA framework

Table 1 Representative Summary of Included Studies

Authors	Year	Study Type	Key Findings
Solano Mendoza et al.	2022	Clinical (CBCT)	MARPE produces skeletal expansion with minimal dentoalveolar effects
Angelieri et al.	2013	Methodological	Introduced midpalatal suture maturation classification
Lee et al.	2010	Case report	Early application of MARPE in severe cases
Brunetto et al.	2017	Clinical	Demonstrated nonsurgical MARPE in adults
Li et al.	2020	Clinical (CBCT)	Bicortical anchorage improves skeletal expansion
Wang et al.	2017	CBCT anatomical	Identified optimal palatal bone thickness
Cantarella et al.	2020	Technical	Digital planning workflow for MARPE
Thakkar et al.	2020	Clinical innovation	Digital MARPE workflow feasibility
Lo Giudice et al.	2020	Technical	CBCT-guided MARPE design
Hsu et al.	2023	Case report	Digital fabrication of MARPE appliance
Minervino et al.	2019	Case report	MARPE guide technique
Stursa et al.	2023	Cadaveric	High accuracy of guided miniscrew placement
Bellocchio et al.	2025	Clinical	Angular deviation ~3°, clinically acceptable accuracy
Wilmes et al.	2022	Clinical/Conceptual	Bone-first principle for MARPE
Hamanaka et al.	2024	In-vitro	Guide design influences accuracy
Vasoglou et al.	2022	Clinical	Accurate guided miniscrew placement
Ronsivalle et al.	2023	Clinical	Digital workflow accuracy consistent
Park et al.	2023	Clinical	Significant skeletal expansion outcomes
Thi Hong Thuy et al.	2025	Prospective	Increased nasal and skeletal dimensions
Oliveira et al.	2021	Clinical	Success linked to suture maturation
Burak & Hilmi	2024	CBCT anatomical	Palatal mucosal thickness variation
Andraws et al.	2024	CBCT study	Regional variation in palatal thickness
Andrei et al.	2025	Review	Digital customization of MARPE
Hoang et al.	2025	Scoping review	Clinical applications of digital MARPE

The majority of included studies were published between 2017 and 2025. A small number of foundational pre-2017 studies (Angelieri et al., 2013; Lee et al., 2010; Brunetto et al., 2017) were incorporated based on their seminal relevance to midpalatal suture classification and early MARPE development, which form the conceptual basis of this review.

consists of six domains: justification of the article's importance, description of the literature search, appropriate referencing, scientific reasoning, appropriate presentation of data, and balanced interpretation. These criteria were considered during manuscript preparation to ensure methodological quality. The application of SANRA criteria in the present review is summarized in Supplementary.

Results

This narrative review, guided by SANRA principles, included studies identified from PubMed, Scopus, and Google Scholar (2017–2025). A total of 24 studies were included based on their relevance to digitally planned and CBCT-guided MARPE, encompassing in-vitro studies, cadaveric investigations, technical workflow reports, and clinical studies. The review addressed the six SANRA domains, as summarized in Supplementary. A representative summary of key included studies is presented in Table 1.

Digital Workflow for MARPE Planning

The overall digital workflow for CBCT-guided MARPE planning—from imaging and virtual planning to appliance fabrication and placement—is summarized in Figure 1.

CBCT acquisition protocols

CBCT imaging represents the initial step in digitally planned MARPE, and most studies recommend a limited field-of-view scan focused on the maxilla to balance diagnostic requirements with radiation exposure in accordance with the as low as reasonably achievable (ALARA) principle.[8] Purpose-driven imaging of the midpalatal suture and adjacent palatal anatomy facilitates assessment of bone thickness and identification of potential miniscrew insertion sites.[9] CBCT use in MARPE should be selectively justified in accordance with the ALARA principle, particularly for evaluating palatal bone thickness, midpalatal suture maturation, and safe miniscrew positioning, as it improves placement accuracy and reduces complications.[8,9]

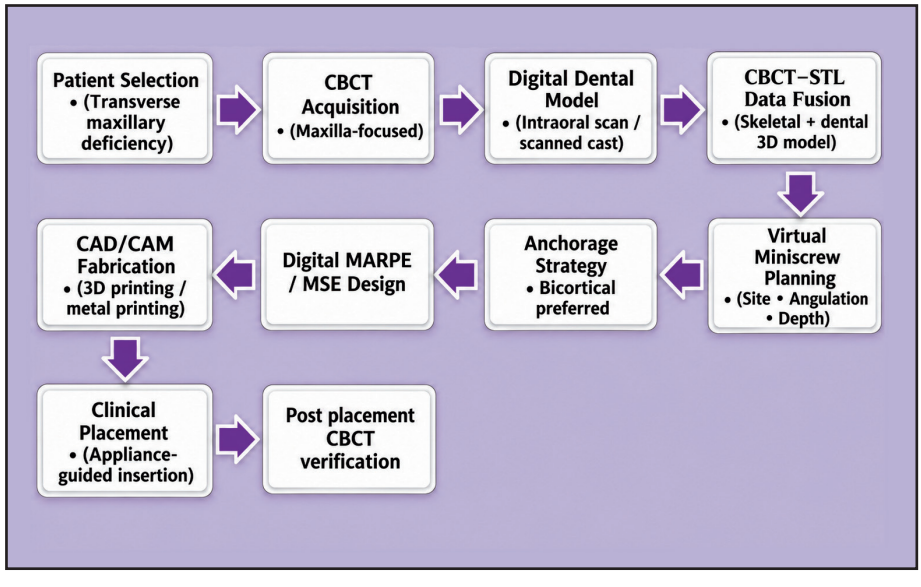


Figure 1 Schematic representation of the digital and CBCT-guided MARPE workflow, illustrating patient selection, CBCT acquisition, CBCT–STL data fusion, virtual miniscrew planning, anchorage strategy, CAD/CAM fabrication, appliance-guided insertion, and post-placement CBCT verification. [CBCT: cone beam computed tomography; STL: stereolithography; MARPE: miniscrew-assisted rapid palatal expansion; MSE: maxillary skeletal expander; CAD/CAM: computer-aided design/computer-aided manufacturing.]

DICOM–STL merging (CBCT + intraoral scans)

A critical step in digital MARPE planning is the integration of skeletal and dental datasets. All the workflows assessed relied on merging CBCT DICOM data with STL files derived from intraoral scans or scanned dental casts. Surface-based registration and dental landmark alignment were commonly employed to ensure accurate superimposition. Cantarella's methodology involved conversion of CBCT data into STL format followed by alignment with optical scans, facilitating precise spatial relationships between the maxilla and the expander.[9]

Virtual miniscrew planning

Virtual planning of miniscrew placement represents a major advantage of digitally guided MARPE workflows. Across reviewed studies, miniscrew sites were selected based on assessment of palatal bone availability and surrounding anatomical structures to minimize root proximity and optimize insertion trajectories.[11,12] Quantitative approaches incorporating regional bone thickness mapping have further supported refinement of angulation and insertion depth.[9] However, most planning protocols remain operator-dependent, and objective validation of virtual planning accuracy in routine clinical settings remains limited.

Bicortical versus monocortical anchorage

Digitally planned MARPE workflows commonly favor bicortical anchorage to enhance miniscrew stability and skeletal force transmission. Virtual planning facilitates deliberate selection of screw length and trajectory to engage both palatal and nasal cortical plates, and several authors have incorporated this strategy to reduce miniscrew loosening and optimize expander positioning.[9,12,13] CBCT-based outcome studies further associate bicortical engagement with improved skeletal expansion and anchorage stability compared with monocortical insertion. Studies also report that reliable bicortical engagement is influenced by individual anatomical variation and biological factors.

Digital design of MARPE/ maxillary skeletal expander (MSE) appliances

Digital design of MARPE appliances aims to translate virtual miniscrew planning into a clinically deliverable appliance. CAD/CAM-based workflows allow customization of connector arms, miniscrew insertion rings, and expansion screws based on skeletal anatomy. Several authors have described digital frameworks integrating appliance design with virtual miniscrew positioning, enabling individualized appliance fabrication and improved transfer accuracy.[9,12,13]

CAD/CAM and 3D printing workflows

CAD/CAM technologies enable fabrication of customized MARPE appliances and transfer guides through methods such as metal laser sintering and three-dimensional printing. Although these approaches may improve planning transfer accuracy, protocols vary widely and standardization of digitally guided MARPE workflows remains limited.[9,14]

CBCT-guided miniscrew placement and surgical guides

Rationale for guided miniscrew insertion

Successful MARPE depends on accurate miniscrew placement, as deviations in site, angulation, or depth may compromise skeletal expansion and anchorage stability. Conventional freehand insertion, guided primarily by clinical landmarks and two-dimensional imaging, is limited by complex palatal anatomy and inter-individual variability. CBCT-guided virtual planning enables three-dimensional assessment of palatal morphology and identification of optimal insertion trajectories.[9,11] Inaccurate placement has been associated with monocortical engagement, screw tipping, and asymmetric expansion.[12] Current studies report reduced angular deviations and clinically acceptable accuracy with guided techniques compared with freehand insertion.[15,16]

Table 2 Overview of surgical guide types used in CBCT-guided miniscrew placement for MARPE, highlighting support mechanisms, key characteristics, advantages, and limitations.[9,12,13,17]

Category	Support	Key Characteristics	Main Advantages	Limitations
Tooth-borne guides	Dentition	Expander- or tooth-supported transfer of planned miniscrew sites	Good stability; improved angular accuracy	Influenced by dental inclination and scan errors
Bone-borne guides	Palatal bone / mucosa	Placement guided by skeletal anatomy (bone-first approach)	Independent of dentition; suitable for adults	Requires precise CBCT planning
Hybrid guides	Dental + skeletal	Laboratory-based transfer templates	Improved appliance positioning accuracy	Semi-digital; added lab steps
Appliance-integrated guides	MARPE/MSE appliance	Prefabricated screw channels act as insertion guide	Simplified clinical workflow	Dependent on appliance fit

Types of guides: tooth-borne, bone-borne, and hybrid

CBCT-guided miniscrew placement can be achieved using tooth-borne, bone-borne, hybrid, or appliance-integrated guides, each differing in their support mechanism and clinical application.

Tooth-borne guides are supported by the dentition and enable transfer of digitally planned miniscrew positions with good positional stability.[14,15] Bone-borne guides rely on palatal bone or mucosal support and follow the bone-first concept, allowing miniscrew placement to be guided primarily by skeletal anatomy.[17] Hybrid guides combine dental and skeletal or mucosal support to improve stability during transfer of the virtual plan to the clinical setting.[9,13] Appliance-integrated guides use prefabricated screw channels within the MARPE or MSE appliance itself to guide miniscrew insertion without a separate surgical guide.[12] The key characteristics, advantages, and limitations of these guide types are summarized in Table 2.

Bone-first principle

The bone-first principle, introduced by Wilmes et al.,[17] describes an anatomy-driven approach to miniscrew placement, in which CBCT-based identification of optimal skeletal anchorage sites precedes appliance design. Instead of adapting miniscrew position to a prefabricated expander, the appliance or guide is designed according to the selected insertion sites. Wilmes et al. reported that appliance-first approaches may result in placement in less optimal bone regions. Studies by Stursa et al.[15] and Bellocchio et al.[16] report clinically acceptable accuracy when transferring bone-driven virtual plans using guided systems.

Clinical protocols for guide use

Clinical protocols for CBCT-guided miniscrew placement generally involve maxilla-focused CBCT acquisition, integration with intraoral scan data, and virtual definition of miniscrew position, angulation, and depth.[12,14,16] Digitally designed surgical guides or appliance-integrated insertion channels are then used to transfer the virtual plan to the clinical setting.

Dedicated guide-based protocols, including metal-sleeved guides and controlled predrilling, have demonstrated acceptable transfer accuracy under clinical conditions.[16] In contrast, appliance-guided workflows enable simplified, single-visit insertion but may offer less control over insertion depth and trajectory.

Accuracy and reliability of guided MARPE techniques

Linear, angular, and depth deviations

Accuracy of guided MARPE miniscrew placement is commonly evaluated using linear, angular, and depth deviations. Among these, angular deviation is the most clinically relevant, as excessive angulation can compromise bicortical engagement, risk nasal floor perforation, and alter force vectors.

Clinical and experimental studies support the reliability of CBCT-guided techniques. Bellocchio et al. reported mean angular deviations of about 3°, with linear deviations within clinically acceptable limits using 3D-printed palatal guides.[16] A study by Stursa et al. showed significantly lower angular deviations with guided placement compared with freehand insertion, though minor depth discrepancies persisted.[15] In vitro, Hamanaka et al. demonstrated that longer guide sleeves improved linear accuracy, underscoring the influence of guide design on placement precision.[18]

While deviations of approximately 2–3° are generally considered clinically acceptable, angular deviations exceeding 5–7° may compromise bicortical engagement, reduce miniscrew stability, and influence expansion symmetry, thereby affecting overall skeletal outcomes.[15,16,19]

In-vitro, cadaveric, and clinical accuracy studies

Evidence on guided miniscrew accuracy across different experimental and clinical models is summarized in Table 3.

Comparison with freehand placement

Across study designs, guided miniscrew placement demonstrates superior accuracy and

Table 3 Summary of in-vitro, cadaveric, and clinical evidence on the accuracy of guided miniscrew placement for MARPE.

Study model	Key purpose	Reported accuracy	Main findings	Clinical implications
In-vitro studies	Controlled evaluation of mechanical factors (e.g., sleeve length, drill tolerance)	Angular deviation ~2–3°, linear deviation ~0.5–1 mm	Hamanaka et al.[18] showed guided drilling consistently outperformed freehand insertion under controlled conditions	Demonstrates mechanical advantage of guides, but may underestimate deviations seen clinically due to absence of soft tissue and patient movement
Cadaveric studies	Simulation of clinical anatomy without patient-related variables	Angular deviation ~2–3°	Stursa et al.[15] found superior angular accuracy with professionally manufactured guides compared with in-house 3D-printed guides	Highlights cumulative errors from planning, fabrication, and handling; underscores need for workflow standardization
Clinical studies	Assessment of real-world accuracy and reliability	Angular deviation ~5–7°	Vasoglou et al.[20] reported lower angular deviations with CBCT-integrated (DICOM–STL) guide design; Ronsivalle et al.[19] found mean angular deviations of 5–7° irrespective of planning software	Suggests that accurate data integration and guide design are more critical than the specific software platform used

Table 4 Comparison of guided versus freehand miniscrew placement in MARPE.

Aspect	Guided miniscrew placement	Freehand miniscrew placement
Planning basis	CBCT-based 3D virtual planning.[9] Anatomy-driven trajectory selection.[13,17]	Clinical landmarks only.[13] No 3D anatomical assessment.[17]
Placement accuracy	Reduced angular and linear deviations.[15,16] Superior accuracy in direct comparisons.[19]	Greater angular deviations, especially sagittal.[15] Inferior in all direct comparisons.[19]
Mean angular deviation	~3° clinically (Bellocchio et al.[16]). ~2–3° in cadaveric/in-vitro models (Stursa et al.[15]; Hamanaka et al.[18]).	Sagittal angular deviation of 5.34° reported for freehand insertion.[15] Guided consistently outperformed freehand in all direct comparisons.[15,19]
Reproducibility	High reproducibility.[15] Reduced operator dependence with standardized protocols.[13]	Operator-dependent.[13] Variable across cases and clinicians.
Anchorage engagement	Predictable bicortical engagement via pre-planned trajectory and screw length.[13]	Frequently monocortical.[7] Especially unreliable in posterior palate.[13]
Risk of complications	Reduced risk of tipping, asymmetry, and nasal floor perforation.[13,15,16]	Higher risk of screw tipping, asymmetry, and suboptimal engagement.[13]
Suitability for posterior palate	Reliable due to CBCT-based safe-zone identification.[17]	Less reliable due to reduced bone availability and limited 2D visualization.[17]
Overall clinical predictability	High, due to pre-validated digital trajectories.[9,13,17]	Variable, dependent on operator skill and anatomy.[13,17]

reproducibility compared with freehand insertion. Direct comparisons have shown significantly greater angular deviations with freehand techniques, particularly in the sagittal plane, underscoring the value of CBCT-based three-dimensional planning in improving placement precision.[15,20] Although freehand insertion is still commonly used in the anterior palate where bone availability is favorable, anatomical variability—especially in posterior regions—limits its reliability in many MARPE cases.[17] Inaccurate freehand placement may result in monocortical engagement, screw tipping, or asymmetric expansion, whereas guide-assisted or appliance-integrated workflows constrain miniscrew trajectories to pre-validated digital plans, thereby improving clinical predictability.[12] The key differences between guided and freehand miniscrew placement are summarized in Table 4.

Sources of error in digital workflows

Despite demonstrable improvements over freehand techniques, guided MARPE workflows are not immune to error. Cumulative inaccuracies may arise at multiple stages of the digital chain, including CBCT acquisition, DICOM–STL superimposition, guide design, manufacturing, and clinical application. Stursa et al. reported that laboratory-related factors significantly influenced placement accuracy, with in-house fabricated guides showing inferior performance compared with commercially produced templates.[15] Bellocchio et al. similarly observed residual deviations

even with high-quality guides, reporting that complete elimination of placement error was not achieved in clinical practice.[16]

Guide design parameters also affect accuracy, with inadequate sleeve length compromising drilling precision.[18] Additional clinical variables, including mucosal resilience, incomplete guide seating, insertion torque, and operator handling, may further influence final miniscrew position. Ronsivalle et al. reported the presence of residual accuracy errors even in optimized workflows.[19]

CBCT-based clinical outcomes of MARPE

Skeletal expansion patterns

CBCT-based studies indicate that MARPE produces predominantly skeletal maxillary expansion in late adolescents and young adults, with significant increases in maxillary width and mean skeletal expansion of approximately 2–3 mm.[21] Suture opening is generally parallel on axial and coronal views, while a characteristic triangular expansion pattern, with greater inferior maxillary separation, reflects effective transmission of orthopedic forces through skeletal anchorage.[22]

Dentoalveolar effects

Although MARPE is intended to minimize dentoalveolar side effects, CBCT studies indicate that minor dental and alveolar changes may still occur. Small reductions in buccalbone thickness (< 0.5 mm) with corresponding increases in palatal thickness suggest adaptive remodeling rather than destructive change.[21] Dental effects are generally limited to mild posterior tooth inclination, minimal molar tipping, and partial relapse during retention; studies report that these dentoalveolar changes are modest and better controlled than those associated with conventional RPE.[22,23]

Miniscrew stability and bone response

Miniscrew stability is a key determinant of MARPE success. CBCT studies suggest that bicortical or posterior bicortical engagement may enhance skeletal expansion and reduce dentoalveolar effects compared with monocortical anchorage by improving force transmission and appliance stability.[7] However, stability is multifactorial; patient age and midpalatal suture maturation strongly influence outcomes. Oliveira et al. reported that failures are more frequent in patients with advanced suture maturation (Angelieri stages D–E), regardless of miniscrew configuration.[24]

Airway and nasal cavity changes

CBCT-based assessments indicate that MARPE produces favorable increases in nasal and airway dimensions, including significant widening of the nasal cavity and extension of expansion into the zygomaticomaxillary region.[22] Prospective studies further demonstrate increased nasal base and cavity width with minimal relapse.[23] Functional respiratory outcomes were variably reported across the included studies; however, CBCT morphologic data from these studies consistently document nasal dimensional gains following MARPE.

Relationship between planning accuracy and outcomes

Although most CBCT outcome studies emphasize morphologic changes rather than planning accuracy, indirect associations suggest that precise control of miniscrew site and insertion depth—particularly with bicortical engagement—supports greater skeletal expansion and improved suture parallelism.[7] Studies report that advanced suture maturation may limit skeletal response despite optimal digital placement planning.[24] CBCT outcome studies report associations between bicortical engagement and increased skeletal expansion, although outcomes vary with suture maturation.[24]

Anatomic considerations for CBCT-guided MARPE

CBCT-based anatomical studies demonstrate considerable variation in palatal bone and mucosal thickness, which directly influences miniscrew

placement in MARPE. The anterior paramedian palate, particularly near the second premolars, generally provides the most favorable cortical thickness and is widely considered a predictable insertion site, although bone thickness decreases posteriorly and varies among individuals.[8,25] Facial growth pattern may further influence palatal morphology, with thinner bone often observed in high-angle patients. In addition to bone thickness, palatal mucosal thickness—typically increasing posteriorly—must also be considered, as excessive soft tissue may compromise effective cortical engagement despite adequate bone availability.[26] CBCT studies report that progressive midpalatal suture interdigitation with increasing age is associated with greater skeletal resistance, and several authors indicate this may influence MARPE outcomes.[25]

Discussion

Advantages of digital and CBCT-guided MARPE

Digital and CBCT-guided MARPE workflows offer several potential advantages over conventional planning approaches. Three-dimensional visualization enables more accurate assessment of skeletal anatomy and facilitates controlled adjustment of appliance position, angulation, and insertion depth, thereby reducing operator dependence and improving planning reproducibility.[9,12] Integration of CBCT and intraoral scan data also supports simulation of miniscrew trajectories, reducing the risk of root proximity and enabling bone-first placement strategies.[17] Accurate evaluation of palatal bone thickness and palatal–nasal floor distance further enhances miniscrew stability through optimized cortical engagement and appropriate screw length selection.[12] In addition, digital workflows allow individualized appliance customization based on skeletal morphology and planned force vectors, contributing to improved appliance adaptation and treatment efficiency.[9,12,27] From a clinical perspective, three-dimensional visualization enhances treatment predictability. Nevertheless, these advantages remain dependent on data quality, software reliability, and operator expertise, underscoring the need for standardized protocols and further clinical validation.

Clinical considerations for optimizing MARPE Outcomes

Treatment outcomes in MARPE are influenced by appliance design, activation protocol, miniscrew characteristics, and insertion site. Bone-borne or hybrid appliances provide greater skeletal expansion and reduced dentoalveolar effects compared with tooth-borne designs, due to more efficient force transfer to basal bone.[6,7]

Direct skeletal force transmission in MARPE is optimized using bone-borne or hybrid appliances that position the expander close to the palatal vault, minimizing dental anchorage.[7] CBCT-guided planning further improves accuracy of miniscrew insertion depth and angulation, reducing force dissipation.[9,12] Activation rates of 0.2–0.5 mm/day are commonly used; however, slower activation may enhance skeletal adaptation and reduce complications, particularly in patients with increased suture maturation.[22,23]

The anterior paramedian palate is considered the most favorable miniscrew insertion site due to greater cortical bone thickness and reduced risk of root proximity, while posterior regions show reduced bone availability.[8,25]

Miniscrews with diameters of 1.5–2 mm and lengths of 10–14 mm are generally recommended to achieve adequate primary stability and facilitate bicortical engagement, which improves skeletal expansion and anchorage stability.[7]

Accurate miniscrew placement is critical, as angular deviations exceeding 5–7° may compromise bicortical engagement, reduce stability, and affect expansion symmetry, highlighting the importance of guided insertion techniques.[15,16,19]

Limitations and challenges of digital and CBCT-guided MARPE

Digital and CBCT-guided MARPE workflows are

associated with several important limitations. Additional radiation exposure remains a concern, particularly in younger patients, necessitating selective CBCT use, limited field-of-view protocols, and strict adherence to the ALARA principle.[9,12,17] Implementation of digital workflows also requires substantial investment in imaging equipment, planning software, and CAD/CAM facilities, raising concerns regarding the cost–benefit balance in routine clinical practice.[9,12] Furthermore, digital planning is associated with a significant learning curve and remains highly operator-dependent, with potential for errors related to CBCT interpretation, data integration, and virtual planning.[12,17] Another important limitation is the considerable variability in digital planning protocols, including differences in CBCT acquisition parameters, miniscrew positioning strategies, appliance design, and guide fabrication methods, which complicates direct comparison across studies.[9,12,14] Importantly, available evidence is largely derived from low-level study designs, with few randomized controlled trials and limited long-term or patient-centered outcome data.[28] Collectively, these limitations highlight that digital MARPE technologies remain in an evolving phase and should be applied judiciously until supported by more robust clinical evidence.

The key advantages and limitations of digital and CBCT-guided MARPE workflows are summarized in Figure 2.

Future directions in digital and CBCT-guided MARPE

Artificial intelligence has the potential to streamline MARPE planning by automating miniscrew site selection, angulation, insertion depth, and safe-zone identification from CBCT data. Hoang et al. reported that digital MARPE workflows may improve planning precision, standardization, and clinical efficiency, while highlighting the need for further clinical validation of these technologies.[28] Dynamic navigation systems represent another emerging approach, providing real-time guidance during miniscrew insertion and potentially overcoming limitations associated with guide seating and mucosal resilience, although cost and technical complexity currently limit widespread adoption.[19] In parallel, advances in CAD/CAM technology, intraoral scanning, and rapid 3D printing support the development of fully chairside MARPE workflows. Wilmes et al. described bone-first planning combined with same-day guide and appliance fabrication, while recent digital design approaches further enable individualized appliance customization

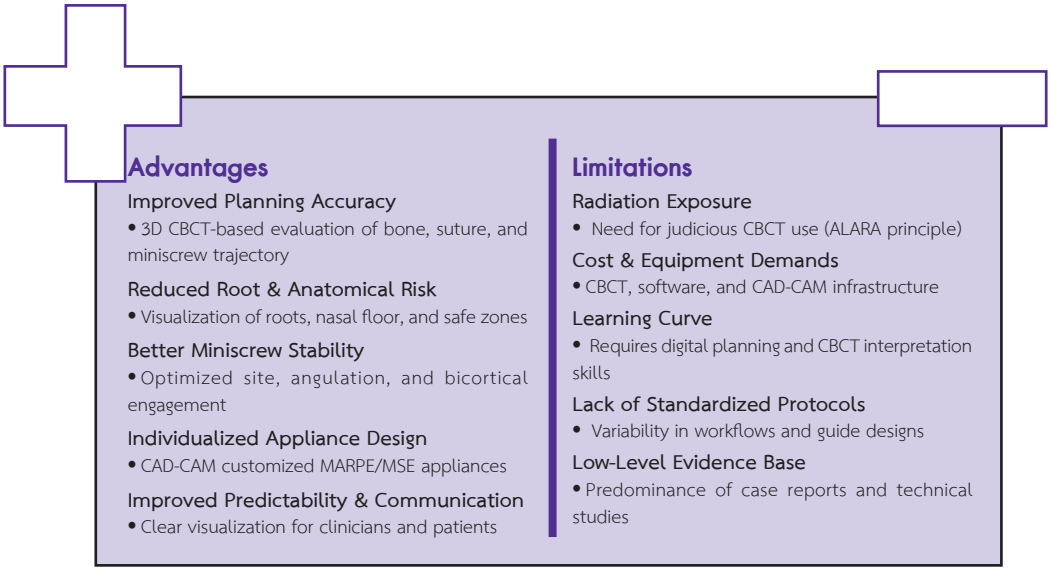


Figure 2 Schematic summary of the advantages and limitations of digital and CBCT-guided MARPE workflows.

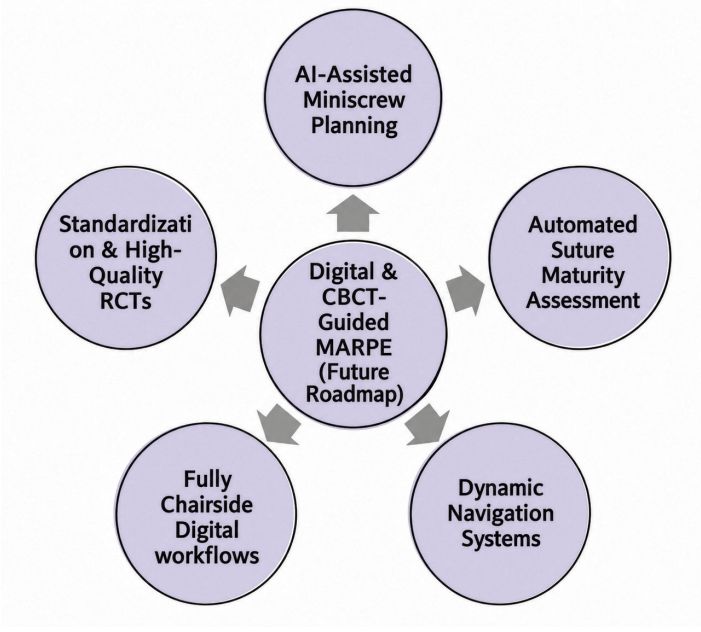


Figure 3 Conceptual overview of future directions in digital and CBCT-guided MARPE.

and improved workflow efficiency.[17,27] Despite these technological developments, the current evidence base remains limited, and well-designed clinical studies are needed to evaluate the impact of digital planning and guided insertion on placement accuracy, skeletal expansion outcomes, miniscrew stability, and patient-reported measures. These emerging directions are schematically illustrated in Figure 3.

Strengths and limitations of this review

While recent scoping and narrative reviews have summarized clinical efficacy and outcomes of MARPE, the present review uniquely focuses on the accuracy and reliability of CBCT-guided and digitally planned workflows, with particular emphasis on quantitative deviations in miniscrew placement and factors affecting transfer fidelity. This narrative review provides a comprehensive synthesis of current evidence on digital and CBCT-guided MARPE, integrating anatomical, biomechanical, clinical, and workflow-related data across diverse study designs.

However, the non-systematic nature of the review and the narrative study selection process may introduce potential selection bias, as studies were identified through targeted database searches and manual thematic review rather than a predefined systematic protocol. Consequently, some relevant studies may not have been captured, and the interpretation of available evidence should be considered exploratory rather than exhaustive. Additionally, rapid technological advancements in digital planning, imaging, and manufacturing may outpace the available clinical evidence, necessitating cautious interpretation of findings.

Conclusion

Digital and CBCT-guided MARPE has emerged as a clinically relevant advancement for the management of maxillary transverse deficiency, particularly in skeletally mature patients. By enabling three-dimensional, anatomy-driven planning, these workflows improve miniscrew positioning, anchorage stability, appliance customization, and overall treatment predictability compared with conventional approaches.

Although available evidence supports favorable skeletal and nasal outcomes with reduced dentoalveolar side effects, current literature is limited by heterogeneous methodologies, lack of standardized protocols, and a predominance of low-level evidence. Future investigations should focus on prospective clinical trials evaluating the impact of digital planning on placement accuracy, skeletal expansion stability, and patient-centered outcomes. With continued technological refinement and robust clinical validation, digital and CBCT-guided MARPE has the potential to become an evidence-based standard in contemporary transverse maxillary expansion.

Author contributions

Sakshi Santoshkumar Jain: Conceptualization, Investigation, Data Curation, Writing – Original Draft, Visualization; **Jyoti Sunny Manchanda:** Conceptualization, Writing – Review & Editing, Supervision; **Santosh Jetu Chavan:** Methodology, Writing – Review & Editing,

Supervision; **Vaibhav Sunil Zanwar:** Investigation; **Vedant S.:** Investigation, Data Curation, Writing – Review & Editing.

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Review Article

In Vitro Compression Model in Orthodontics: A Review of Literature

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Luay Thanoon Younis*** Syatirah Najmi Abdullah** Fara Fariza Zahar****

Abstract

Background: In vitro models provide a controlled and ethically acceptable approach to investigating orthodontic procedures, materials, and biological responses without involving human or animal subjects. They are widely used to study cellular responses, biomechanical properties, friction, bond strength, and material biocompatibility. **Objective:** To review the applications of in vitro models in orthodontic research, with particular emphasis on their potential use in investigating cellular senescence in response to simulated orthodontic forces. **Materials and methods:** This review examines the applications of in vitro models in orthodontic research, including cell culture systems, mechanical testing, friction studies, bond strength assessment, biomechanical analysis, wear testing, and biocompatibility evaluation. Particular attention is given to cellular models involving oral tissue-derived cells, such as fibroblasts, osteoblasts, and periodontal ligament cells, and their responses to simulated orthodontic forces. **Results:** In vitro models have facilitated the investigation of cellular and biomechanical responses to orthodontic forces and materials. Previous cellular studies have identified changes in cellular markers following the application of simulated orthodontic forces. However, the application of in vitro models specifically to investigate cellular senescence under simulated orthodontic loading remains an area requiring further investigation. **Conclusion:** In vitro models offer a valuable platform for investigating biological responses to orthodontic forces under controlled conditions while minimising ethical concerns associated with human and animal studies. Further research is warranted to establish in vitro models for investigating orthodontically induced cellular senescence.

Keywords: Cellular Senescence, In vitro models, Orthodontics

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Introduction

In vitro models are laboratory-based research or studies that are carried out without using living things like people or animals to imitate and comprehend various orthodontic procedures and treatments. These models eliminate the ethical and practical constraints associated with using human subjects in research studies of specific orthodontic treatment components under controlled conditions. Our grasp of orthodontic principles, materials, and techniques is greatly improved by in vitro models. In vitro models can be used for cell culture models, mechanical testing, friction studies, bond strength testing, biomechanical analysis, wear testing and material biocompatibility. Cell culture models are most used as researchers can cultivate many cell types from oral tissues, including fibroblasts, osteoblasts, and cells from the periodontal ligament. Investigating cellular reactions to orthodontic stresses, materials, and therapies can be done using these cell cultures.

Literature review

An overview of in vitro compression models in dentistry

In vitro compression models in orthodontics research can be broadly categorized into two main types: simulated tooth movement systems and craniofacial simulation models. One commonly used in vitro compression model in orthodontics is the simulated tooth movement system. This system typically involves a tooth, or a segment of the dental arch mounted in a device that can apply controlled compressive forces. The resulting tooth movement or other responses, such as changes in bone density or periodontal ligament behaviour, can then be measured and analysed.[1] These models provide insights into the complex interplay between applied forces, tooth movement, and surrounding tissues, which is crucial for optimizing orthodontic treatment planning and outcomes.[2]

Another type of in vitro compression model used in orthodontics is the craniofacial simulation model.[3] These models replicate the biomechanical properties of the craniofacial complex, including the bones, cartilage, and soft tissues.[3] By applying compressive forces to these models, researchers can study the resulting deformations, stresses, and strains within the craniofacial structures. This information can be used to understand the biomechanical response of the face to various orthodontic interventions, such as the use of functional appliances or the application of forces during orthognathic surgery.[4]

The simulated tooth movement system is a widely used in vitro compression model in orthodontics. These models typically involve a single tooth or a segment of the dental arch mounted in a device that can apply controlled compressive forces. By analysing the resulting tooth movement or changes in the surrounding tissues, researchers can gain insights into the biomechanical and biological responses to orthodontic forces.[5,6] These models provide a highly controlled and reproducible environment to study the intricate interplay between the applied forces, tooth movement, and the various components of the periodontium, including the alveolar bone, periodontal ligament, and gingiva.[7]

In contrast, craniofacial simulation models replicate the biomechanical properties of the entire craniofacial complex, including the bones, cartilage, and soft tissues.[8] By applying compressive forces to these models, researchers can investigate the resulting deformations, stresses, and strains within the craniofacial structure.[8] This information is crucial for understanding the biomechanical response of the face to various orthodontic interventions, such as the use of functional appliances or orthognathic surgery.

While both simulated tooth movement systems and craniofacial simulation models offer valuable insights, they differ in their scope and focus. Simulated tooth movement systems primarily concentrate on the local biomechanical and biological responses of

the periodontium, whereas craniofacial simulation models provide a more comprehensive understanding of the overall craniofacial response to applied forces. The choice of in vitro compression model depends on the specific research questions and the level of detail required in the investigation.

In vitro models utilized in orthodontics research

In vitro models made from cell cultures are crucial for investigating different types of tooth movement, orthodontic mechanics and associated processes. In order to study the biological reactions to orthodontic stresses, materials, and treatments, these models entail cultivating cells originating from oral tissues, such as periodontal ligament cells, osteoblasts, and osteoclasts. The key function that periodontal ligament cells play in the transmission of pressures from orthodontic appliances to the tooth and surrounding bone makes them essential for orthodontic studies.[9,10] It is possible to apply mechanical stresses to cultured cells that mimic orthodontic settings. By simulating the forces applied by braces, wires, and aligners, researchers examine how cells react to compression, tension, and shear stress.[2] We can better understand inflammation and tissue remodelling by using in vitro models that investigate how cells respond to mechanical loading by secreting cytokines and growth factors.[11] In vitro compression models have also been employed to investigate the effects of orthodontic forces on the periodontal tissues.[12] These models can simulate the application of compressive forces on the periodontal ligament and alveolar bone, allowing researchers to study the resulting cellular and tissue-level changes.[12] This information is crucial for understanding the biological mechanisms underlying tooth movement and the potential risks associated with excessive or uncontrolled orthodontic forces,[13] such as root resorption or loss of supporting bone.

The clinical significance of in vitro compression models in orthodontics research is multifaceted. These models provide a controlled and reproducible environment to investigate the biomechanical and biological responses of the periodontium during orthodontic tooth movement, which is not easily achievable in clinical settings.[14] The insights gained from these models can inform the development of more effective and safe orthodontic treatment protocols, leading to improved patient outcomes and reduced risk of adverse effects, such as root resorption or alveolar bone loss.[15]

Furthermore, in vitro compression models can be used to evaluate the performance and design of orthodontic appliances, such as braces, aligners, or functional appliances. By simulating the compressive forces experienced by these appliances during use, researchers can assess their biomechanical characteristics, optimize their designs, and ensure their clinical effectiveness and safety.[14-16]

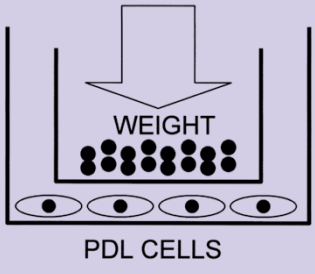
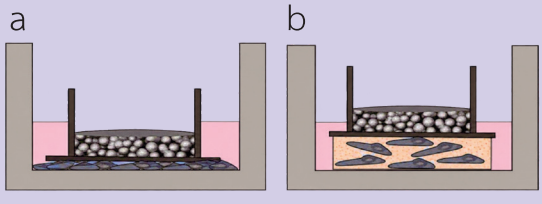
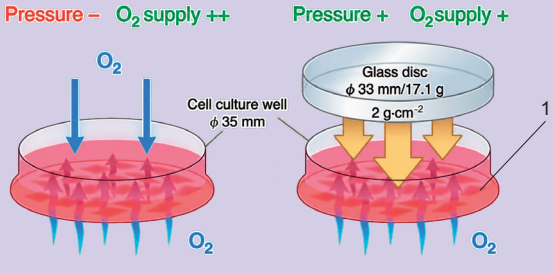
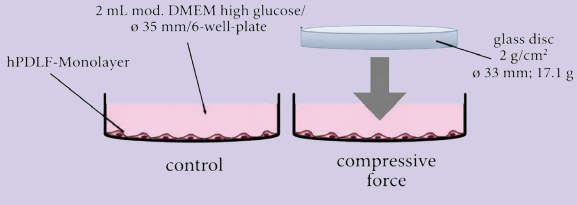
In summary, in vitro compression models have become an essential tool in orthodontics research, providing valuable insights into the biomechanical and biological responses of the periodontium to applied forces. These models enable a deeper understanding of the complex processes involved in orthodontic tooth movement, leading to the development of more efficient and patient-centered treatments.[15,16]

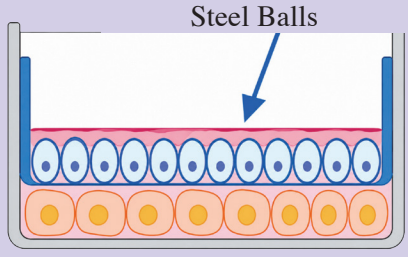
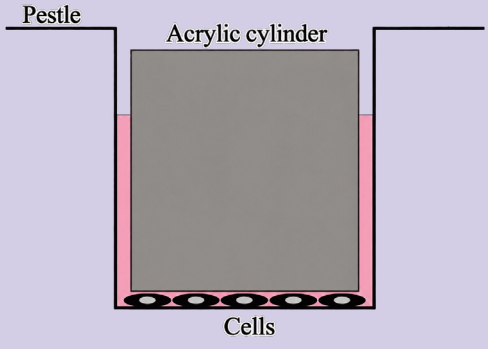
In vitro model studying cellular changes due to simulated orthodontic forces

Due to different patients and treatment approaches, the exact magnitude of orthodontic forces on periodontal cells in vivo can vary.[17] The consensus of achieving orthodontic tooth movement is applying force without detrimental tissue damage. Despite this, a well-established in vitro model of the early phase of orthodontic tooth movement compression side in HPDLF is already capable of inducing a reactive synthesis of proinflammatory cytokines and remodelling molecules.[1] A model which consisted of glass cylinders exerting a static compressive force of 2g/cm^2 on

a cell monolayer, was used to observe the process of HPDLF restructurement.[12] It is hypothesised that HPDLF generally die due to compression and primarily contribute to periodontal tissue organisation during orthodontic tooth movement via the inflammatory response.[18,19] A study which used an in vitro model HPDLF restore homeostasis by preserving cellular structures under static compression via a slower cell cycle and a lower division rate.[12] According to this study, the reduction of proliferation is a critical part of the re-organisation process of HPDLFs under compressive force, in addition to cellular inflammation and cell death.[12]

Table 1 Comparing different in vitro models simulating orthodontic compression forces.

Year	Research Title & Author	Research Objective	In Vitro Model Components
2002	Periodontal Ligament Cells Under Mechanical Stress Induce Osteoclastogenesis by Receptor Activator of Nuclear Factor B Ligand Up-Regulation via Prostaglandin E2 Synthesis by Kanzaki, et al.[1]	To study how mechanical stress affects the osteoclastogenesis-supporting activity of PDL cells	
2018	In Vitro Weight-Loaded Cell Models for Understanding Mechanodependent Molecular Pathways Involved in Orthodontic Tooth Movement: A Systematic Review by Janjic, et al.[18]	Systematic review to identify all studies in the field of dentistry with focus on mechanobiology using in vitro loading models applying uniaxial static compressive force	
2019	The role of mechanotransduction versus hypoxia during simulated orthodontic compressive strain—an in vitro study of human periodontal ligament fibroblasts by Ullrich, et al.[19]	To investigate expression patterns of genes and proteins that were previously identified to be associated with orthodontic tooth movement after compressive force application in the presence of a normal or reduced oxygen supply	
2021	In Vitro Compression Model for Orthodontic Tooth Movement Modulates Human Periodontal Ligament Fibroblast Proliferation, Apoptosis and Cell Cycle by Brockhaus, et al.[11]	To study morphology of hPDLF changes towards more unstructured, unsorted filaments under mechanical compression	

Year	Research Title & Author	Research Objective	In Vitro Model Components
2023	CD97 inhibits osteoclast differentiation via Rap1a/ERK pathway under compression by Wang, et al.[20]	To investigate the relationship between CD97 expression and osteoclast differentiation using models of OTM and static compression application	
2024	Effects of continuous and released compressive force on osteoclastogenesis in vitro by Changkhaokam, et al.[21]	To quantify the fusion of mononuclear RAW 264.7 cells (a murine osteoclastic-like cell line) into multinucleated osteoclasts under a hydrostatic pressure-generated mechanical compression-the new model of various magnitudes and durations.	

In vitro compression model and cellular senescence

In vitro compression models have emerged as valuable tools to study the impact of orthodontic forces on cellular senescence. These models allow researchers to simulate the compressive stresses experienced by periodontal tissues during orthodontic treatment and investigate the resulting cellular and molecular changes.[22,23]

By applying controlled compressive forces to simulated tooth movement systems or craniofacial simulation models, researchers can examine markers of cellular senescence, such as increased expression of cell cycle regulators like p16 and p21, telomere shortening, and elevated senescence-associated beta-galactosidase activity.[24,25] Examining these senescence-related markers in the periodontal ligament and alveolar bone cells can offer valuable insights into how orthodontic forces may lead to premature aging and impairment of these crucial cell populations. This opens new research avenues to help understand the biological mechanisms behind senescence in orthodontics and develop strategies to mitigate potential adverse effects.

In vitro model predictability and measured outcome

In vitro models can be quite predictable, particularly when experimental settings are carefully regulated and standardized. Researchers can controllably manipulate specific variables, such as cell types, drug concentrations, and environmental parameters, using in vitro models. Under these specific conditions, this control can lead to predictable responses. In vitro models are valuable for examining the underlying mechanisms of biological processes. Predictions about how cells will react to particular interventions or stimuli can be more precise when the pathways involved are well-understood. However, in vitro models may be hindered by a lack of the complexity found in living organisms. They fall short of accurately capturing the intricate relationships between the many organs, cell types, and physiological systems present in vivo.[25] Additionally, the numerous connections and feedback loops in real organisms can produce results that may not be straightforward to anticipate based on individual in vitro studies. Studies of cells, tissues, or organisms in a controlled

laboratory setting, separate from a living organism, are frequently conducted using in vitro models.[20] Imaging is essential to these models, as it enables the visualization and analysis of various cellular and molecular processes.[26] Specific molecules or cell structures are marked with fluorescent dyes or tags to facilitate this analysis.[27]

The visualisation of dynamic processes and particular biological components is made possible by fluorescence microscopy. Fluorescence microscopy is a powerful imaging method that makes use of fluorescence to see particular chemicals, structures, or activities inside of cells and tissues.[28] Target molecules are marked with fluorescent proteins or dyes to enable non-invasive and real-time observation of their distribution, localization, and interactions.[29] When used with in vitro models, fluorescence microscopy offers useful insights into the dynamic features of biological processes. The ability to directly witness previously invisible molecular interactions and events has revolutionised cell biology. For researching biological reactions to stress in in vitro models, fluorescence microscopy is an invaluable tool.[26] In this context, the term "stress" can be used to describe a variety of physiological and environmental difficulties that cells may encounter, including oxidative stress, heat shock, nutritional shortage, and others. Fluorescence microscopy techniques enable researchers to see and examine how cells respond to stimuli, determine the effect on cellular constituents, and investigate the underlying mechanisms.[29] This method also produces a set of pictures and information that helps scientists comprehend in detail how cells function, how chemicals interact, and how biological molecules behave in an in vitro model.[30] Although in vitro models provide insights into cellular behaviour, it's crucial to recognise that before conclusions from cell culture studies can be directly applied to medical care, they must first be verified through animal models and clinical trials.

Discussion

The move towards emerging in vitro models, particularly 3D tissue cultures, represents a significant step forward in orthodontic research. These models strive to more accurately replicate the complex physiological conditions and interactions present in the in vivo environment, bridging the gap between traditional in vitro methods and the inherent complexity of animal models. In vitro models offer a more ethically sound alternative to human and animal testing. This is a crucial consideration, especially as research delves deeper into the effects of orthodontic forces at the cellular level.

Conclusion

Emerging in vitro models, including 3D tissue cultures, aim to bridge the gap between conventional in vitro models and the complexity of animal models. These new technologies have the potential to more accurately mimic physiological conditions and interactions. To date, there is no established in vitro model examining cellular senescence under simulated orthodontic forces. Previous cellular studies have identified new markers when applying simulated forces. In vitro models remain the best option for cellular studies, as they are more ethically safe compared to human and animal testing.

Author contributions

Naadira Jamaluddin: Conceptualization, Investigation, Data curation, Writing and Original Draft; **Nik Mukhriz Nik Mustapha:** Supervision; **Aida Nur Ashikin Abd Rahman:** Supervision, Project administration; **Luay Thanoon Younis:** Supervision; **Syatirah Najmi Abdullah:** Validation and Review of the scientific and technical content; **Fara Fariza Zahar:** Methodology and Validation.

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AI-Assisted Writing Declaration

During the preparation of this manuscript, the authors used ChatGPT (OpenAI, GTP-5.5) solely for language editing, including grammar, punctuation, and clarity of expression. The authors reviewed and approved all changes and take full responsibility for the content and accuracy of the manuscript.

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