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Thai J Orthod Vol.15 No.1 2025

CONTENTS

Original Article

Upper Lip Changes After Upper Incisor Proclination in Deep Bite Patients — 6

Piyatida Tiamlom
Chairat Charoemratrote

Factors Influencing Child Compliance in Deep Bite Correction with a Removable Anterior Bite Plane — 17

Thanapat Sangwattanarat
Supunsa Pongtiwattanakul
Udom Thongudomporn

Accuracy of Intraoral Scanner for Centric Relation Record in Comparison to Vinyl Polysiloxane — 26

Rawinan Luangsukrerk
Napat Nalamliang

Comparison of Cephalometric Measurements Obtained by Digital Software, Artificial Intelligence-Assisted Software and Manual Tracing — 36

Utsav Gautam
Rabindra Man Shrestha
Jyoti Dhakal

Clinical Accuracy of Structured-Light vs Active-Illumination Multi-View Stereo 3D Facial Scanners: A Comparative Study — 45

Danaiya Supakanjanakanti
Teepawat Witeerungrot
Nattawat Patanalertpiboon
Kanokporn Santavalimp

Systematic review and meta-analysis

Comparison of Heat Generation Between Manual Metal Strips and Motor Stripping Discs for Interproximal Reduction: A Systematic Review and Meta-Analysis — 56

Prachworrakit Kaewsirirat
Chaiyapol Chaweewannakorn
Nita Viwattanatipa
Nuntinee Nanthavanich Saengfai

Case Report

Orthodontic Space Closures with Canine Substitution for Bilateral Congenitally Missing Maxillary Lateral Incisors: A Case Report — 68

Sutti Malaivijitnond

Thai Journal of Orthodontics

Original Article

Upper Lip Changes After Upper Incisor Proclination in Deep Bite Patients

Piyatida Tiamlom* Chairat Charoemratrote**

Abstract

Background: No previous studies examined the effects of upper lip (UL) change following upper incisor (UI) intrusion by labial proclination in deep bite (DB) non-growing patients. **Objective:** To compare changes in the UI and UL after labial proclination between UI retroclination (RI) and normal inclination (NI) groups in DB patients. **Materials and methods:** Pretreatment (T1) and posttreatment (T2) lateral cephalograms of 41 subjects who underwent UI labial proclination were divided into two groups according to UI inclination: RI group (UI-THL< 113°) and NI group (113°≤ UI-THL ≤ 119°). Cephalograms used the true horizontal and true vertical lines to measure the UI and UL parameters. Treatment changes were compared both within and between the groups. **Results:** At T1, the RI group showed significantly more retroclined and retruded UI, increased incisal show at rest (ISR) and overbite compared to the NI group. Soft tissues were comparable, except for thicker lip in RI. At T2, the RI group exhibited normal inclination and position, while greater proclination and protrusion were observed in NI. No significant differences were observed in the ISR, overbite, or soft tissue variables between the groups. The treatment change (T2-T1) in both groups exhibited a significant proclination of the UIs. However, the RI group showed no significant change in the UL, while NI group revealed significant UL protrusion. **Conclusion:** The UL changes in the RI group did not show significant differences. In contrast, the NI group showed more UL protrusion, although it exhibited lesser proclination of UI compared to RI group.

Keywords: Deep bite, Inclination, Intrusion, Lip change, Proclination

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Introduction

Deep bite (DB) is one of the malocclusions that leads patients to seek orthodontic treatment. It is defined by an excessive vertical overlap of the upper incisors (UI) over the lower incisors when the teeth are in centric occlusion.[1] The prevalence of DB in Thailand ranges from 20.50 % to 24.50 %.[2,3] DB can cause traumatic occlusion, which has a negative effect on dental health, including the teeth, periodontal tissue, muscles, and temporomandibular disorder.[4] This condition not only affects the masticatory system but also impacts facial aesthetics.[5] Therefore, correcting a DB improves functional occlusion and enhances the aesthetic smile.

One of the options for correcting a DB is relative intrusion by labial proclination of the incisor teeth.[6] Exploring the changes in dental position that affect the soft tissue profile after correction is essential for treatment planning because successful orthodontic treatment not only establishes good occlusion but also achieves an attractive facial appearance.[7]

Previous studies that reported on DB correction used various methods and dentoalveolar changes after treatment.[8-11] However, few reports discussed the effects on the soft tissue profile following treatment.[9] Furthermore, the existing studies tend to focus on children who have not completed their growth.[9-11] Only one study examined the flaring of incisor teeth, which revealed that for every 1 mm of UI protraction, the upper lip (UL) protruded by 0.10 mm but it was not conducted in DB patients, and no categorization was made based on the inclination of the UIs before treatment.[12]

Since inclination and anteroposterior position of the UIs play an essential role in aesthetics,[13] the purpose of this study was to investigate the position of the UIs and UL in the facial profile before and after relative intrusion, as well as the changes during treatment in non-growing patients.

Materials and methods

Subjects

This retrospective study was conducted following approval from the Ethics Committee, Faculty of Dentistry, Prince of Songkla University (No: EC6407-050). The subjects were selected from a population who underwent labial proclination of the UI using Roth's prescription preadjusted bidimensional edgewise fixed appliances (Ormco™) with 0.018 × 0.025-inch slots on the incisors and 0.022 × 0.028-inch slots on the canines and posterior teeth. Treatment was performed at the Faculty of Dentistry, Prince of Songkla University between 2014 and 2020.

The inclusion criteria were non-growing patients verified from their cervical vertebrae maturation index in sixth stage,[14] aged between 18 and 35 years to minimize the effect of the growth and aging process,[15] overbite ≥ 3.50 mm, availability of pretreatment (T1) and posttreatment (T2) lateral cephalograms, and no craniofacial deformity. The subjects that satisfied the inclusion criteria were divided into two groups according to the inclination of the UIs compared to the true horizontal reference line (THL°) at T1: retroclination group (RI) with UI-THL < 113° and normal inclination group (NI) with UI-THL between 113° and 119° (norm = 116 ± 3°).[16]

Methods and landmarks

Lateral cephalograms were taken using an Orthopantomograph® OP300 (Instrumentarium Dental, Tuusula, Finland) with magnifications of 10.45 %. All lateral cephalograms were obtained in the natural head position with centric occlusion at T1 and T2. All cephalograms were manually traced. Each tracing was scanned and saved as a JPEG image, and the enlargement correction was integrated into the analysis process using ImageJ software, version 1.53a (NIH, Bethesda, MD, USA). The true vertical reference line (TVL) was set on the sella and parallel to the front edge of T1 cephalograms. THL was set to the plane that passed the sella and was perpendicular to the TVL.[16] Cephalometric landmarks, reference planes, and measurements are shown in Figures 1, 2, 3, and Table 1.

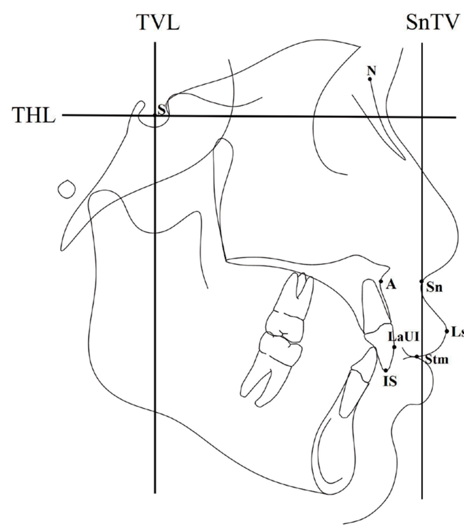

Figure 1 Cephalometric landmarks and reference planes.
S: sella, N: nasion, A: point A, LaUI: the midpoint of labial surface of upper incisor, IS: incisor superior, Sn: subnasale, Ls: labrale superioris, Stm: stomion, THL: true horizontal reference line, TVL: true vertical reference line, SnTV: a line parallel to the TVL passing through Sn

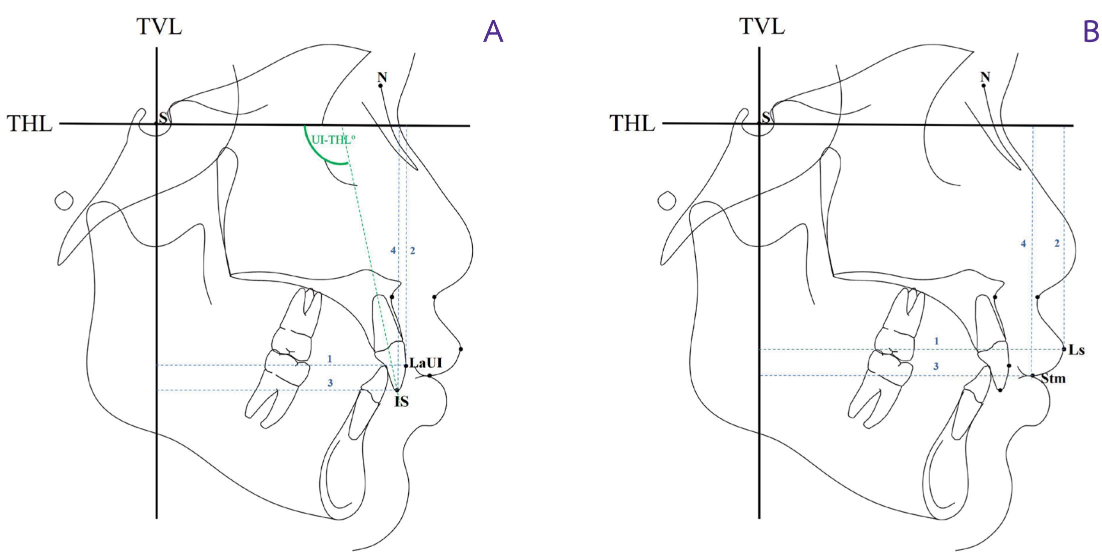

Figure 2 (A) Angular and linear measurements of dental variables; 1: TVL-LaUI, 2: THL-LaUI, 3: TVL-IS, 4: THL-IS
(B) Linear measurements of soft tissue variables; 1: TVL-Ls, 2: THL-Ls, 3: TVL-Stm, 4: THL-Stm

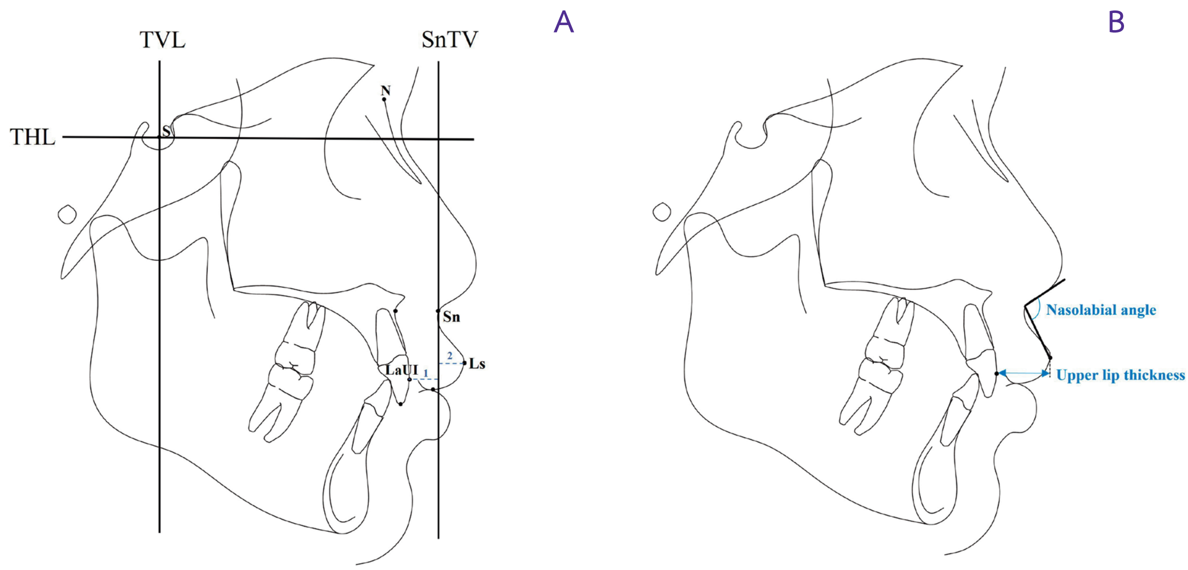

Figure 3 (A) Linear measurements at SnTV; 1: SnTV-LaUI, 2: SnTV-Ls (B) Additional cephalometric measurements: nasolabial angle and upper lip thickness

Table 1 Definitions of angular and linear measurements

Angular and linear measurements	Definitions
Dental	
UI-THL (degree)	Angle between the THL and long axis of the upper incisor
TVL-LaUI (mm)	Perpendicular distance from the TVL to LaUI
THL-LaUI (mm)	Perpendicular distance from the THL to LaUI
TVL-IS (mm)	Perpendicular distance from the TVL to incisor superior (IS)
THL-IS (mm)	Perpendicular distance from the THL to IS
SnTV-LaUI (mm)	Perpendicular distance from the SnTV to LaUI
ISR, Incisal show at rest (mm)	Distance parallel to TVL from the IS to Stm
Soft tissue	
TVL-Ls (mm)	Perpendicular distance from the TVL to Ls
THL-Ls (mm)	Perpendicular distance from the THL to Ls
TVL-Stm (mm)	Perpendicular distance from the TVL to Stm
THL-Stm (mm)	Perpendicular distance from the THL to Stm
SnTV-Ls (mm)	Perpendicular distance from the SnTV to Ls
Upper lip thickness (mm)	Distance parallel to THL from the LaUI to Ls

Reliability

All lateral cephalometric tracings and measurements were performed by the same operator who is an orthodontic resident supervised by a Thai Board-Certified Orthodontist. Two weeks after the first tracing, 30 randomly selected lateral cephalograms were retraced and remeasured.

Method error was calculated using Dahlberg's formula (ME= $\sqrt{\frac{\Sigma D^2}{2n}}$), where n represents the number of duplicated measurements and D represents the difference between two measurements in a pair. This calculation revealed that the differences were less than 0.50 mm and less than 0.50 degree without significant clinical difference. The result of testing the internal reliability with the intraclass correlation coefficient was ≥ 0.938, which demonstrated an excellent level of reliability.[17]

Statistical analysis

The sample size was calculated using G*power software, version 3.1.9.4 (Franz Faul, Kiel University, Germany). The calculation was performed at a significance level of 0.05, a test power of 0.80, and an effect size of 1.20 based on a previous study.[12] Therefore, a sample size of 12 subjects per group was required. The Shapiro-Wilk test was used to test the normality of the data distribution. If the data had a normal distribution, parametric statistics were used but if the data did not have a normal distribution, non-parametric statistics were used. The differences in gender between the two groups were analysed using the Chi-squared test. Paired *t* test or Wilcoxon signed-rank test was used to compare the changes during treatment (T2-T1) within the same group. Independent *t* test or Mann-Whitney *U* test was used to compare the differences between the variables in T1, T2, and T2-T1 between the two groups.

Results

The demographic characteristics of the subjects are shown in Table 2.

At T1, there were significant differences in all dental variables between the RI and NI groups. No significant differences were found in SnTV-Ls (mm) and the nasolabial angle. However, lip thickness was the only soft tissue variable to show a significant difference between the groups. The RI group showed more thickness than the NI group (Table 3).

At T2, there were significant differences in UI-THL (degree), SnTV-LaUI (mm), and UI-NA (degree) (mm). Specifically, the UIs in the RI group exhibited normal inclination and position, while the UIs in the NI group were proclined and protruded compared to the norm values. On the other hand, no significant

Table 2 Demographic characteristics of the subjects

Variable	RI group (n = 21)	NI group (n = 20)	*P* value
Gender[1] (male/female)	3/18	5/15	0.387
Age[2] (years)	23.33 ± 3.14	22.90 ± 5.61	0.831
Treatment duration[2] (years)	3.00 ± 1.28	2.60 ± 0.97	0.426

Values are presented as number or mean ± standard deviation.

[1]Chi-squared test was performed.

[2]Independent *t* test was performed.

Table 3 Comparison of pretreatment (T1) cephalometric variables between the RI and NI groups

Variable	Norm[16]	RI group	NI group	*P* value
Dental				
UI-THL[1] (degree)	116 ± 3	101.42 ± 8.28	115.84 ± 3.00	< 0.001***
SnTV-LaUI[1] (mm)	-8 ± 1	-10.82 ± 2.03	-8.08 ± 2.37	0.002**
UI-NA[2] (degree)	22 ± 6	10.81 ± 5.92	24.73 ± 3.90	< 0.001***
UI-NA[1] (mm)	5 ± 2	1.62 ± 2.76	5.73 ± 1.94	< 0.001***
ISR[2] (mm)	N/A	4.60 ± 1.26	3.50 ± 0.88	0.013*
Overbite2 (mm)	2 ± 1	5.71 ± 1.54	4.23 ± 0.98	0.002**
Soft tissue				
SnTV-Ls[1] (mm)	5 ± 1	3.96 ± 2.00	3.94 ± 1.77	0.974
Nasolabial angle[1] (degree)	90 ± 10	94.23 ± 7.62	93.50 ± 7.52	0.784
Lip thickness[1] (mm)	N/A	15.71 ± 2.16	12.92 ± 2.01	0.001**[a]

Values are presented as mean ± standard deviation.

[1] Independent *t* test or [2] Mann-Whitney *U* test was performed to compare between two groups.

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

Table 4 Comparisons of posttreatment (T2) cephalometric variables between the RI and NI groups

Variable	Norm[16]	RI group	NI group	*P* value
Dental				
UI-THL[1] (degree)	116 ± 3	113.52 ± 9.39	121.12 ± 2.97	0.002**
SnTV-LaUI[1] (mm)	-8 ± 1	-8.64 ± 1.73	-6.59 ± 2.81	0.013*
UI-NA (degree)	22 ± 6	22.89 ± 7.43	29.65 ± 4.46	0.006**
UI-NA[1] (mm)	5 ± 2	4.50 ± 2.80	7.38 ± 2.09	0.003**
ISR[2] (mm)	N/A	2.44 ± 0.61	2.15 ± 0.66	0.248
Overbite[2] (mm)	2 ± 1	2.59 ± 0.80	2.13 ± 0.46	0.080
Soft tissue				
SnTV-Ls[1] (mm)	5 ± 1	4.02 ± 1.93	5.01 ± 1.74	0.140
Nasolabial angle[1] (degree)	90 ± 10	94.35 ± 7.09	90.11 ± 8.43	0.125
Lip thickness[1] (mm)	N/A	14.00 ± 2.40	12.42 ± 1.87	0.052

Values are presented as mean ± standard deviation.

[1] Independent *t* test or [2] Mann-Whitney *U* test was performed to compare between the two groups.

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

differences were observed in the incisal show at rest (ISR), overbite, or soft tissue variables between the two groups. The UL parameters in both groups were in the normal range as indicated by the SnTV-Ls (mm) and nasolabial angle that were within the normal limits (Table 4).

The dental differences between T2 and T1 indicated significant differences in all variables in both the RI and NI groups. Specifically, the UIs of the RI group showed more significant labial movement along with a greater reduction in ISR and overbite compared to the NI group. The soft tissue differences between T2 and T1 revealed that the RI group did not show signif icant differences, except for a reduction in lip thickness. In contrast, the NI group showed significant differences in all soft tissue parameters with more labial movement of the UL compared to the RI group (Table 5).

Table 5 Comparison of treatment changes (T2-T1) between RI and NI groups

Variables	RI group (T2–T1)	NI group (T2–T1)	Between-group test *P* value
Dental			
UI-THL[1] (degree)	12.09 ± 3.80	5.27 ± 3.03	< 0.001***
SnTV-LaUI[1] (mm)	2.17 ± 1.23	1.48 ± 0.46	0.027*
UI-NA[1] (degree)	12.08 ± 4.12	4.92 ± 3.06	< 0.001***
UI-NA[2] (mm)	2.88 ± 1.16	1.65 ± 0.66	< 0.001***
ISR[2] (mm)	-2.15 ± 0.80	-1.35 ± 0.55	0.005**
Overbite[1] (mm)	-3.12 ± 1.20	-2.10 ± 0.93	0.014*
TVL-LaUI[1] (mm)	1.93 ± 0.75	1.40 ± 0.64	0.045*
THL-LaUI[1] (mm)	-2.00 ± 0.72	-1.50 ± 0.65	0.050
TVL-IS[2] (mm)	2.58 ± 1.11	1.96 ± 0.72	0.043*
THL-IS[2] (mm)	-1.98 ± 0.78	-1.46 ± 0.61	0.013*
Soft tissue			
Ls-SnTV[2] (mm)	0.06 ± 0.43	1.08 ± 0.86	0.002**
Nasolabial angle[2] (degree)	0.11 ± 2.73	-3.38 ± 2.89	0.001**
Lip thickness[1] (mm)	-1.71 ± 1.01	-0.50 ± 0.82	0.001**
TVL-Ls[2] (mm)	0.06 ± 0.51	1.03 ± 0.43	< 0.001***
THL-Ls[2] (mm)	0.00 ± 0.98	-0.37 ± 0.46	0.045*
TVL-Stm[2] (mm)	0.04 ± 0.14	0.84 ± 0.55	< 0.001***
THL-Stm[2] (mm)	0.12 ± 0.64	-0.34 ± 0.51	0.022*

Values are presented as mean ± standard deviation.

[1] Paired *t* test/ Independent *t* test.

[2] Wilcoxon signed-rank test/Mann-Whitney *U* test

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

Discussion

This study focused on DB patients who had completed their growth. Thus, this study aimed to limit the influence of growth on soft tissues during treatment. Therefore, the results obtained were solely attributed to changes that resulted from orthodontic treatment. The THL and TVL in the natural head position were used as reference planes, which offered the advantage of stability and lack of variability among individuals.[18] This method is suitable for assessing facial beauty as it represents the genuine head position to reveal the clinical characteristics in patients.[16]

Although cone beam computed tomography is currently useful in studying both soft and hard tissues, it is not yet widely used in every clinic due to the high cost and concerns of radiation exposure.[19,20] As a result, the use of lateral cephalograms still has advantages and is more widely used. Therefore, this study was conducted using lateral cephalograms.

This study divided subjects into two groups based on inclination of the UIs (UI-THL °) at pretreatment. The RI group had an UI-THL of 101.42 ± 8.28° and an UI-NA of 10.81 ± 5.92°. The NI group had an UI-THL of 115.84 ± 3.00 degree and an UI-NA of 24.73 ± 3.90°. The UI of the RI group resembled the UI in Angle Class II Division 2 malocclusion characterized by retroclined and retruded UIs, increased overbite, and greater ISR,[21] whereas the UI of NI group had increased overbite and ISR but normal inclination (Table 3).

After treatment, UI proclination of 2.58 ± 1.11 mm (P < 0.001) was observed in the RI group (Figure 6). However, UL protraction of 0.06 ± 0.51 mm (P = 0.353) resulted in a ratio of UI proclination to UL protraction of 1:0.02. Additionally, the thickness of the UL decreased by 1.71 ± 1.01 mm (P < 0.001). In contrast, the NI group with an UI proclination of 1.96 ± 0.72 mm (P = 0.001) and an UL protraction of 1.03 ± 0.43 mm (P = 0.001) resulted in a ratio of UI proclination to UL protraction of 1:0.52. The thickness of the UL decreased by 0.50 ± 0.82 mm (P = 0.047). This occurrence can be explained in a study by Mirabella et al.[12] who found that for every 1 mm of protraction, the UL protruded by 0.10 mm, and the thickness of the UL decreased by 0.80 mm. The decrease in the thickness of the UL is attributed to the UIs pressing down on the lip. Therefore, the lips only protrude slightly.

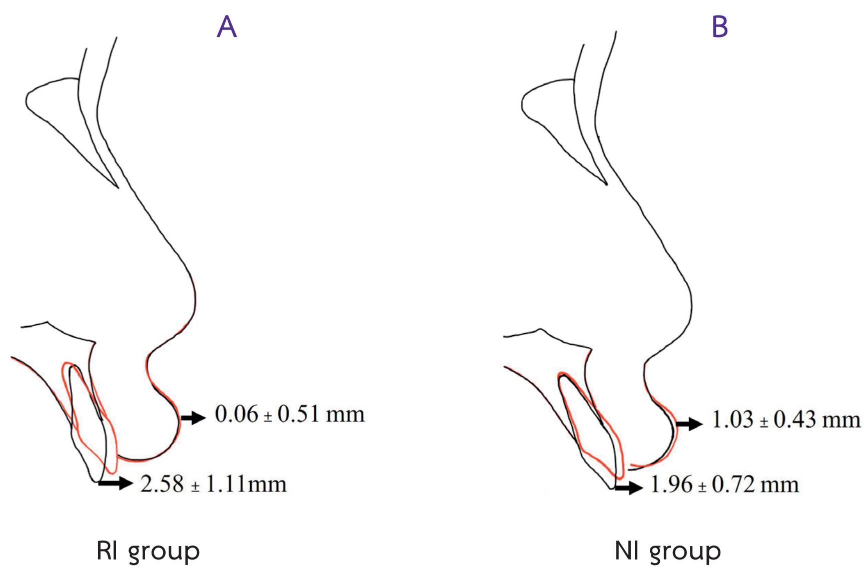

Figure 6 Representation of the UI and UL changes in the RI group (A) and NI group (B)

Since the ISR impacts smile aesthetics, a range of 2-4 mm is appropriate.[22] Patients with excessive ISR may have a gummy smile.[23,24] Furthermore, the degree of inclination of the UIs was related to the amount of ISR, with more retroclined UIs associated with increased ISR,[25] which was in agreement with this study. It was found that ISR before treatment in the RI group was significantly higher than the NI group (RI = 4.60 ± 1.26 mm, NI = 3.50 ± 0.88 mm; $P = 0.013$). When correction of DB is performed by proclination, the UIs can reduce ISR. This study revealed a reduction in ISR to 2.15 ± 0.80 mm and 1.35 ± 0.55 mm in the RI and NI groups, respectively.

The nasolabial angle is a parameter commonly used to assess facial beauty.[26,27] Nandini et al.[28] Emphasized that the nasolabial angle should be within a normal range for a pleasing facial profile. In this current study, the nasolabial angles at T1 for both the RI and NI groups were 94.23 ± 7.62°and 93.50 ± 7.52°, respectively. Following proclination of the UIs, it was observed that the nasolabial angle in the RI group did not show a significant change ($P = 0.372$), which was consistent with no significant changes in the UL after treatment. In contrast, the NI group showed a significant decrease in the nasolabial angle by 3.38 ± 2.89° ($P = 0.001$), which corresponded to protrusion of the UL. Nevertheless, this change did not have harmful effects on the soft tissue profile.

The increased responsiveness of the NI group to UI labial movement compared to the RI group may be attributed to the initially thinner UL. Unfortunately, there is no existing study in a proclination situation, but only in a study by Oliver, which found that patients with thinner lips are more responsive to changes when teeth are moved in a retraction situation.[29] In this study, the NI group had a significantly thinner UL at the beginning (12.92 ± 2.01 mm) compared to the RI group (15.71 ± 2.16 mm) that resulted in a greater response to tooth movement.

Limitations of this study need mentioning. First, the results cannot be applied in adolescent subjects or in cases of long-term soft tissue changes after retention. Second, due to the limited number of studies conducted in non-growing patients, it is challenging to draw comparisons between the current research and existing publications. Third, this study did not examine the effects of changes by the lower incisors on the UL. Fourth, as this was a retrospective study, the patients were not treated with the same mechanics. Therefore, a randomized controlled trial is suggested.[30] In addition, the amount of crowding and the relationship between sagittal and vertical skeletal patterns were not included in this study. These points should be considered in future studies.

The clinical applications for correction of DB from this study include two points. First, performing proclination in RI patients results in no change in the UL with normal inclination, normal overbite, and normal ISR. Second, performing proclination in NI patients would finish with a more protruded UL but within normal limits, normal overbite, normal ISR, and slight UI proclination. Therefore, careful treatment is necessary to prevent excessive proclination.

Conclusion

The UL changes in the RI group did not show signif icant differences. In contrast, the NI group showed more UL protrusion, although it exhibited less proclination of the UI compared to the RI group.

Author contributions

PT: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing, Visualization, Project administration; CC: Conceptualization, Methodology, Validation, Formal analysis, Resources, Writing, Visualization, Project administration, Supervisions.

Ethical statement

This research protocol was approved by the Human Ethics Committee, Faculty of Dentistry, Prince of Songkla University (No: EC6407-050).

Disclosure statement

The authors have no conflicts of interest.

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References

1. Moorrees CF, Gron AM, Lebret LM, Yen PK, Fröhlich FJ. Growth studies of the dentition: a review. Am J Orthod 1969;55(6):600-16.
2. Thasanabanchong S, Raksaseri P. The components of occlusal pattern in a group of Thai school children 7-11 years of age. J Dent Assoc Thai 1986;36(6):207-16.
3. Kitsahawong S. Prevalence of malocclusion of secondary school student in Muang district, Khon Kaen. Khon Kaen Dent J 2000;3(1):56-65.
4. Sonnesen L, Svensson P. Temporomandibular disorders and psychological status in adult patients with a deep bite. Eur J Orthod 2008;30(6):621-9.
5. Littlewood SJ, Mitchell L. An introduction to orthodontics: OUP Oxford 2019:55-60.
6. Nanda R. Correction of deep overbite in adults. Dental Clinics of North America 1997;41(1):67-87.
7. Ruankaeo K, Suntornlohanakul S. Factors affecting patient satisfaction in orthodontic treatment. Thai J Orthod 2023;13(1):44-51.
8. Varlık SK, Alpakan ÖO, Türköz Ç. Deepbite correction with incisor intrusion in adults: a long-term cephalometric study. Am J Orthod Dentofacial Orthop 2013;144(3):414-9.
9. Aydoğdu E, Özsoy Ö P. Effects of mandibular incisor intrusion obtained using a conventional utility arch vs bone anchorage. Angle Orthod 2011;81(5):767-75.
10. McDowell EH, Baker IM. The skeletodental adaptations in deep bite correction. Am J Orthod Dentofacial Orthop 1991;100(4):370-5.
11. Parker CD, Nanda RS, Currier GF. Skeletal and dental changes associated with the treatment of deep bite malocclusion. Am J Orthod Dentofacial Orthop 1995;107(4):382-93.
12. Mirabella D, Bacconi S, Gracco A, Lombardo L, Siciliani G. Upper lip changes correlated with maxillary incisor movement in 65 orthodontically treated adult patients. World J Orthod 2008;9(4):337-48.
13. Cao L, Zhang K, Bai D, Jing Y, Tian Y, Guo Y. Effect of maxillary incisor labiolingual inclination and anteroposterior position on smiling profile esthetics. Angle Orthod 2011;81(1):121-9.
14. Baccetti T, Franchi L, McNamara Jr JA, editors. The cervical vertebral maturation (CVM) method for the assessment of optimal treatment timing in dentofacial orthopedics. Semin Orthod 2005;11(3):119-29.
15. Nanda RS. The rates of growth of several facial components measured from serial cephalometric roentgenograms. Am J Orthod 1955;41(9):658-73.
16. Nuntasukkasame A, Suntornlohanakul S, Charoemratrote C. Natural head position: the role in lateral cephalometric analysis. OJ Thai Assoc Orthod 2012;2:10.
17. Koo TK, Li MY. A Guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med 2016;15(2):155-63.
18. Cooke MS, Orth D, Wei SH. A summary five factor cephalometric analysis based on natural head posture and the true horizontal. Am J Orthod Dentofacial Orthop 1988;93(3):213-23.
19. Wen J, Liu S, Ye X, Xie X, Li J, Li H, et al. Comparative study of cephalometric measurements using 3 imaging modalities. J Am Dent Assoc 2017;148(12):913-21.
20. Unat B, Samruajbenjakun B. The use of cone beam computed tomography in orthodontics. Thai J Orthod 2020;9(1):19-29.
21. Jain N, Soni S. An overview of class II division 2 malocclusion. Int J Health Sci 2021;5(S2):214-21.
22. Jeelani W, Fida M, Shaikh A. The maxillary incisor display at rest: analysis of the underlying components. Dental Press J Orthod 2018;23(6):48-55.
23. Silberberg N, Goldstein M, Smidt A. Excessive gingival display--etiology, diagnosis, and treatment modalities. Quintessence Int 2009;40(10):809-18.
24. Hunt O, Johnston C, Hepper P, Burden D, Stevenson M. The influence of maxillary gingival exposure on dental attractiveness ratings. Eur J Orthod 2002;24(2):199-204.
25. Sarver D, Ackerman M. Dynamic smile visualization and quantification: part 2. Smile analysis and treatment strategies. Am J Orthod Dentofacial Orthop 2003;124:116-27.

26. Dua V, Gupta S, Singh C. Evaluation of the nasolabial angle in the Indian population. Contemp Clin Dent 2010;1(2):79-82.
27. Quinzi V, Paskay L, D'Andrea N, Albani A, Annalisa M, Saccomanno S. Evaluation of the nasolabial angle in orthodontic diagnosis: a systematic review. Appl Sci 2021;11:1-18.
28. Nandini S, Prashanth CS, Somiah SK, Reddy SR. An evaluation of nasolabial angle and the relative inclinations of the nose and upper lip. J Contemp Dent Pract 2011;12(3):152-7.
29. Oliver BM. The influence of lip thickness and strain on upper lip response to incisor retraction. Am J Orthod 1982;82(2):141-9.
30. Faraoni D, Schaefer ST. Randomized controlled trials vs. observational studies: why not just live together? BMC Anesthesiol 2016;16(1):102.

Original Article

Factors Influencing Child Compliance in Deep Bite Correction with a Removable Anterior Bite Plane

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Abstract

Background: An important factor that influences the treatment success of deep bite correction using a removable anterior bite plane (RABP) is patient compliance. To date no studies have reported on the factors that influence patient compliance during treatment with an RABP, especially the wearing protocols. **Objective:** To investigate and compare patient compliance between two RABP wearing protocols: full-time wear with RABP on during meals (F+M), and RABP off during meals (F-M) and to evaluate possible factors that might affect patient compliance. **Materials and methods:** Thirty-three participants with deep bite (mean age 10.88 ± 2.16 years) were randomly assigned to either the F+M (n = 18) or F-M group (n = 15). The ActualWear was individually recorded by a TheraMon microsensor embedded in the RABP for the duration of six months. This study defined compliance as the ratio of actual duration of wearing an RABP (ActualWear) and the recommended duration of wear (RecommendedWear). The RecommendedWear was based on the ideal, but sensible, expected wearing duration of each wearing protocol. The Mann-Whitney *U* test compared between-group differences of compliance, age, gender, wearing protocol, type of motivation, type of school, and parental occupation ($\alpha = 0.05$). **Results:** Patient compliance was significantly influenced by age and type of motivation ($P < 0.001$), but not by the wearing protocol, gender, type of school, or parental occupation ($P \geq 0.05$). **Conclusion:** The RABP wearing protocols did not affect patient compliance. However, age and type of motivation affected patient compliance during RABP use for deep bite correction.

Keywords: Anterior bite plane, Deep bite, Microsensor, Patient compliance, Wear duration

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Introduction

Excessive vertical overlapping of the anterior teeth of more than 4 mm is called deep bite.[1] This malocclusion is found in children in the range of 18.40 % to 34.50 %.[2] It can create a range of issues that affect one or more individual teeth, surrounding alveolar bone structures, as well as soft tissues. These problems may occur independently or in conjunction with other malocclusions. The clinical manifestations of a deep bite include shortened lower facial height, flattened mandibular plane angle, decreased gonial angle, large overjet, supraocclusion of incisors, infraocclusion of posterior teeth, and excessive curve of Spee.[3]

Deep bite correction can be achieved by extrusion of posterior teeth, intrusion of anterior teeth, proclination of anterior teeth, and combination treatment. A removable anterior bite plane (RABP) is regularly used for deep bite correction in growing patients by the combination of posterior teeth extrusion and proclination of anterior teeth.[4-6]

The two most recommended RABP wearing instructions found in the literature are full-time wearing, which includes during meals (F+M),[7,8] and full-time wearing except during meals (F-M).[9,10] A previous study found no difference in cephalometric changes between the F+M and F-M wearing protocols, but noted a different rate of deep bite correction.[4] The different rate of deep bite correction may be due to varying levels of compliance between protocols. It is possible that wearing an RABP during a meal might cause patient discomfort that affects cooperation. Conversely, removing the appliance during meals might reduce wearing time if the eating period is prolonged, which potentially leads to inconsistent appliance use.

Assessing patient compliance with removable appliances during wear is challenging. Subjective assessments of patient compliance, such as the patient, parent, or doctor reports, are not reliable. Objective assessment is recommended for a more accurate compliance evaluation to reduce limitations.[11] The TheraMon microsensor offers a solution by detecting temperature when the appliance is worn intraorally. The accuracy of this device in measuring the wearing time of removable orthodontic appliances was demonstrated in previous studies.[12]

The level of compliance in this study was defined as the ratio of the actual duration of wearing an RABP (ActualWear) to the recommended duration specified in each RABP wearing protocol (RecommendedWear). The factors that influence patient compliance with RABP treatment, particularly the wearing protocols, have not been documented in existing studies. This study aimed to compare patient compliance between two RABP wearing protocols: F+M and F-M. Moreover, since several factors, such as age, gender, educational levels, and types of malocclusion, were shown to correlate with patient compliance levels,[13] our secondary objective was to investigate other possible factors that affect patient compliance in wearing an RABP.

Materials and methods

Trial design

This prospective study was approved by the Human Research Ethics Committee of the Faculty of Dentistry, Prince of Songkla University with ethical approval number: EC6601-001. The study was registered at the Thai Clinical Trial Registry under the identifier TCTR20230305001.

Sample size calculation

According to a previous study[14] on the correlation between wearing time and patient compliance, the sample size was calculated using G*Power software version 3.1 (Heinrich Heine University Düsseldorf, Düsseldorf, Germany). The coefficient of standard deviation daily wear time was 0.35, and the effect size was 0.592 with $\alpha = 0.05$ and $\beta = 0.95$. The calculated sample size of this study was 31 participants.

Participants and eligibility criteria

Thirty-three participants were recruited in this study at the Orthodontic Clinic of the Dental Hospital, Faculty of Dentistry, Prince of Songkla University, Thailand. The inclusion criteria were: 1) dental deep bite (overbite > 4 mm); 2) molar Class I or II relationship; 3) Class I or mild Class II skeletal relationship (ANB = 1° – 9°); 4) growing patient (CVM stage ≤ CS5); 5) normo- or hypodivergent pattern (SN-MP < 35°); 6) no signs and symptoms of temporomandibular disorders; and 7) no history of orthodontic treatment. The exclusion criteria were: 1) noncooperative patients; 2) incomplete root formation of the mandibular incisors on panoramic radiography; or 3) long-term use of anti-inflammatory or immunosuppressive medications.

Randomization and blinding

All participants were randomly assigned into either the F+M group or F-M group using computer-generated numbers (random.org). All numbers were randomized before the recruitment, and the generated numbers were printed and enclosed in sealed envelopes. All participants received the sequence from top to bottom. Before entering the trial, all participants with their parents were obligated to furnish written informed consent. The treatment was administered by one orthodontist while data collection and measurements were executed by a single researcher. Due to the known wearing protocol, blinding of both subjects and the orthodontist was not feasible. Nevertheless, blinding was maintained during the statistical analysis for subject identification and allocation.

Demographic data collection

We collected demographic information from all patients before starting the intervention. The demographic data used in this study included age, gender, patient's type of motivation, type of school (private or public), and parental occupation (self-employed or employed). Based on Piaget's theory of cognitive development,[15] children aged 11 and above were found to be significantly more logical than those of earlier age groups. Therefore, the patients were divided into two age groups: < 11 years of age and ≥ 11 years of age. In addition, the type of motivation was defined as either internal or external. Internal motivation refers to the intrinsic factors that drive individuals to seek or adhere to treatment based on personal desires. External motivation, in contrast, is influenced by extrinsic factors such as social influences and parental encouragement.[16] The patient and accompanied guardian were asked at the time of the initial visit for data collection whether the motivation was internal or external. If both internal and external motivation were mentioned, the patient would be classified into an external motivation group because external motivation has an impact on internal motivation.[17]

Appliance design and interventions

All participants were assigned to wear the RABP that consisted of Adam's clasps at the maxillary first molar, a labial bow, and a baseplate with an anterior bite plane made from poly (methyl-methacrylate), which was embedded with a temperature microsensor (TheraMon, Hargelsberg, Austria) near the soft tissue side (Figure 1). The F+M group subjects were informed to wear the RABP full-time with the exception of tooth brushing. On the other hand, the F-M group subjects were informed to wear the RABP full-time except during tooth brushing and meals. All participants were recalled monthly for 6 months. All participants were instructed to avoid cold drinks or foods and not to soak the appliance in warm or hot water.

Wearing duration measurement

The objective wearing duration was recorded using the TheraMon microsensor embedded in the RABP. Data from the microsensor was transferred to a computer via radio frequency identification using the TheraMon pen reader. All data were analyzed using

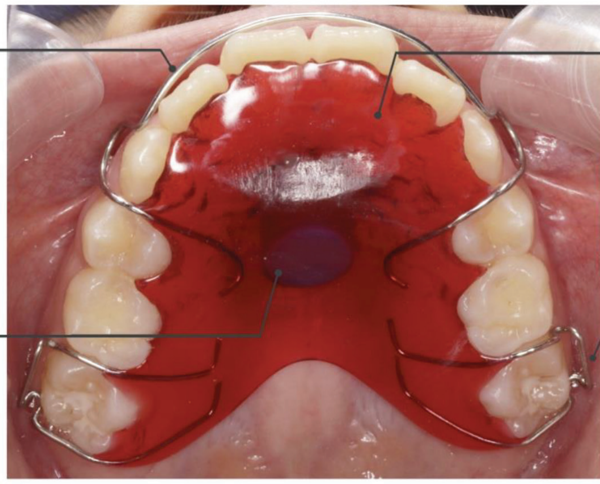

Figure 1 Removable anterior bite plane with TheraMon microsensor.

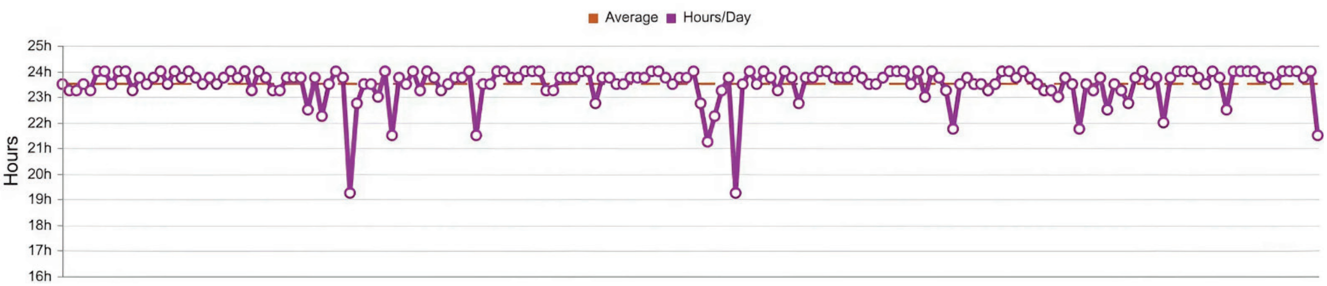

Figure 2 Output data from the TheraMon software demonstrating the average and actual wearing duration per day.

TheraMon software (Figure 2). The total wearing time for the duration of 6 months was recorded.

Eating duration evaluation

All participants were asked to self-report the duration of a typical meal. These individual reports were then used to calculate the mean eating duration for one meal across all participants. The estimated total eating time for the 6-month study period was then calculated based on this mean eating duration.

Patient compliance measurement

After six months of wearing the RABP, the actual wearing time (ActualWear) was the objective wearing time that was recorded from the microsensor. The recommended wearing duration (RecommendedWear) was calculated from six months duration (4,320 hours). The estimated eating duration for six months was calculated from the patient's self-report, and for brushing time, the recommended two minutes per brushing period.[18]

Patient compliance percentage (% Compliance) was calculated using this equation:

$$\% \text{ Compliance} = \frac{\text{ActualWear}}{\text{RecommendedWear}} \times 100 \%$$

The RecommendedWear for the F+M group was calculated from this formula:

$$\text{RecommendedWear}_{(F+M)} = (6 \text{ months duration}) - (\text{brushing time})$$

The RecommendedWear for the F-M group was calculated from this formula:

$$RecommendedWear_{(F\text{-}M)} = (6\ \text{months duration}) - (\text{brushing time}) - (\text{eating time})$$

Statistical analysis

The Statistical Package for Social Sciences (SPSS version 29, SPSS Inc., IBM, Armonk, NY, USA) was used for the statistical analysis. The Shapiro-Wilk test showed that all data were non-normally distributed. The Mann-Whitney *U* test was performed to compare the differences between the two groups. The Spearman's rank correlation coefficient was performed to examine the correlation between initial overbite and patient compliance. The significance level was set at 0.05.

Results

A total of 36 participants were recruited; however, three participants declined to participate. The remaining 33 subjects were randomly assigned into the F+M and F-M groups with a 1:1 allocation ratio. No dropouts occurred during this trial. Table 1 shows the baseline characteristics. The average participant age in this study was 10.88 ± 2.16 years (range 8-14 years) with 15 males and 18 females. The average initial overbite was 5.51 ± 1.47 mm.

Between-group comparisons indicated no significant differences in the average meal time per day between the F+M and F-M groups ($P \geq 0.05$) (Table 2). However, the average daily wearing time in the F+M group was significantly higher than in the F-M group ($P < 0.001$) (Table 2).

Table 1 Characteristics of the participants before observation.

Variable	Mean ± SD
Age (y)	10.88 ± 2.16
Initial overbite (mm)	5.51 ± 1.47
Gender, n (%)	
Male	15 (45.45 %)
Female	18 (54.55 %)
Wearing protocol, n (%)	
F+M	18 (54.55 %)
F-M	15 (45.45 %)

F+M, full-time appliance wearing except for tooth brushing; F-M, full-time appliance wearing except for meals and tooth brushing.

Table 2 Average wearing times and average meal times in each wearing protocol.

	F+M (Mean ± SD)	F-M (Mean ± SD)	*P* value
Average daily wearing time (hour)	22.68 ± 1.34	19.60 ± 2.38	< 0.001***
Average meal time per day (min)	103.94 ± 19.32	98.87 ± 12.44	0.388

F+M, full-time appliance wearing except for tooth brushing; F-M, full-time appliance wearing except for meals and tooth brushing. *P* value of Mann-Whitney *U* tests.

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

Table 3 Comparisons of the percentages of patient compliance[+] in each variable.

Variable	Compliance percentage (%, Mean ± SD)	*P* value
Age		
< 11 years old (n = 14)	89.50 ± 10.15	0.005**
≥ 11 years old (n = 19)	97.67 ± 4.45	
Gender		
Male (n = 15)	94.16 ± 5.63	0.625
Female (n = 18)	93.32 ± 10.75	
Wearing protocol		
F+M (n = 18)	95.61 ± 5.66	0.233
F-M (n = 15)	91.42 ± 11.10	
Motivation type		
Internal (n = 17)	88.37 ± 9.83	< 0.001***
External (n = 16)	98.73 ± 2.26	
School type		
Private school (n = 20)	94.68 ± 6.58	0.941
Public school (n = 13)	92.21 ± 11.34	
Parental occupation		
Self-employed (n = 15)	92.69 ± 10.14	0.426
Employed (n = 18)	94.55 ± 7.46	

[+]Patient compliance percentage was calculated using this equation:

$$\text{Compliance percentage} = \frac{\text{ActualWear}}{\text{RecommendedWear}} \times 100\%$$

F+M, full-time appliance wearing except for tooth brushing; F-M, full-time appliance wearing except for meals and tooth brushing. *P* value of Mann-Whitney *U* tests.

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

Patients under 11 years old had a significantly lower compliance percentage than patients aged 11 years and over ($P < 0.001$). The compliance percentage was significantly higher in participants with external motivation than in participants with internal motivation ($P < 0.001$). However, there were no significant differences in compliance percentages between genders, wearing protocols (F+M or F-M), private and public schools, or parental occupations (self-employed versus employed) ($P \geq 0.05$) (Table 3). The correlation between initial overbite and patient compliance was not significant (r = 0.005; $P = 0.980$).

Discussion

The success of deep bite correction in growing patients using an RABP often relies on patient compliance in following the wearing instructions. A patient's willingness to cooperate and adhere to all treatment recommendations can significantly influence orthodontic treatment outcomes.

Based on the RABP wearing protocols, the F+M group had a longer instructed wearing duration than the F-M group. Moreover, the F+M group tended to have higher patient compliance than the F-M group, but the difference was not statistically significant. The average meal time per day observed in this study was similar in both groups but higher than that reported for American teenagers aged 15 and older.[19] This study found that the RABP wearing protocols did not impact patient compliance. This might be because the protocols differed only during meals, which may not have affected the patients' habits of wearing the RABP after mealtime. In this study, both male and female observed compliance levels were comparable. This finding contrasts with the results of a previous study,[13] which reported that females generally had a higher cooperation level than males. On the other hand, another previous study[20] reported that males had more significant compliance with clear aligner therapy than females. This might be attributed to variations in individual parental care provided within each family. Different levels of parental involvement and support could influence the compliance behaviors of children regardless of their gender.

This study found that patients under 11 years of age were less compliant than patients aged 11 years and over. This result was consistent with previous studies[21,22] that reported younger patients were generally less mature and motivated than older patients, which led to lower compliance. However, several studies[23-25] have found no relationship between age and compliance. These conflicting results may be due to factors such as the development of an independent identity and variations in parental attention.[26]

A previous study[27] reported that laypeople had low recognition of deep bite and high esthetic tolerance for it. Our study found that the amount of initial overbite had no effect on patient compliance. This may be because the patients did not recognize deep bite as a problem. Moreover, parental recognition of the deep bite may not have been sufficient to encourage appliance wearing in accordance with the orthodontist's instructions.

The type of school (private or public) attended by the patients in this study did not have a direct effect on compliance levels. The nature of the educational institution does not influence patient adherence to the RABP wearing instructions. However, one study[28] reported that knowledge of a patient's performance in the school environment might assist in predicting compliance levels. This discrepancy highlights the need for further research. Future studies should explore potential factors within the school environment that might impact patient compliance beyond the simple classification of schools as either private or public.

Parental occupation had no effect on the level of patient compliance in our study. This might be due to individual differences in education and parenting styles. However, a previous study[29] found that the mother's occupation had a significant effect on changing the compliance level in growing patients. Moreover, our study did not include other parental factors that might influence compliance, such as parental involvement or attitudes towards orthodontic treatment.

Participants with external motivation had a higher compliance percentage than those with internal motivation, which might be explained by factors such as parental attitudes. The external reasons for seeking orthodontic treatment were primarily from the parents. This finding was consistent with previous studies, which showed that parental involvement can significantly impact a child's compliance during orthodontic treatment.[30-32]

The TheraMon microsensor provides precise measurements of wearing duration that surpasses the accuracy of traditional data collection methods such as self-report logbooks.[33] This study collected the duration times of wearing the RABP daily using the objective measurements of the TheraMon microsensor. Participants in the F+M group were expected to wear the appliance for nearly 24 hours daily, while those in the F-M group were expected to maintain an average daily wear time of 22.50 hours (accounting for an average meal time of about 1.50 hours per day). The observed average daily wearing durations were 22.68 hours for the F+M group and 19.60 hours for the F-M group, which was the result of 91 % to 96 % compliance with the wearing instructions. The recorded wearing duration might have been affected by the Hawthorne effect,[34] as patients were aware of being closely observed. In real-life conditions, the level of compliance might be lower than in these experimental conditions. Additionally, a recent study[4] found that wearing an RABP for a longer duration resulted in a faster rate of deep bite correction. Further investigation of the association between the rate of deep bite correction and patient compliance is required.

The factors affecting patient compliance during deep bite correction with an RABP include age and type of motivation. Younger patients should receive compliance reinforcement to increase compliance. Moreover, motivation from parents is also the key to successful treatment with removable orthodontic appliances.

Conclusion

The removable anterior bite plane wearing instructions did not affect patient compliance. Both the F+M and F-M wearing protocols had similar compliance levels. Patient adherence during deep bite correction with a removable anterior bite plane was affected by age and type of motivation.

Author contributions

TS: Conceptualization, Methodology, Software, Formal analysis, Data curation, Writing-Original draft preparation; SP: Methodology, Formal analysis; UT: Visualization, Investigation, Resources, Supervision, Funding acquisition, Writing-Reviewing and Editing, Project administration.

Ethical statement

This research protocol was approved by the Human Ethics Committee of the Faculty of Dentistry, Prince of Songkla University, with Ethical Approval Number: EC6601-001.

Disclosure statement

The authors have no conflicts of interest.

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References

1. Ghafari JG, Macari AT, Haddad RV. Deep bite: treatment options and challenges. Semin Orthod 2013;19(4):253-66.
2. Dimberg L, Lennartsson B, Arnrup K, Bondemark L. Prevalence and change of malocclusions from primary to early permanent dentition: a longitudinal study. Angle Orthod 2015;85(5):728-34.
3. Watted N, Lone IM, Zohud O, Midlej K, Proff P, Iraqi FA. Comprehensive deciphering the complexity of the deep bite: insight from animal model to human subjects. J Pers Med 2023;13(10):1472.
4. Sangwattanarat T, Thongudomporn U. Effectiveness of removable anterior bite planes with varied mealtime protocols in correcting deep bites among growing patients: a randomized clinical trial. Angle Orthod 2024;94(6):615-22.
5. Baccetti T, Franchi L, Giuntini V, Masucci C, Vangelisti A, Defraia E. Early vs late orthodontic treatment of deepbite: a prospective clinical trial in growing subjects. Am J Orthod Dentofacial Orthop 2012;142(1):75-82.
6. Pairatchawan N, Viteporn S, Thongudomporn U. Mandibular incisor root volume changes between anterior bite planes fabricated from acrylic resin and thermoplastic materials: a prospective randomized clinical trial. Angle Orthod 2022;92(6):755-63.
7. Marwah N. Textbook of pediatric dentistry. 4th ed. London, United Kingdom: JP Medical Ltd; 2018.p. 454-62.
8. Hutami IR, Novianty SI, Indrawati SV, Rinaryo AD, Rahadian

A, Christiono S, et al. The effects of anterior bite plane on temporomandibular joint and mandibular morphology. Saudi Dent J 2023;35(6):720-6.

9. Adams CP, Kerr WJS, Adams CP. The design, construction, and use of removable orthodontic appliances. 5th ed. London; Boston: Butterworth-Heinemann; 1990.p.144.
10. Ciavarella D, Laurenziello M, Guida L, Montaruli G, Gallo C, Tepedino M, et al. Dentoskeletal modifications in Class II deep bite malocclusion treatment with anterior bite plane functional appliance. J Clin Exp Dent 2017;9(8):e1029-34.
11. Nahajowski M, Lis J, Sarul M. The use of microsensors to assess the daily wear time of removable orthodontic appliances: a prospective cohort study. Sensors 2022; 22(7):2435.
12. Moreno-Fernández A, Iranzo-Cortés JE, Paredes-Gallardo V, García-Sanz V, Tarazona-Álvarez B, Almerich-Silla JM, et al. Effectiveness of removable appliances with temperature sensors in orthodontic patients: a systematic review and meta-analysis. Eur J Orthod 2022;44(2):134-45.
13. Sodor-Botezatu A, Anistoroaei D, Cernei ER, Golovcencu L, Stan AN, Zegan G, editors. Assessment of factors influencing orthodontic patient cooperation. Iasi, Romania; IEEE 2022.p.1-4.
14. Charavet C, Le Gall M, Albert A, Bruwier A, Leroy S. Patient compliance and orthodontic treatment efficacy of Planas functional appliances with TheraMon microsensors. Angle Orthod 2018;89(1):117-22.
15. Thompson P. Foundations of educational technology. Oklahoma: Oklahoma State University Libraries; 2018.p.9-17.
16. Proffit WR, Fields HW, Larson B, Sarver DM. Contemporary orthodontics. Philadelphia: Elsevier Health Sciences; 2018.p.54-5.
17. Wijaya JA, Girsang E, Nasution AN. Internal and external factors that affect employee motivation at Materna Medan Hospital. Contag: Sci Period J Public Health Coast Health 2023;5(4):1318.
18. Creeth JE, Gallagher A, Sowinski J, Bowman J, Barrett K, Lowe S, et al. The effect of brushing time and dentifrice on dental plaque removal in vivo. J Dent Hyg 2009;83(3):111-6.
19. Hamrick K, Andrews M, Guthrie J, Hopkins D, McClelland K. How much time do Americans spend on food? Washington: U.S. department of agriculture; 2011. EIB-86. Economic Research Service.
20. Timm LH, Farrag G, Baxmann M, Schwendicke F. Factors influencing patient compliance during clear aligner therapy: a retrospective cohort study. J Clin Med 2021;10(14):3103.
21. Albino J, Tedesco L, Phipps G. Social and psychological problems of adolescence and their relevance to dental care. Int Dent J 1982;32(2):184-93.
22. Friedman IM, Litt IF. Adolescents' compliance with therapeutic regimens: psychological and social aspects and intervention. J Adolesc Health Care 1987;8(1):52-67.
23. Bartsch A, Witt E, Sahm G, Schneider S. Correlates of objective patient compliance with removable appliance wear. Am J Orthod Dentofacial Orthop 1993;104(4):378-86.
24. Sergl HG, Zentner A. Predicting patient compliance in orthodontic treatment. Semin Orthod 2000;6(4):231-6.
25. Cucalon A, III, Smith RJ. Relationship between compliance by adolescent orthodontic patients and performance on psychological tests. Angle Orthod 1990;60(2):107-14.
26. Albino JEN. Factors influencing adolescent cooperation in orthodontic treatment. Semin Orthod 2000;6(4):214-23.
27. Boonchuay N, Thongudomporn U, Leethanakul C, Lindauer SJ, Youravong N. Overbite recognition and factors affecting esthetic tolerance among laypeople. Angle Orthod 2023;93(2):205-12.
28. Firth F, Bennani F, Stacknik S, Farella M. Orthodontic patient co-operation: a review of the clinician's role in predicting and improving patient compliance. Australas Orthod J 2019;35(1):5-12.
29. Dai L, Wu T, Hu Y, Li S, Liu W. Does the efficacy of behavior management techniques differ between children from single-child and multi-child families?: a quasi-experimental study. Front Public Health 2022;10: 840483.
30. Perillo L, d'Apuzzo F, De Gregorio F, Grassia V, Barbetti M, Cugliari G, et al. Factors affecting patient compliance during orthodontic treatment with aligners: motivational protocol and psychological well-being. Turk J Orthod 2023;36(2):87-93.
31. Jeamkatanyoo L, Suntornlohanakul S. Compliance in retainer wearing after orthodontic treatment. Thai J Orthod 2022;12(2):44-50.
32. Jeamkatanyoo L, Suntornlohanakul S, Tianviwat S. Factors influencing orthodontic patient compliance with removable retainers. Thai J Orthod 2024;14(2):36-44.
33. Tsomos G, Ludwig B, Grossen J, Pazera P, Gkantidis N. Objective assessment of patient compliance with removable orthodontic appliances: a cross-sectional cohort study. Angle Orthod 2014;84(1):56-61.
34. Abdulraheem S, Bondemark L. Hawthorne effect reporting in orthodontic randomized controlled trials: truth or myth? Blessing or curse? Eur J Orthod 2018;40(5):475-9.

Original Article

Accuracy of Intraoral Scanner for Centric Relation Record in Comparison to Vinyl Polysiloxane

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Abstract

Background: Centric relation (CR) is a maxillomandibular position used in dental procedures. Conventional CR bite registration may be inaccurate due to material limitations, such as dimensional changes. Intraoral scanners (IOS) offer a modern alternative, minimizing these limitations and improving patient comfort. However, few studies have evaluated the accuracy of IOS for CR recording. **Objective:** To compare the accuracy of digital CR recordings from an IOS with conventional CR bite registration through quantitative occlusal contact analysis. **Materials and methods:** Twenty-nine healthy individuals participated. CR was recorded using bimanual manipulation with silicone bite indexes (Silagum-Putty; DMG, Germany). Conventional CR bite records were obtained using vinyl polysiloxane (O-Bite; DMG, Germany). IOS scans (iTero Element 2; Align Technologies, USA) recorded CR using the silicone bite index. Recordings were repeated over two visits. CR first contact and sites of close proximity (SCP) were identified. McNemar's test assessed trueness, and Cohen's kappa evaluated repeatability. **Results:** Significant differences in trueness were found between conventional and iTero scans for CR first contact ($P < 0.001$) and SCP detection ($P < 0.001$ in the first visit and $P = 0.027$ in the second visit). Repeatability was comparable for conventional methods (kappa = 0.860 for CR first contact and 0.880 for SCP) and iTero scans (kappa = 0.707 for CR first contact and 0.865 for SCP). **Conclusion:** While repeatability of both methods showed similar acceptable agreement, the trueness of identifying CR first contact and SCP was better in conventional bite registration.

Keywords: Centric Relation, Jaw Relation Record, Reproduction, Vinyl polysiloxane

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Introduction

Centric relation is a maxillomandibular relationship in which the condyles articulate in the anterior-superior position against the posterior slopes of the articular eminence.[1,2] It serves as a recordable and repeatable position, regardless of the presence or the position of teeth.[1,2] At this position, the centric occlusion, which is defined as the occlusion of opposing teeth when the mandible is in centric relation, is also developed. This position is universally accepted as the reference position of choice for many dental procedures, including full mouth rehabilitation, restoration of posterior teeth, orthodontic treatment and management of patients with temporomandibular disorders in both dentate and edentulous individuals.[3-6]

Centric relation bite registration is one of the most critical determinants of dental procedure success.[2,7] The selection of an appropriate mandibular guidance method and accurate, dimensionally stable recording materials is fundamental principles in bite registration.[7,8] A number of techniques including the tongue tip to soft palate technique, the chin point guidance technique, the anterior guidance technique using Lucia jig/leaf gauge, the Gothic arch tracing and the bimanual manipulation technique have been developed and used routinely for centric relation record.[9] Many studies have investigated the reproducibility of the centric relation. High reliability and reproducibility of the CR with small variations, which were considered as a clinically acceptable procedure, have been revealed.[4,7] Nowadays, the most acceptable techniques are bimanual manipulation, use of an anterior deprogramming device and chin point guidance which are comparable in reproducibility and accuracy.[4,7,9-11]

Although the conventional bite registration has been the standard of practice for many decades, bite registration materials inaccuracies in the reproduction of the CR bite registration have been found. The linear dimensional change, accuracy and surface hardness of various bite registration materials are measured over time.[8,12-14] Vinyl polysiloxane (PVS) and polyether were found to be dimensionally more stable than other materials but are obliged to be articulated within 24-48 hours for accurate registration.[7,8,12]

With advancements in digital dentistry technology, intraoral scanners have been introduced to provide digital dental model without the need for impression of maxilla and mandibular arch and new techniques for CR bite registration emerged.[15,16] Contrary to conventional bite registration, intraoral scanners allow clinicians to directly acquire data from the mouth, and the recording takes place without an interposed medium minimizing the potential errors and the impact of materials limitations.[15] Digital recording is easier to use for clinicians and is highly accepted by patients. It may potentially reduce the chair time, laboratory time, enhance patient comfort, and allow for visualizing the bite registration immediately.[17-19] The accuracy for full arch dentate scans and virtual interocclusal records has been previously evaluated.[20] A systematic review provided information about the accuracy of static virtual articulation. However, it presented some limitations due to the small number of clinical studies. Most of them used three-dimensional laboratory scanners to digitize the casts rather than an intraoral scanner.[21] The use of intraoral scanning for recording CR is a new technique and few studies have investigated the reliability or validity of CR bite registration using an intraoral scanner.[15,22] Though a previous study found equivalent accuracy of the maxillomandibular relationship recorded at the CR by intraoral scanners and the conventional method, only a single dentate participant was involved.[22] The clinical study comparing the accuracy of the CR position recorded using IOSs verified by occlusal contact remains sparse.

To further evaluate the new technology of bite registration record techniques, the aim of this study is to evaluate the accuracy of digital recordings of centric relation obtained from an intraoral scanner through the quantitative comparison of occlusal contacts in normal adult patients.

Materials and methods

Subjects

This cross-sectional study was approved by the Human Ethics Committee of the Faculty of Dentistry, Chulalongkorn University (Ethical Approval Number: HREC-DCU 2023-015). The sample size was determined by n4Studies application (version 2.3)[23] based on data from a pilot study at the 95 % level of significance with 80 % power. The calculated sample size was 26 subjects. Considering a drop-out rate of 10 %, the total sample size was 30 subjects. The subjects were healthy and cooperative adults with permanent dentition. The inclusion criteria were the following: 1) adults aged 20-25 years; 2) permanent dentition with a minimum of 24 teeth; 3) no acute dental disease or periodontal disease; 4) no cuspal-coverage dental restoration; 5) no posterior open bite. The exclusion criteria were the following: 1) the presence of signs and symptoms of temporomandibular disorders; 2) active orthodontic treatment; 3) the presence of tooth mobility; 4) dental restoration during the experiment.

All subjects were fully informed about the objectives of the study and were required to provide signed consent.

Centric relation technique

The bimanual manipulation was selected as a centric recording technique for this study with the subject in a supine position. A single dental specialist, possessing over three years of experience in regular clinical application of this technique, performed all manipulations. Prior to initiating the centric relation manipulation, silicone bite indexes were made by placing additional Vinyl Polysiloxane (Silagum-Putty; Dental Material-Gesellschaft, Germany) in the area of the anterior teeth (canine to canine).

To obtain centric relation through the bimanual manipulation technique, the operator positioned themselves behind the subject, placing four fingers of each hand along the lower border of the subject's mandible near the gonial angles. The thumbs were laid over the mandibular symphysis. The operator then applied upward pressure at the gonial angles with the fingers, while simultaneously exerting gentle downward pressure with the thumbs at the chin. This coordinated force guided the mandible into centric relation by seating the condyles in the most superior position within the glenoid fossa.[7] The subject was instructed to hold this position until the materials were set.

Centric relation bite registration

Operators captured two recordings of centric relation on each subject under the same clinical settings. Each centric relation recording was repeatedly performed in two visits, scheduled for 7 days after the first visit at approximately the same time of day.

Conventional centric relation bite registration

Centric relation bite records were obtained from each subject using vinyl polysiloxane bite registration material (O-Bite; Dental Material-Gesellschaft, Germany) since this method since this method had demonstrated high accuracy compared to other contemporary materials for centric relation (CR) bite records.[7] The PVS material was applied onto the occlusal surface of the mandibular teeth, then the silicone bite index was placed at the anterior teeth. The subject was instructed to close and hold their bite until the material was fully set, and the bite record was carefully removed from the mouth to minimize any risk of distortion or tearing, especially in thin areas near the sites of close proximity (SCP). Immediate photographing and analysis were performed within 24 hours.

Digital intraoral scanner

The intraoral scanner system used in this study was iTero Element 2 (Align Technologies, San Jose, California, USA), carried out by a single operator following the manufacturer's instructions. Whole maxillary and mandibular arches were initially scanned. Subsequently, silicone bite indexes were placed at the anterior teeth. Once the position was achieved, the head of the intraoral scanner was placed on the right and left sides of the arches to record the interarch relationship.

Data Analysis

Comparing the centric relation first contact

Centric relation first contact (CR first contact) was identified at areas where the teeth were in contact with the opposing teeth (no interocclusal space) when the mandible was in the CR position. For the conventional centric relation bite registration, the CR first contact was identified and recorded by the perforation of bite registration using anatomical landmarks (Figure 1). For the digital recording of centric relation, the iTero software provided the occlusogram, an image of the casts with color-coded markings identifying the interocclusal space between the arches. According to the manufacturer, red represented no interocclusal space. In this way, the occlusogram showed the presence of CR first contact at similar anatomical sites on the virtual casts as on the bite records. Then, the CR first contact present at the same anatomical sites was recorded for further analysis.[24]

Comparing the Sites of close proximity

Sites of close proximity (SCP) were identified in areas where the interocclusal space was less than or equal to 200 µm. For the conventional centric relation bite registration, the bite registration and calibration molds made from the same PVS material of known thickness were placed together on a lightbox (Figure 2). A camera was set at a fixed distance to capture the image for further analysis using the ImageJ software program (U.S. National Institutes of Health, Bethesda, Maryland, USA). The image was converted from color to grayscale. Thresholding and particle analysis tools were used to identify areas of the bite records with a 200 µm thickness and represent them as red.[24,25]

For the digital recording of centric relation, the iTero software provided the occlusogram, an image of the casts with color-coded markings identifying the interocclusal space between the arches. According to

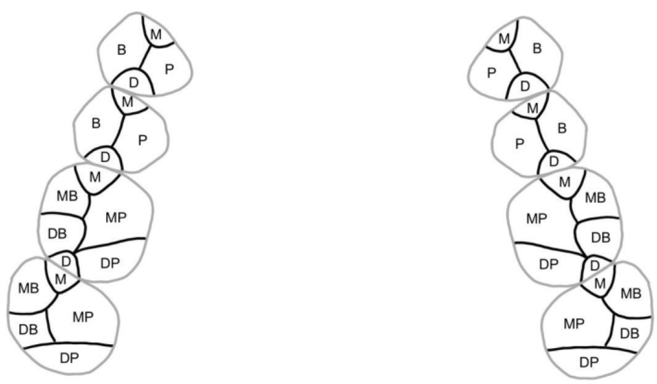

Figure 1 Anatomical landmarks based on the dental anatomy of the upper arch (B: Buccal, P: Palatal, M: Mesial, D: Distal, MB: Mesio-buccal, DB: Disto-buccal, MP: Mesio-palatal, DP: Disto-palatal)

Figure 2 PVS material in known thickness placed together on a lightbox (50, 100, 150, 200, 250, 300, 350 µm)

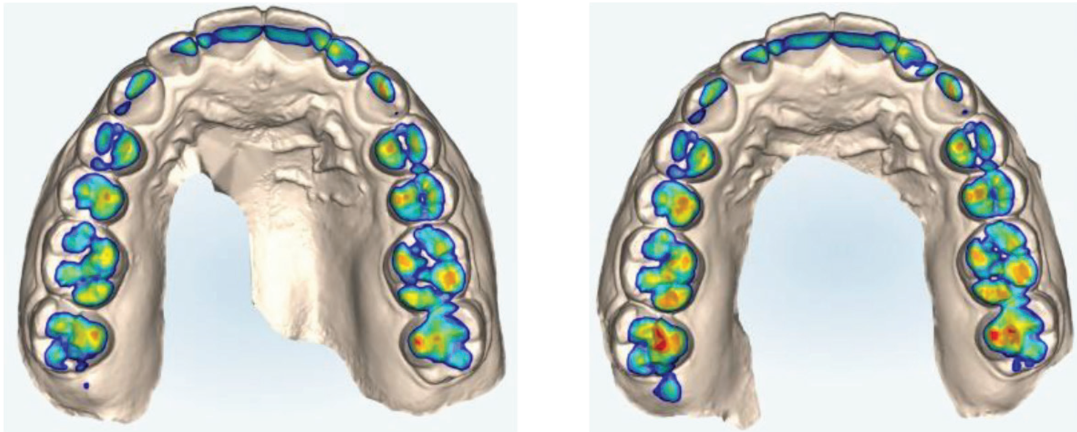

Figure 3 Occlusogram of two recordings generated by iTero software (Left: the first visit, Right: the second visit)

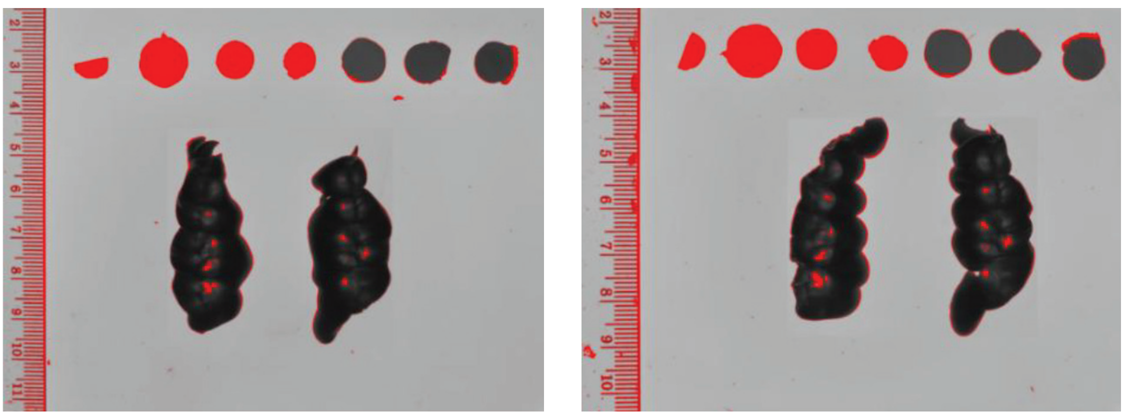

Figure 4 Trans-illuminated PVS bite records (analyzed at 200 μm)

the manufacturer, red represented no interocclusal space, orange represented 0 to 200 μm of interocclusal space, and yellow and other colors represented greater than 200 μm. In this way, the occlusogram showed the presence or absence of SCP at similar anatomical sites on the virtual casts as those on the bite records. The occlusogram was then captured for further analysis.

Statistical Analysis

The data were analyzed using IBM SPSS Statistics 28 (IBM Corp, United States) at a 5 % significance level. The difference in CR first contact between the two groups was determined using McNemar's test. The trueness of the intraoral scans was analyzed by comparing the measurements with the control. Repeatability was tested through the measurements of repeated scans using Cohen's Kappa Statistic.

Results

A total of 30 subjects were recruited for this study. One of them was withdrawn from the experiment due to inability to complete the second visit in time. So, there were 29 subjects for the analysis. An example of recorded CR first contact and site of close proximity in each subject was shown in Figure 3 and Figure 4. The results were summarized in Table 1 and 2.

Table 1 McNemar's test was used to evaluate trueness in identifying CR first contact and SCP.

Trueness (McNemar's Test)		*P* value
CR first contact	First Conventional Recording vs. First Digital Scan	< 0.001
	Second Conventional Recording vs. Second Digital Scan	< 0.001
Site of close proximity	First Conventional Recording vs. First Digital Scan	< 0.001
	Second Conventional Recording vs. Second Digital Scan	0.027

Table 2 Cohen's kappa statistic was used to assess the repeatability.

Repeatability		Kappa value
CR first contact	conventional bite registration	0.860
	iTero digital recordings	0.707
Site of close proximity	conventional bite registration	0.880
	iTero digital recordings	0.865

The trueness of identifying centric relation (CR) first contact was evaluated using McNemar's test. The comparison between the two conventional recordings of CR obtained by the operator on different visits showed no significant difference ($P = 0.118$), indicating consistency in identifying CR first contact between the two conventional recordings. However, significant discrepancies were observed when comparing the first conventional bite registration with the first scan (iTero) ($P < 0.001$) and the second conventional bite registration with the second scan (iTero) ($P < 0.001$). This suggests that the digital recordings obtained with the iTero scanner were significantly different from the conventional method in identifying CR first contact.

For identifying sites of close proximity (SCP), McNemar's test also showed significant differences. The comparison between the first conventional recording and the first scan (iTero) yielded a P value of < 0.001, indicating a significant discrepancy in SCP detection between the two methods. The comparison between the second conventional recording and the second scan (iTero) showed a smaller but still statistically significant difference ($P = 0.027$).

In terms of repeatability, the Cohen's kappa statistic was used to assess the consistency of those methods. For the conventional bite registration, the kappa value for identifying CR first contact was 0.860, indicating strong agreement, while the kappa for identifying SCP was higher at 0.880, reflecting strong agreement. For the iTero digital recordings, the repeatability was similar. The kappa value for CR first contact was 0.707, indicating moderate agreement. The repeatability for identifying SCP with the iTero scanner was also higher, with a kappa value of 0.865, reflecting strong agreement.[26]

Discussion

This study aimed to assess the accuracy of digital recordings of centric relation obtained from an intraoral scanner by quantitatively comparing occlusal contacts in terms of both trueness and repeatability. Based on the results obtained in this study, the hypothesis stating that multiple digital recordings of centric relation obtained from an intraoral scanner can identify the same CR first contact consistently can be accepted. However, discrepancies in trueness were observed, particularly when compared to conventional methods.

The accuracy for full arch dentate scans and virtual interocclusal records has been previously evaluated.[20] A systematic review by Shadid R. provided information about the accuracy of static virtual articulation. However, it presented some limitations due to the small number of clinical studies. Most of them used three-dimensional laboratory scanners to digitize the casts rather than an intraoral scanner.[21] The use of intraoral scanning for recording CR is a new technique and few studies have investigated the reliability or validity of CR bite registration using an intraoral scanner.[15,22] One of them only purposed a technique for direct digital recording of CR using an intraoral scanner without accuracy comparison.[15,22] Though another one[22] provided statistical comparison of accuracy with model superimposition and concluded that the iTero produced the best trueness and precision compared with other scanners, it included only a single dentate participant, and only one CR recording technique was measured without reliability test.

The accuracy of identifying CR first contact revealed significant differences between the iTero digital scans and conventional methods, with McNemar's test showing P values of less than 0.001 for both comparisons. These results suggest that the CR first contact identified by the iTero scanner differs significantly from those obtained using conventional methods. Previous studies have also reported similar challenges when comparing digital scanners with conventional methods, suggesting that while digital methods offer consistency, their accuracy in replicating conventional CR may vary due to factors such as scanner algorithms and operator technique.[24]

The repeatability of the methods was analyzed using Cohen's kappa statistic.[26] Conventional bite registration showed strong agreement for identifying CR first contact (kappa = 0.860) and for identifying sites of close proximity (SCP) (kappa = 0.880). In comparison, iTero recordings demonstrated slightly lower repeatability. The Kappa value for CR first contact was 0.707, indicating moderate agreement, but not as strong as the conventional bite registration. For SCP, the iTero scanner showed a Kappa value of 0.865, which was comparable to the conventional method. While the precision for SCP detection was high and nearly matched the performance of the conventional approach, the slightly lower Kappa value for CR first contact suggests that digital scans might have more variability in capturing this specific aspect of the centric relation.

According to the present results, factors such as digital scanning technology, algorithms, operator skill, scanning protocols, data collection, and patient-related variables may contribute the reduced repeatability of the intraoral scanner. In bite registrations, intraoral scanners have demonstrated repeatability in capturing the location and size of occlusal contacts. However, challenges arise in accurately measuring occlusal contact intensities. Wong et al. identified interocclusal distortions, with positive values potentially leading to hyper-occluded CAD-CAM restorations and negative values indicating distortions.[13] In that study, the authors credited these differences to potential flaws in the scanner software algorithm, which serves to match the maxillary and mandibular arches together. Furthermore, the researchers pointed out that the observed interocclusal distortion could be attributed to inaccuracies within the software, encompassing the entire sequence of image capturing, stitching, and postprocessing capabilities. This dependence on software-based processes may also provide insight into the diminished level of agreement observed in the study.[13]

The potential variation in bite force among participants could be a confounding factor for occlusal contact intensity readings during the study. The strategic decision to undertake an in vivo study with participants not only increased the clinical relevance of the findings but also presented a greater challenge in achieving thorough standardization of participant bite force.[27] Out of all the clinical studies within the dentate group, only a single study instructed patients to sustain the intercuspal jaw position while applying a consistently light occlusal force, achieved through the utilization of electromyographic feedback.[28]

As the intraoral scanner gathers data by navigating a relatively small camera through the curved arch, it undergoes a process of repeated analysis and stitching of scanned surface fragments to construct the overall shape, inevitably resulting in distortion. Flugge conducted a comparative analysis of digital impressions captured with the iTero intraoral scanner and desktop scanners, revealing that extraoral scan data exhibited greater accuracy than intraoral data. Challenges arising from the presence of saliva, reflections from teeth and surrounding tissues, and movements of both patients and operators' hands during scanning contribute to uncertainties, deformations, and ultimately introduce errors into the final dataset.[29]

Limitations of the present study include the variability associated with clinical studies, making it challenging to standardize occlusal force among participants. Additionally, the sample size of 29 healthy participants may not fully represent the diversity of anatomical variations and clinical conditions encountered in broader dental practice. A more extensive and diverse participant pool would enhance the generalizability of the study's findings. Also, the study's emphasis on a single intraoral scanner model (iTero) might limit the generalizability of the findings to other scanner brands with potentially distinct performance characteristics. A comparative analysis involving multiple scanner models would contribute to a more comprehensive evaluation of intraoral scanner reliability. In addition, the accuracy using in this study compared the appearance of anatomical landmark which cannot reflect the overall clinical maxilla-mandibular accuracy. Overall model superimposition with bite registration analyzing by the discrepancy at each dimension should be performed in the future.

Only one investigator is involved in identifying the contact areas in this study. It would be beneficial if the data is analyzed by two or more independent investigators from diverse specialties to investigate the variability between clinicians in terms of interpreting occlusal contacts and clearances in further study. Furthermore, the study investigates static occlusal relationships with no simulation of excursive movements. Therefore, it is advised that further research explore virtual articulators and inter-occlusal records in protrusive and laterotrusive positions.

These results suggest that, while digital methods may offer practical benefits, clinicians should be aware of the discrepancies in CR identification when transitioning from conventional to digital techniques. However, the digital dental field is rapidly evolving, with continuous advancements in software and hardware for intraoral scanners. Regular upgrades may be necessary to keep up with improvements in accuracy and efficiency, as well as to leverage new features that enhance functionality. Furthermore, the incorporation of dimensionally stable bite registration materials, such as ideal self-cured acrylic that exhibits no dimensional changes during polymerization, in conjunction with digital methods may enhance treatment outcomes.

As dentistry progresses into the digital era, understanding the capabilities and limitations of intraoral scanners becomes crucial. The results of this study may inform practitioners about the efficacy of this technology, potentially influencing its integration into routine dental procedures. Ultimately, the successful incorporation of intraoral scanners in centric relation recording could lead to improved efficiency, reduced chair time, and enhanced overall patient experience.

Conclusion

While the repeatability of both methods showed similar acceptable agreement, the trueness of identifying CR first contact and SCP was better in conventional bite registration method.

Author contributions

RL: Methodology, Data collection, Software analysis, Writing-Original Draft; NN: Conceptualization, Methodology, Writing-Review & Editing, Resource, Supervision, Project administration, Funding acquisition.

Ethical statement

This research protocol was approved by the Human Ethics Committee of the Faculty of Dentistry, Chulalongkorn University (Ethical Approval Number: HREC-DCU 2023-015).

Disclosure statement

The authors have no conflicts of interest.

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References

1. The glossary of prosthodontic terms 2023:10th ed. J Prosthet Dent 2023;130(4 Suppl 1):e1-3.
2. Goldstein GR. Centric relation: a needed reference position. J Prosthodont 2023;32(6):482-8.
3. Becker CM, Kaiser DA, Schwalm C. Mandibular centricity: centric relation. J Prosthet Dent 2000;83(2):158-60.
4. Galeković NH, Fugošić V, Braut V, Ćelić R. Reproducibility of centric relation techniques by means of condyle position analysis. Acta Stomatol Croat 2017;51(1):13-21.
5. The glossary of prosthodontic terms: 9th ed. J Prosthet Dent 2017;117(5s):e1-105.
6. Wasinwasukul P, Thongudomporn U, Promsawat M. Comparison of masticatory muscle effort when chewing on an anterior bite plane fabricated from hard and soft materials. Thai J Orthod 2024;14(2):17-27.
7. Kattadiyil MT, Alzaid AA, Campbell SD. What materials and reproducible techniques may be used in recording centric relation? best evidence consensus statement. J Prosthodont 2021;30(S1):34-42.
8. Anup G, Ahila SC, VasanthaKumar M. Evaluation of dimensional stability, accuracy and surface hardness of interocclusal recording materials at various time intervals: an in vitro study. J Indian Prosthodont Soc 2011;11(1): 26-31.
9. Keshvad A, Winstanley RB. Comparison of the replicability of routinely used centric relation registration techniques. J Prosthodont 2003;12(2):90-101.
10. Kantor ME, Silverman SI, Garfinkel L. Centric-relation recording techniques—a comparative investigation. J Prosthet Dent 1972;28(6):593-600.
11. de Moraes Melo Neto CL, Dos Santos DM, de Magalhães Bertoz AP, Moreno ALM, Goiato MC. Comparison of techniques for obtaining centric relation based on the reproducibility of the condylar positions in centric relation-a systematic review. Eur J Dent 2022;16(2):251-7.
12. Tejo SK, Kumar AG, Kattimani VS, Desai PD, Nalla S, Chaitanya KK. A comparative evaluation of dimensional stability of three types of interocclusal recording materials-an in-vitro multi-centre study. Head Face Med 2012;8:27.
13. Wong KY, Esguerra RJ, Chia VAP, Tan YH, Tan KBC. Three-dimensional accuracy of digital static interocclusal registration by three intraoral scanner systems. J Prosthodont 2018;27(2):120-8.
14. Dwivedi A, Maru K, Sharma A. A comparative evaluation of three dimensional accuracy of different types of interocclusal recording materials - an in vitro study. Med Pharm Rep 2020;93(3):280-6.
15. Radu M, Radu D, Abboud M. Digital recording of a conventionally determined centric relation: a technique using an intraoral scanner. J Prosthet Dent 2020;123(2):228-31.
16. Camcı H, Salmanpour F. A new technique for testing accuracy and sensitivity of digital bite registration: a prospective comparative study. Int Orthod 2021;19(3): 425-32.

17. Fraile C, Ferreiroa A, Romeo Rubio M, Alonso R, Pradíes Ramiro G. Clinical study comparing the accuracy of interocclusal records, digitally obtained by three different devices. Clin Oral Investig 2022;26(6):4663-8.
18. Jeamkatanyoo L, Suntornlohanakul S, Tianviwat S. Factors influencing orthodontic patient compliance with removable retainers. Thai J Orthod 2024;14(2):36-44.
19. Ruankaeo K, Suntornlohanakul S. Factors affecting patient satisfaction in orthodontic treatment. Thai J Orthod 2023;13(1):44-51.
20. DeLong R, Knorr S, Anderson GC, Hodges J, Pintado MR. Accuracy of contacts calculated from 3D images of occlusal surfaces. J Dent 2007;35(6):528-34.
21. Shadid R, Sadaqah N. Accuracy of virtual static articulation: a systematic review. Int J Prosthodont 2022;35(5):627–46.
22. Revilla-León M, Agustín-Panadero R, Zeitler JM, Barmak AB, Yilmaz B, Kois JC, et al. Differences in maxillomandibular relationship recorded at centric relation when using a conventional method, four intraoral scanners, and a jaw tracking system: a clinical study. J Prosthet Dent 2023.
23. Ngamjarus C, Chongsuvivatwong V, McNeil E. n4Studies: Sample size calculation for an epidemiological study on a smart device. Siriraj Med J 2016;68:160-70.
24. Abdulateef S, Edher F, Hannam AG, Tobias DL, Wyatt CCL. Clinical accuracy and reproducibility of virtual interocclusal records. J Prosthet Dent 2020;124(6):667-73.
25. Nalamliang N, Sumonsiri P, Thongudomporn U. Are occlusal contact area asymmetry and masticatory muscle activity asymmetry related in adults with normal dentition? CRANIO® 2022;40(5):409-17.
26. McHugh ML. Interrater reliability: the kappa statistic. Biochem Med (Zagreb) 2012;22(3):276-82.
27. Botsford KP, Frazier MC, Ghoneima AAM, Utreja A, Bhamidipalli SS, Stewart KT. Precision of the virtual occlusal record. Angle Orthod 2019;89(5):751-7.
28. Iwauchi Y, Tanaka S, Kamimura-Sugimura E, Baba K. Clinical evaluation of the precision of interocclusal registration by using digital and conventional techniques. J Prosthet Dent 2022;128(4):611-7.
29. Flügge TV, Schlager S, Nelson K, Nahles S, Metzger MC. Precision of intraoral digital dental impressions with iTero and extraoral digitization with the iTero and a model scanner. Am J Orthod Dentofacial Orthop 2013;144(3):471-8.

Thai Journal of Orthodontics

Original Article

Comparison of Cephalometric Measurements Obtained by Digital Software, Artificial Intelligence-Assisted Software and Manual Tracing

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Abstract

Background: Cephalometric analysis is essential in orthodontic treatment, gradually transforming from manual to digital tracing. With the advent of artificial intelligence (AI), landmark identification is now automated; offering precision, speed, and space efficiency. As machine errors may occur during landmark identification, it is necessary to verify whether digital software and AI-assisted software are reproducible and reliable when compared to manual tracing. **Objective:** To evaluate and compare the reproducibility and reliability of linear and angular measurements obtained by manual tracing, digital software and AI-assisted software. **Materials and methods:** Pretreatment lateral cephalograms of fifty patients were used. The same investigator conducted all analyses using manual tracing, digital software (AutoCeph) and AI-assisted software (WebCeph). Seventeen cephalometric parameters were constructed from 27 anatomical landmarks. Seven linear, nine angular and one ratio were taken from cephalometric analyses. Kruskal Wallis test was used to compare the difference in parameters obtained by three methods. Intraclass correlation coefficient (ICC) was used to determine reproducibility and reliability between linear and angular measurements obtained by three methods. **Results:** Statistically significant differences were observed for upper incisor to point A ($P = 0.02$), Jarabak's ratio ($P = 0.03$) and N perpendicular to point A ($P = 0.02$). ICC values for repeated cephalometric measurements were highest for AI-assisted software (> 0.98), followed by digital software (> 0.87) and manual tracing (> 0.86). **Conclusion:** Digital software and AI-assisted software perform good reproducibility and reliability compared to manual tracing.

Keywords: Artificial-Intelligence assisted software, Cephalometry, Digital software, Manual tracing

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Introduction

Cephalometric analysis is an essential diagnostic tool in treatment planning, valuable for evaluating treatment outcomes. Cephalometry was introduced in the field of orthodontics by Broadbent in USA and Hofrath in Germany in 1931.[1] Traditional methods involve manual tracing of anatomical landmarks which is time-consuming and prone to errors due to human fatigue. Ricketts who was a pioneer in cephalometric methodology advocated the use of computers because they could process large amounts of data into clinically useful information.[2] The advantages of using computer-assisted digital cephalometric analysis over traditional manual tracing include precision in measurement, decreased human error, enhanced speed and reduced physical storage space.[3-5] Recent advancements in digital cephalometry have offered a promising alternative, addressing many limitations of conventional techniques. AI has made the automatic identification of cephalometric landmarks easier through artificial neural networks and deep learning.[6,7] Popular digital tracing software include AutoCeph, Dolphin Imaging, Nemoceph, Quick Ceph, Vistadent, WebCeph, etc.

AutoCeph is a two-dimensional cephalometric analysis digital software that requires manual landmark identification. WebCeph is a two-dimensional AI-assisted cephalometric program that is programmed as a web-based platform for computer applications. The most unique feature of WebCeph is that it automatically identifies landmarks using AI. Reliability refers to the consistency in measurement at different times and under various conditions. In contrast, reproducibility refers to the consistency in measurements by the same or different examiners using the tool in the same way.

Previous studies have shown AutoCeph as a reliable tool for cephalometric tracing; however, its reliability has not been evaluated in our population. A study done by Yassir et al.[8] suggested that WebCeph still requires refinement and improvement due to poor landmark identification and measurement inconsistencies; therefore, a cephalometric analysis should be accompanied by visual checks by a clinician. Other studies suggest that WebCeph can be used for routine cephalometric analysis and clinical research.[9] This study highlights the reproducibility and reliability of manual, digital software and AI-assisted software for cephalometric analysis in Nepali samples.

Previous research has highlighted variability in landmark identification accuracy among different software, particularly with structures including point A, and porion, which can impact measurements.[5,10] This study aims to further evaluate these measurement difficulties including point A, and porion.

Materials and methods

This cross-sectional comparative study used a cephalogram of patients visiting the Department of Orthodontics, Kantipur Dental College Teaching Hospital & Research Center. The inclusion criteria was pretreatment cephalograms of patients aged 15-30 years with the availability of both good-quality film and digital files. The samples were excluded with craniofacial anomalies and distorted landmarks. The study period was from February to March 2024. Ethical clearance was obtained from the Institutional Review Committee. (Reference no: 03/24)

The sample size was calculated using data from the study done by Prince et al.[9]

$$N = \frac{2(Z\alpha+Z\beta)^2 \times (SD)^2)}{(d)^2}$$

Where, $Z\alpha = 1.96$ $Z\beta = 0.84$

Power = 80 %

d = Mean difference, SD = Standard deviation

Mean difference = 2.50, Standard deviation = 4.47,

$$N = \frac{2(Z\alpha+Z\beta)^2 \times (SD)^2)}{(d)^2} = \frac{2(7.84)^2 \times (4.47)^2)}{(2.50)^2} = 50$$

The same investigator (UG) marked twenty-seven anatomical landmarks on lateral cephalogram to evaluate cephalometric parameters: Downs' analysis,

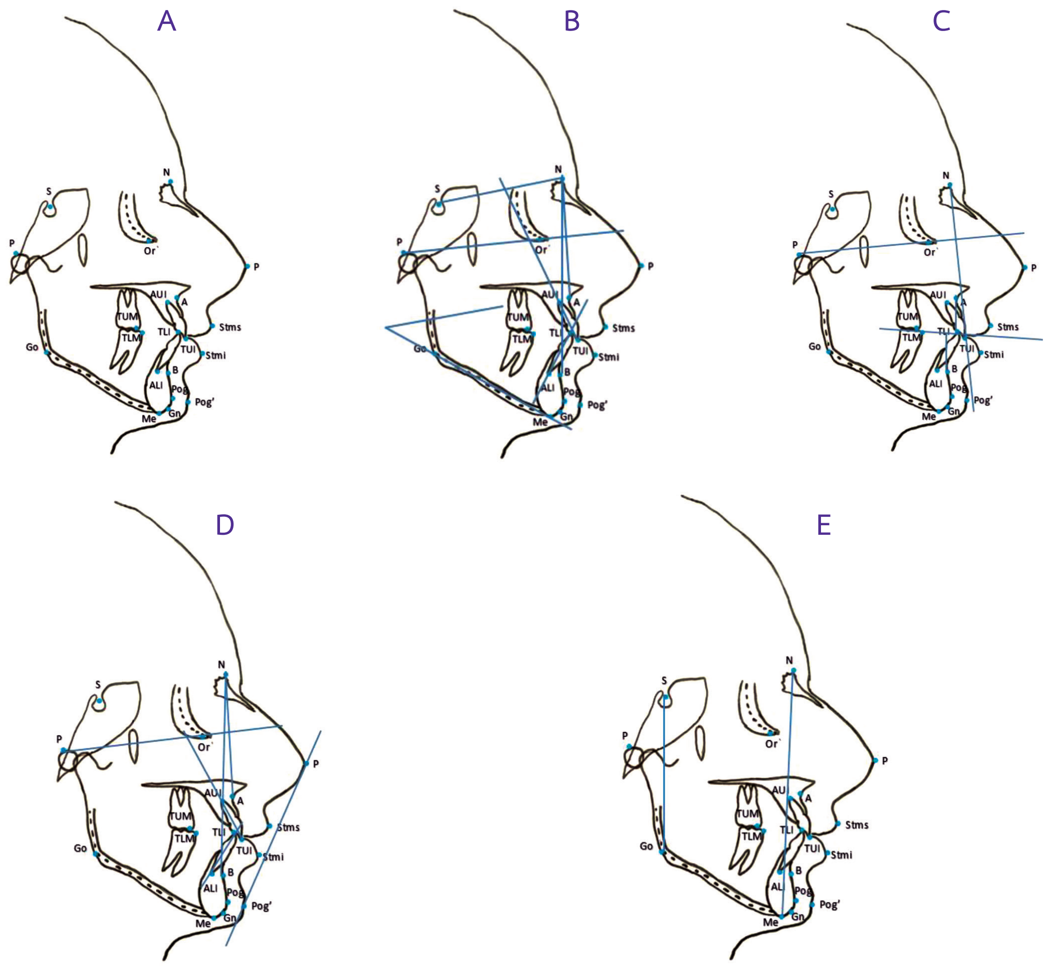

Figure 1 (A) Anatomical landmarks used in the study
(B) Angular parameters used in the study
(C, D) Linear parameters used in the study and
(E) Jarabak's ratio used in the study

Anatomic landmarks used in this study (Figure 1A)

1) Sella (S), 2) Nasion (N), 3) Point A (A), 4) Point B (B), 4) Porion (P), 5) Orbitale (Or), 6) Pogonion (Pog), 7) Gnathion (Gn), 8) Menton (Me), 9) Gonion (Go), 10) Tip of upper incisor (TUI), 11) Apex of upper incisor (AUI), 12) Tip of lower incisor (TLI), 13) Apex of lower incisor (ALI), 14) Tip of upper molar (TUM), 15) Tip of lower molar (TLM), 16) Pronasale (P), 17) Stomiom superious (Stms), 18) Stomiom inferious (Stmi), 19) Soft tissue pogonion (Pog')

Angular measurement (Figure 1B)

1) SNA, 2) SNB, 3) ANB, 4) Incisor mandibular plane angle (IMPA), 5) Go-Gn SN, 6) Facial axis, 7) Upper incisor to NA (U1 to NA), 8) Lower incisor to NB (L1 to NB), 9) Interincisal angle

Linear measurement (Figure 1C, 1D)

1) N perpendicular to point A (N per PtA), 2) N perpendicular to Pogonion (N per Pog), 3) Wits appraisal, 4) Upper incisor to NA (U1 to NA), 5) Lower incisor to NB (L1 to NB), 6) Upper lip to E plane (UL to E), 7) Lower lip to E plane (LL to E)

Ratio (Figure 1E)

Jarabak's ratio: Ratio of posterior facial height/anterior facial height multiplied by 100, where posterior facial height is measured from Sella to Gonion and anterior facial height is measured from Nasion to Menton.[11]

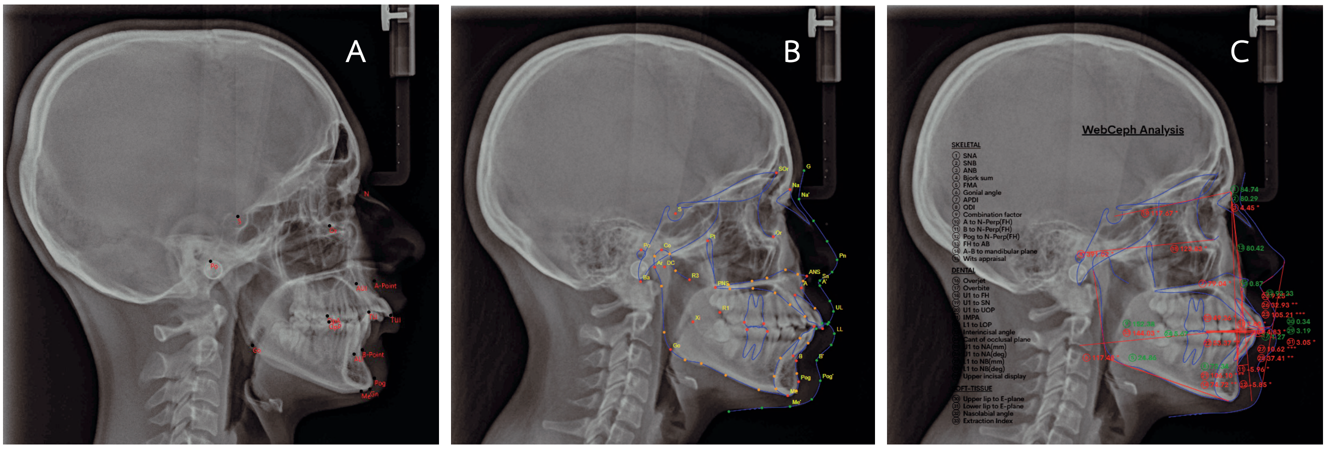

Figure 2 (A) Landmark identification in AutoCeph
(B) Automatic landmark identification with AutoCeph
(C) Automatic linear and angular measurement with WebCeph

Steiner's analysis, Tweed's analysis, McNamara analysis, Wits appraisal, and Jarabak's ratio. Seventeen cephalometric parameters were constructed from 27 anatomical landmarks, comprising 7 linear, 9 angular parameters, and 1 ratio (Figure 1 A-E). All linear and angular measurements for the manual tracing method were recorded using a lead pencil on acetate paper using a millimeter ruler and a cephalometric protractor. For bilateral anatomical landmarks that do not overlap an average of the two landmarks was used and for rotated incisors tracing was done by visualizing the tooth's position that most accurately reflects the tooth's true position.

Landmark identification for AutoCeph version 1.1.2 (CSIR-Cental Scientific Instruments Organisation (CSIR-CSIO), Chandigarh, India) was carried out using a mouse-controlled cursor. For bilateral landmarks, an average of the two landmarks was used and was marked by the cursor on the software as shown in Figure 2A. The digital films were calibrated by digitizing two points (10 mm) on the ruler. For WebCeph version 2.0.0 (AssembleCircle Inc., Seoul, South Korea), AI automatically identified and digitalized the landmarks (Figure 2B). Image calibration was done with a guide ruler size of 10 mm which was marked between two points. After landmark identification, various parameters were generated by both the software as shown in Figure 2C. Only ten cephalograms were analyzed daily to avoid human errors. For bilateral landmarks and rotated incisors, the software algorithm locates the landmarks. A visual inspection was performed to identify any deviations in anatomical landmarks, which were subsequently corrected as necessary. Ten radiographs were randomly selected and retraced digitally and manually after ten days to test intra-observer reliability.[9]

Data analysis was performed using SPSS version 20 (IBM Crop., Armonk, NY, USA). Data distribution was not normal as shown by the Shapiro-Wilk test. Kruskal Wallis test was used to compare linear and angular measurements for three different cephalometric tracing methods. Further Post hoc Dunn test was done among the statistically significant parameters. Ten radiographs were randomly selected to evaluate the intra-class reliability of each tracing technique, and the ICC for repeated cephalometric measurements was calculated (where ICC > 0.75 showed good agreement).[9] The level of significance was set as $P < 0.05$.

Results

When a comparison of linear and angular measurements of digital software, AI-assisted software and manual tracing was done, there was a statistically significant difference for three parameters, upper incisor to point A (P = 0.03), N perpendicular to point

Table 1 Comparisons of linear and angular measurements of manual, digital and AI-assisted software tracing using the Kruskal Wallis test

Variables	Mean values and standard deviation of cephalometric parameters			*P* value
	Manual	Digital software	AI-assisted software	
SNA (degree)	82.39 ± 4.23	83.05 ± 4.09	83.36 ± 4.21	0.50
SNB (degree)	80.61 ± 4.62	80.74 ± 4.40	80.76 ± 4.66	0.95
ANB (degree)	1.78 ± 3.20	2.30 ± 3.18	2.60 ± 3.31	0.31
IMPA (degree)	91.62 ± 10.74	92.61 ± 8.52	94.42 ± 8.48	0.44
Go-Gn SN (degree)	32.10 ± 9.85	30.76 ± 6.11	29.53 ± 6.58	0.39
U1 to NA (degree)	30.44 ± 9.21	28.42 ± 6.86	26.44 ± 6.41	0.02*
L1 to NB (degree)	24.86 ± 8.04	25.84 ± 7.12	25.92 ± 7.03	0.78
Interincisal angle (degree)	122.12 ± 12.11	123.84 ± 12.39	125.60 ± 11.67	0.37
Facial angle (degree)	85.89 ± 5.02	85.26 ± 11.35	88.11 ± 4.73	0.13
N per PtA (mm)	-2.34 ± 4.40	-1.80 ± 4.60	-0.16 ± 3.66	0.02*
N per Pog (mm)	-6.49 ± 8.72	-6.27 ± 9.43	-3.05 ± 7.90	0.11
Wits appraisal (mm)	0.67 ± 3.82	2.65 ± 13.70	1.45 ± 4.23	0.64
Jarabak’s ratio	66.27 ± 6.63	66.80 ± 6.20	69.42 ± 6.41	0.03*
U1 to NA (mm)	7.12 ± 3.75	6.28 ± 5.94	5.47 ± 2.80	0.07
L1 to NB (mm)	5.35 ± 2.81	5.83 ± 4.05	5.67 ± 2.51	0.71
UL to E (mm)	-0.77 ± 3.50	-1.48 ± 3.70	-1.01 ± 3.50	0.52
LL to E (mm)	0.95 ± 3.30	0.86 ± 3.42	0.80 ± 3.20	0.91

*Statistically significant at $P < 0.05$

Table 2 Post hoc Dunn test for the comparison of parameters in each group

Variables	Tracing methods	*P* value
U1 to NA	Manual vs AutoCeph	0.60
	Manual vs WebCeph	0.02*
	AutoCeph vs WebCeph	0.48
N per PtA	Manual vs AutoCeph	1.00
	Manual vs WebCeph	0.02*
	AutoCeph vs WebCeph	0.18
Jarabak’s ratio	Manual vs AutoCeph	1.00
	Manual vs WebCeph	0.03*
	AutoCeph vs WebCeph	0.21

*Statistically significant at $P < 0.05$

Table 3 ICC of cephalometric parameters among manual digital software and AI-assisted software to assess reproducibility

Variables	ICC
SNA (degree)	0.99
SNB (degree)	0.99
ANB (degree)	0.99
IMPA (degree)	0.99
Go-Gn SN (degree)	0.99
U1 to NA (degree)	0.97
L1 to NB (degree)	0.98
Interincisal angle (degree)	0.97

Variables	ICC
Facial angle (degree)	0.98
N per PtA (mm)	0.97
N per Pog (mm)	0.99
Wits appraisal (mm)	0.88
Jarabak's ratio	0.99
U1 to NA (mm)	0.86
L1 to NB (mm)	0.99
UL to E (mm)	0.97
LL to E (mm)	0.92

ICC = Intraclass correlation coefficient

Table 4 ICC of repeated cephalometric measurements to assess the reliability

Variables	Intraclass Correlation Coefficient (ICC)		
	Manual	Digital software	AI-assisted software
SNA (degree)	0.94	0.99	0.99
SNB (degree)	0.97	0.98	0.99
ANB (degree)	0.98	0.98	0.99
IMPA (degree)	0.95	0.99	0.99
Go-Gn SN (degree)	0.97	0.98	0.99
U1 to NA (degree)	0.86	0.87	0.99
L1 to NB (degree)	0.90	0.92	0.98
Interincial angle (degree)	0.98	0.98	0.99
Facial angle (degree)	0.93	0.95	0.98
N per PtA (mm)	0.87	0.96	0.99
N per Pog (mm)	0.88	0.90	0.98
Wits appraisal (mm)	0.89	0.95	0.99
Jarabak's ratio	0.90	0.90	0.99
U1 to NA (mm)	0.92	0.98	0.99
L1 to NB (mm)	0.88	0.97	0.99
UL to E (mm)	0.98	0.95	0.94
LL to E (mm)	0.97	0.93	0.98

ICC = Intraclass correlation coefficient

A (P = 0.03) and Jarabak's ratio (P = 0.03). The other cephalometric parameters did not show a significant difference. Descriptive statistics of linear and angular measurements of manual, digital software and AI-assisted software are shown in Table 1. Comparisons of linear and angular measurement of manual, digital software and AI-assisted software tracing using the Kruskal Wallis test are shown in Table 1. Post hoc Dunn test was done for statistically significant parameters: U1 to NA ($P < 0.01$), N per PtA ($P < 0.00$), and Jarabak's ratio ($P < 0.00$) as shown in Table 2. All ICC values of repeated measurement to assess reliability showed ICC > 0.86 as shown in Table 3. ICC of repeated cephalometric measurements showed the highest ICC value for AI-assisted software (ICC > 0.98), followed by digital software (ICC > 0.87) and manual tracing (ICC > 0.86) as shown in Table 4.

Discussion

This study showed that both digital software (AutoCeph) and AI-assisted software (WebCeph) demonstrated good reproducibility and reliability compared to manual tracing. The ICC showed that the level of agreement was high for AI-assisted software (ICC > 0.98) followed by digital software (ICC > 0.87) which is similar to study done by Prince et al.[9] Since the finding from intra-examiner statistics showed ICC > 0.98 for AI-assisted software, it is reliable to be used as a cephalometric tool which is similar to the study by Hwang et al.[12] However study done by Yassir et al.[8] Showed that due to poor landmark identification and inconsistency measurement, WebCeph should be used with caution and accompanied by visual checks by clinicians. This discrepancy may be due to the difficulty for AI algorithms in WebCeph to consistently identify complex anatomical landmarks. ICC of repeated cephalometric parameters to assess reproducibility showed that ICC > 0.85 for three tracing methods which showed good agreement (ICC > 0.75). A slightly lower value of ICC for Wits appraisal and upper incisor to NA linear measurement (ICC < 0.90) is due to difficulty in landmarks identification (point A and point B), as shown by Santora et al.[13]

The inter-examiner error is greater than the intra-examiner error in accordance to the study done by Sayinsu et al.[14] and Kunz et al.[15] A single observer carried out landmark identification, tracing, and measurement in this study. Reliability for digital software (ICC > 0.87) is higher than manual tracing (ICC > 0.86) for all of the measured parameters, suggesting that digital software is a reliable alternative for cephalometric analysis which is similar to the result shown by Mahto et al.[4] The use of cephalometric software diminishes the errors that occur during manual tracing.[16-17]

The parameters including point A perpendicular to NA, upper incisor to point A and Jarabak's ratio showed significant differences between WebCeph and manual tracing, as determined by the Dunn test. This may be due to inaccuracies in identifying landmarks, such as porion, using WebCeph as reported by Paul et al.[18] Difficulties in the detection of point A contribute to tracing variability with overlapping of ANS and upper incisors in two-dimensional projection in manual and WebCeph tracing as reported by Baig et al,[19] and Azeez et al.[10] The upper incisor to NA showed clinical and statistical differences exceeding two degrees, which could influence the decision about incisor retraction and torque management while the upper incisor to point A is within the acceptable range, posing no impact clinically.[12] Jarabak's ratio may be overestimated or underestimated by AI-assisted software making manual confirmation advisable for most of the cases.[20]

The application of digital and AI-assisted software for cephalometric analysis reduces the human errors that could arise during manual tracing. The process of digitization has become easy and rapid but for complex anatomical structures like rotated incisors, asymmetry manual correction is still required.[21] Additionally, AI algorithms can be modified to improve the accuracy of identifying complex landmarks. This study highlights the strength of digital and AI-assisted software, particularly for routine analyses.

This study was performed by a single investigator which limits the inter-examiner reliability. Further studies could be performed to evaluate inter-examiner reliability to visualize the performance of these three tracing methods across diverse geographical locations with varying radiographic settings. This study did not assess the time required for performing cephalometric analysis by these three tracing methods, future research could be performed to compare the time efficiency for these methods.

Additionally, digital software login delays and occasional software glitches impede efficiency, while AI-assisted software free version disrupts analysis with intrusive advertisements.

Conclusion

Both digital software and AI-assisted software demonstrated good reproducibility and reliability compared to the manual tracing method. Therefore, both the digital software and AI-assisted software can be used for routine cephalometric analysis.

Author contributions

UG: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation; RS: Conceptualization, Methodology, Software, Validation, Supervision, Formal analysis, Investigation, Resources, Data Curation; JD: Conceptualization, Methodology, Software, Validation, Supervision, Formal analysis, Investigation, Resources, Data Curation.

Ethical statement

This research protocol was approved by the Human Ethics Committee of the Kantipur Dental College Teaching Hospital and Research Center, Kathmandu University (No. of IRB - 03/24).

Disclosure statement

The authors have no conflicts of interest.

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References

1 Broadbent BH. A new x-ray technique and its application to orthodontia. Angle Orthod 1931;1(2):45-66.
2. Ricketts RM, Bench RW, Hilgers JJ, Schulhof R. An overview of computerized cephalometrics. Am J Orthod Dentofacial Orthop 1972;61(1):1-28.
3. Ali F. Assessing the reliability of computer aided digital cephalometric tracing versus manual cephalometric tracing-a comparative study. J Chem Health Risk 2024;14(1):237-50.
4. Mahto RK, Kharbanda OP, Duggal R, Sardana HK. A comparison of cephalometric measurements obtained from two computerized cephalometric software with manual tracings. J Indian Orthod Soc 2016;50(3):162-70.
5. Chen SK, Chen YJ, Yao CC, Chang HF. Enhanced speed and precision of measurement in a computer-assisted digital cephalometric analysis system. Angle Orthod 2004;74(4):501-7.
6. Subramanian AK, Chen Y, Almalki A, Sivamurthy G, Kafle D. Cephalometric analysis in orthodontics using artificial intelligence-a comprehensive review. BioMed Res Int 2022;2022(1):1880113.
7. Junaid N, Khan N, Ahmed N, Abbasi MS, Das G, Maqsood A, et al. Development, application, and performance of artificial intelligence in cephalometric landmark identification and diagnosis: a systematic review. InHealthcare 2022;10(12):2454.
8. Yassir YA, Salman AR, Nabbat SA. The accuracy and reliability of WebCeph for cephalometric analysis. J Taibah Univ Med Sci 2022;17(1):57-66.
9. Prince STT, Srinivasan D, Duraisamy S, Kannan R, Rajaram K. Reproducibility of linear and angular cephalometric

measurements obtained by an artificial-intelligence-assisted software (WebCeph) in comparison with digital software (AutoCeph) and manual tracing method. Dental Press J Orthod 2023;28(1):1-21.

10. Azeez MS, Surji FF, Kadir OS, Karim R. Accuracy and reliability of WebCeph digital cephalometric analysis in comparison with conventional cephalometric analysis. World J Dent 2023;14(8):727-32.
11. Jarabak's JR, Fizzell JA. Technique and treatment with light-wire edgewise appliances. 2nd ed. St. Louis, MO: Mosby; 1972.p.1253.
12. Hwang HW, Park JH, Moon JH, Yu Y, Kim H, Her SB, et al. Automated identification of cephalometric landmarks: part 2—might it be better than human? Angle Orthod 2020;90(1):69-76.
13. Santoro M, Jarjoura K, Cangialosi TJ. Accuracy of digital and analogue cephalometric measurements assessed with the sandwich technique. Am J Orthod Dentofacial Orthop 2006;129(3):345-51.
14. Sayinsu K, Isik F, Trakyali G, Arun T. An evaluation of the errors in cephalometric measurements on scanned cephalometric images and conventional tracings. Eur J Orthod 2007;29(1):105-8.
15. Kunz F, Stellzig-Eisenhauer A, Widmaier LM, Zeman F, Boldt J. Assessment of the quality of different commercial providers using artificial intelligence for automated cephalometric analysis compared to human orthodontic experts. Am J Orthod Dentofacial Orthop 2023;29(1):1-6.
16. Baumrind S, Frantz RC. The reliability of head film measurements: 1. landmark identification. J Orthod 1971;60(2):111-27.
17. Trpkova B, Major P, Prasad N, Nebbe B. Cephalometric landmarks identification and reproducibility: a meta-analysis. Am J Orthod Dentofacial Orthop 1997;112(2):165-70.
18. Paul PL, Tania SM, Rathore S, Missier S, Shaga B. Comparison of accuracy and reliability of automated tracing android appwith conventional and semiautomated computer aided tracing software for cephalometric analysis–a crosssectional study. Int J Orthod Rehab 2022;13:39-51.
19. Baig N, Gyasudeen KS, Bhattacharjee T, Chaudhry J, Prasad S. Comparative evaluation of commercially available AI-assisted cephalometric tracing programs. BMC Oral Health 2024;24(1):1241.
20. Shafique HZ, Zaheer R, Jan A, Mughal AT, Shahid R, Ghaffar F, et al. Vertical skeletal changes after extraction and nonextraction orthodontic treatment. Eur J Dent 2023;17(1):227-33.
21. Meriç P, Naoumova J. Web-based fully automated cephalometric analysis: comparisons between app-aided, computerized, and manual tracings. Turk J Orthod 2020;33(3):142-49.

Original article

Clinical Accuracy of Structured-Light vs Active-Illumination Multi-View Stereo 3D Facial Scanners: A Comparative Study

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Abstract

Background: Three-dimensional facial scanners are widely used in medical and dental fields for diagnostics, treatment planning, and postoperative evaluations. While scanner specifications provide nominal accuracy, actual clinical accuracy may vary due to facial complexity. **Objective:** This study aimed to evaluate and compare the clinical accuracy of two 3D facial scanners with different technologies: the structured light system (Artec® Space Spider, Artec 3D, Luxembourg) and the active illumination multi-view stereo system (Lumio® 3D, Lumio 3D Corporation, Thailand). **Materials and methods:** Fourteen participants underwent simultaneous 3D facial scanning using both scanners. An examiner measured distances and displacements between imaginary lines defined by anatomical landmarks, both directly on the participants' faces and on their 3D models. Measurements were categorized into three groups and analyzed using one-way ANOVA and the Kruskal-Wallis test. Deviations in displacements and distances between each scanner's data and the direct measurements were evaluated using paired *t*-tests and Wilcoxon signed-rank tests ($P < 0.05$). **Results:** No statistically significant differences were found among the three measurement groups overall. However, a significant difference in displacement deviation was observed between the two scanners in the orbital and nasal regions. **Conclusion:** Artec® space spider and Lumio® 3D scanners showed no significant difference in facial scanning accuracy compared to the direct measurement method. However, significant discrepancies were noted in the eye and nose region, likely due to anatomical complexity and movement. These areas may require special attention for improved scanning precision.

Keywords: Facial scan, Accuracy, Structure light, Active illumination multi-view stereo

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Introduction

Orthognathic surgery is a procedure used to correct malocclusions and enhance facial esthetic. A precise extra-and intraoral examination is required for accurate surgical planning for the best results. In practice, facial measurements with a ruler or a Vernier caliper, as well as facial photographic analysis from various angles, are used. Unfortunately, these methods may result in discrepancies due to a variety of factors, such as different measures, low-quality measuring tools, or patients moving their faces during the examination. Furthermore, even if these two-dimensional photographs are recorded, they cannot be measured repeatedly, making data collection complicated.[1]

Modern dentistry and surgery have greatly benefited from technology, particularly the use of computers. Surgery planning and simulation using a three-dimensional computer system is known as computer-aided surgical simulation (CASS).[2] Real face measuring and photographic analysis have been substituted in the preoperative data gathering by three-dimensional data collection methods like 3D facial scans and extra- and intraoral scans. Moreover, the data can be measured as distance, representing surface based measurement, and displacement, representing straight line measurement. These two types of data are essential for various facial analyses in both 2D and 3D formats and are used in orthodontic treatment as well as bone and soft tissue surgery. These data are more precise and are independent of both individual measurements and other variables.[3,4] Additionally, the collected data can be continuously measured at any moment. The virtual surgical planning is more accurate when combined with the 3D skull model from computed tomography, which affects the surgical outcome in many ways, particularly the facial esthetic and patient satisfaction.[5,6]

On the market, 3D facial scanners come in a variety of systems and brands. Each one has a unique capture technique and a unique nominal accuracy, which is the accuracy determined by the factory. The majority of 3D scanners utilized in the medical field are non-contact systems including photogrammetry, active wavefront sampling, and structured light. Due to the fact that, unlike contact groups, they do not change an object's surface as a result of probe pressure.[7-9] Artec® Space Spider 3D (Artec 3D, Senningerberg, Luxembourg) is a non-contact scanner based on the Structured Light principle, which is widely used today. It has a light source and is equipped with a receptor on the scanner's body to pick up reflex light. The examiner may need some practice to adjust the distance between the subject and receptor because of the form of the handheld scanner. An average facial scan takes 5 to 10 minutes to complete.[10] Lumio®3D (Lumio 3D corporation, Bangkok, Thailand) is a brand-new 3D facial scanner from Thailand that features a desktop design and an active illumination multi-view stereo system. Multiple captures from 8-12 cameras in various positions are rendered to generate a 3D model. The scan should take between 2-3 minutes. These facial scanners have 0.05 and 0.10 millimeters of nominal accuracy, respectively.[11] Because the structure of a human face is more complex than that of a geometric object, the practical accuracy, or the accuracy used in practice, may differ from the nominal accuracy.[12]

This study's goal was to determine and compare the accuracy of two 3D facial scanners, the Artec® Space Spider 3D and Lumio®3D. This study may aid in selecting the appropriate facial scanner for medical use, enhance the performance of the surgeon, and lower unnecessary costs.[13-15]

Materials and methods

Study design

This study was a non-randomized clinical trial. The study was approved by the Human Research Ethics Committees of the Faculty of Dentistry, Prince of Songkla University (EC6402-013 and registered in the Thai Clinical Trials Registry (TCTR20210927005).

Sample size calculation was performed by G*Power 3.1 software (Heinrich Heine University Düsseldorf, Germany). Based on the study by Zhao YJ et al.,[12] an effect size were determined. Using a two-tailed *t*-test with a significance level (α) of 0.05 and a power ($1-\beta$) of 0.80, the minimum required sample size was calculated to be 12 participants. Accounting for a 20 percent potential dropout rate, the final sample size was increased to 14 participants. Two scanners, Artec® Space Spider (Artec 3D, Senningberg, Luxembourg) and Lumio® 3D (Lumio 3D corporation, Bangkok, Thailand) were the testing devices (figure 1).

Subjects

Participants aged between 18 and 50 years who voluntarily consented were included in the study. Individuals were excluded if they presented with head and neck infections, maxillofacial trauma, or dentofacial anomalies such as cleft lip and palate or hemifacial microsomia. Further exclusion criteria included inability to follow instructions during facial scanning, such as maintaining a still position with a neutral facial expression. Volunteers with excessive facial hair, facial tattoos, permanent cosmetic markings, or neurovascular conditions affecting facial movement were also excluded due to potential interference with scan accuracy.

The volunteers were informed about the details of the study and were consent and signed before enrollment.

Scanning and rendering the 3D facial models.

Participants were instructed to undergo scanning with both scanners in random order on the same day by the same examiner, while maintaining a relaxed head position and facial expression, keeping their eyes closed, and remaining still during the scan. Each scanner recorded five captures from each participant. The scanning time from the posture adjustment to the completion of the scanning process was recorded.

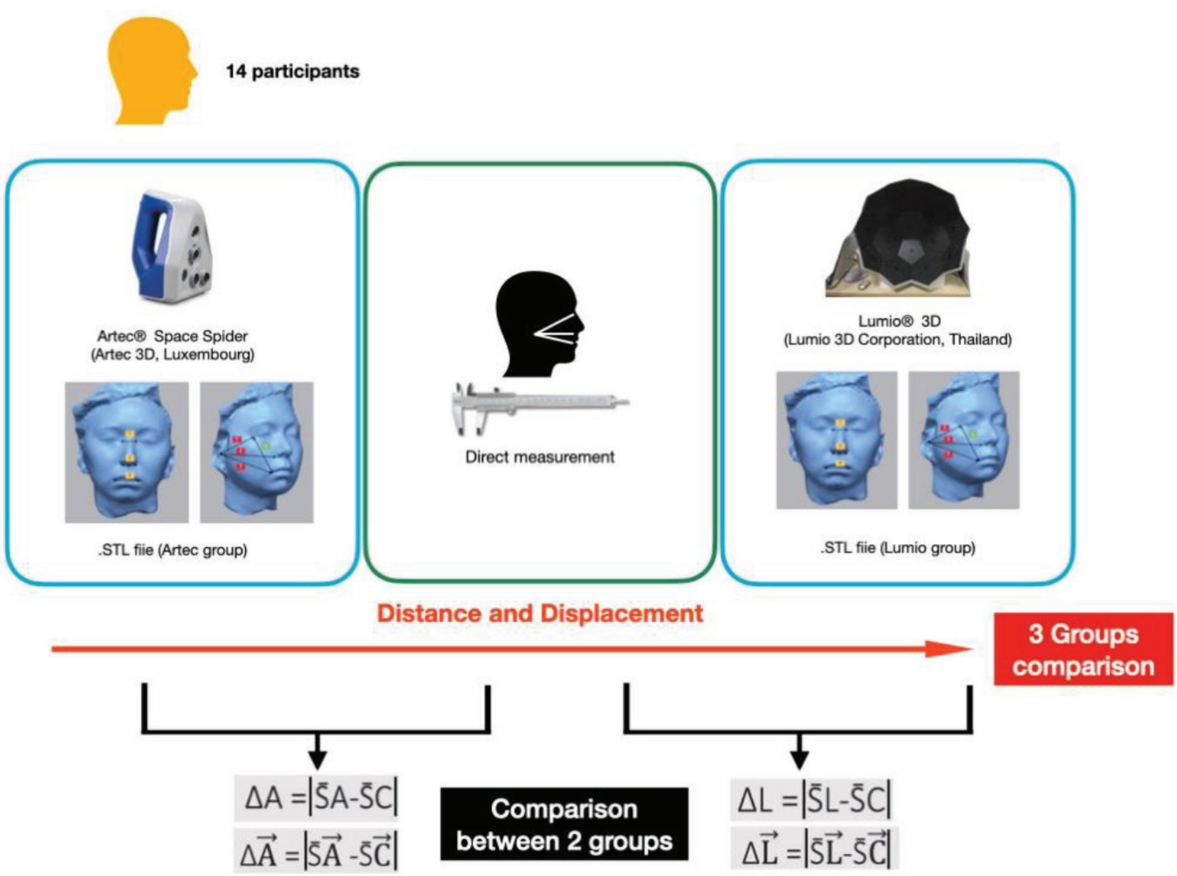

Figure 1 The study framework includes the scanning, measuring, and comparing of data.

The scanned images were rendered in the standard triangular language (STL) format.

Establishing and measuring anatomical landmarks

The imaginary lines on the frontal view and the right lateral view of the faces as shown in Figure 2 were measured. There were 3 horizontal lines on the frontal views. Line 1(Intercanthal line, IC) extended from the right to the left medial canthal points. Line 2 (Interalar line, IA) extended from the right to the left alar bases. Line 3 (Intercommissural line, IM) extended from lip commissures from right to left. There were 1 vertical line and 3 horizontal lines on the lateral of the face: Line 4, the vertical line (V), connected the right lateral canthal to the right lip commissure, Line 5 (Lateral canthus-tragus, LT) connected the right tragus to the right lateral canthal point, Line 6 (Alar-tragus, AT) was drawn from the right tragus to the right alar base, Line 7 (Lip commissure – tragus, MT) connected the right tragus to the right lip commissure (figure 2). The direct measurement of the distance (c) of each line was performed in millimeters by using dental floss attached to the surface of the face and calculated using a ruler with 1 decimal. The displacement ($\vec{c}$) of each line was measured in millimeters with 1 decimal by using a Vernier caliper. Each measurement was taken five times and calculated the average of distance and displacement.

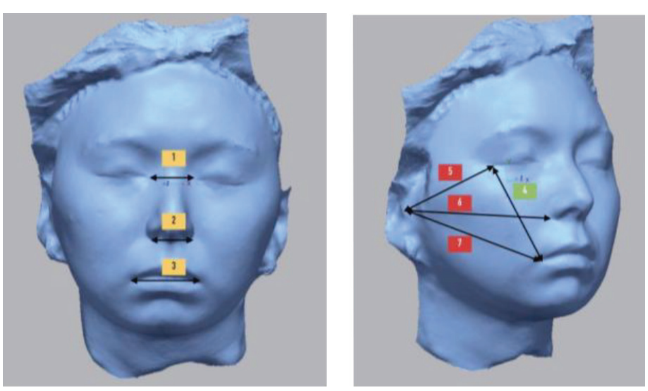

Figure 2 Actual faces and three-dimensional models both had seven lines placed on the frontal and lateral views.

3D model measurement

The 3D models were imported into Geomagic Control X version 2018.1.0 (3D Systems, Morrisville, NC, USA). The anatomical landmarks, representing actual facial measurements, were manually identified, and the seven designated imaginary lines were subsequently constructed. The distance of each line was measured using surface-based techniques, while the displacement was evaluated using straight-line measurements. The average of distance and displacement from the Artec group and the Lumio group were measured by a different examiner, who was blinded to the scanner source of each dataset and was independent of the examiner conducting the scans.

Statistical analysis

Demographic data and scanning times were analyzed using descriptive statistics. One-way ANOVA and the Kruskal-Wallis test were used to determine statistically significant differences among the direct measurement group, the Artec group, and the Lumio group, with a significance level set at P value < 0.05. The Scheffé test was planned for post hoc analysis to identify significant differences between individual pairs of groups. The amount of the deviation of distance and displacement in absolute value between the Artec group ($\Delta A, \Delta \vec{A}$), the Lumio ($\Delta L, \Delta \vec{L}$) and the direct measurement at each line was calculated and compared between 2 groups with the paired t-test and Wilcoxan signed-rank test. For the computation, SPSS Statistics (SPSS® 25.0, SPSS Inc.) was utilized. The study confirmed measurement reliability with an intraclass correlation coefficient of 0.91, assessed after one month.

Result

There were 14 participants, 12 females and 2 males, with a mean age of 29.57 ± 2.87 years. The average scanning time of Artec® Space Spider 3D scanner and Lumio®3D scanner is 95.86 ± 18.19 and

27.25 ± 7.76 seconds, respectively.

Although there was no statistically significant difference in distance and displacement among the three groups (Table 1 and Table 2), a significant difference was observed in the amount of displacement deviation for line 1 (Intercanthal line, IC) and line 2 (Interalar line, IA), as shown in Table 4. However, the difference in distance between the 2 groups was not statistically significant (Table 3).

Table 1 Distance values from direct Measurement, Artec, and Lumio Groups for Each Line.

Line	Measurement	Mean (SD)	Median (IQR)	Min-Max	95 % CI (lower, upper)	*P* value
Line 1 (IC)	Direct	40.00 (4.24)	39.70 (5.22)	31.10-46.90	37.55, 42.45	0.923[a]
	Artec	39.96 (3.53)	40.35 (4.41)	33.82-47.44	37.92, 42.00	
	Lumio	39.48 (3.58)	39.95 (5.34)	32.67-46.62	37.41, 41.55	
Line 2 (IA)	Direct	36.87 (4.33)	36.85 (5.63)	28.30-44.00	34.37, 39.37	0.895[a]
	Artec	37.18 (4.15)	37.33 (6.00)	30.32-44.34	34.79, 39.57	
	Lumio	37.60 (3.79)	37.77 (5.65)	30.22-41.76	35.41, 39.79	
Line 3 (IM)	Direct	58.48 (6.27)	59.75 (7.57)	41.50-67.30	54.86, 62.10	0.257[k]
	Artec	61.18 (6.19)	62.95 (7.25)	44.04-68.41	57.60, 64.75	
	Lumio	60.88 (5.67)	62.79 (8.54)	46.11-66.63	57.61, 64.15	
Line 4 (V)	Direct	75.33 (5.29)	74.95 (9.53)	68.70-85.00	72.27, 78.38	0.752[a]
	Artec	76.71 (5.23)	76.28 (6.89)	67.29-87.00	73.69, 79.73	
	Lumio	75.62 (4.65)	74.77 (6.34)	68.15-84.18	72.93, 78.30	
Line 5 (LT)	Direct	83.98 (5.67)	83.55 (7.78)	75.50 - 96.90	80.71, 87.25	0.745[a]
	Artec	82.43 (5.32)	81.20 (8.05)	75.76-94.59	79.36, 85.50	
	Lumio	83.16 (4.96)	81.85 (7.54)	75.33-93.47	80.29, 86.02	
Line 6 (AT)	Direct	121.99 (5.58)	122.20 (10.07)	112.40-129.40	118.76, 125.21	0.877[k]
	Artec	122.62 (4.57)	123.84 (6.85)	113.91-128.45	119.98, 125.26	
	Lumio	121.92 (4.55)	122.88 (5.31)	112.46-126.59	119.29, 124.55	
Line 7 (MT)	Direct	113.94 (5.38)	115.90 (9.15)	103.80-120.00	110.83, 117.05	0.909[k]
	Artec	113.51 (4.20)	114.46 (7.53)	105.88-119.54	111.08, 115.93	
	Lumio	113.39 (4.81)	114.60 (8.24)	104.88-120.46	110.62, 116.17	

[a] one-way ANOVA test

[k] Kruskul-Wallis test

IC = Intercanthal line, IA = Interalar line, IM = Intercommissural line, V = vertical line, LT = lateral canthus to tragus line, AT = Alar to tragus line, MT = Lip commissure to tragus line

Table 2 Displacement values from direct Measurement, Artec, and Lumio Groups for Each Line.

Line	Measurement	Min-Max	Mean	Median (IQR)	95 % CI (lower, upper)	*P* value
Line 1 (IC)	Direct	29.00-36.60	31.89 (1.96)	31.80 (2.13)	30.75, 33.02	0.097[a]
	Artec	28.14-36.29	32.10 (2.27)	32.01 (3.32)	30.79, 33.40	
	Lumio	29.67-38.29	33.56 (2.25)	33.89 (3.34)	32.26, 34.86	
Line 2 (IA)	Direct	24.00-35.00	31.11 (3.29)	32.00 (4.45)	29.21, 33.01	0.106[k]
	Artec	22.36-35.40	32.01 (3.48)	32.71 (3.69)	30.00, 34.02	
	Lumio	23.60-37.14	33.34 (3.56)	33.92 (3.46)	31.28, 35.39	
Line 3 (IM)	Direct	36.60-56.80	50.98 (4.87)	51.75 (5.03)	48.17, 53.79	0.484[k]
	Artec	42.26-56.14	52.16 (3.82)	52.48 (5.67)	49.96, 54.37	
	Lumio	40.96-57.13	52.53 (4.31)	53.36 (4.69)	50.04, 55.02	
Line 4 (V)	Direct	66.20-79.80	71.09 (4.30)	70.65 (6.48)	68.61, 73.58	0.455[k]
	Artec	67.02-70.47	72.50 (4.35)	72.02 (7.35)	69.99, 75.02	
	Lumio	67.59-80.56	72.51 (4.31)	71.58 (6.85)	70.02, 75.01	
Line 5 (LT)	Direct	72.00-82.70	76.61 (3.73)	76.45 (6.83)	74.46, 78.77	0.847[a]
	Artec	69.13-81.71	76.21 (3.63)	76.11 (5.29)	74.12, 78.31	
	Lumio	72.07-82.80	77.00 (3.47)	77.21 (5.21)	75.00, 79.01	
Line 6 (AT)	Direct	96.80-111.40	105.62 (4.62)	107.35 (6.28)	102.95, 108.29	0.594[k]
	Artec	96.04-110.96	105.64 (4.09)	107.01 (3.97)	103.28, 108.01	
	Lumio	97.24-113.72	106.93 (4.57)	107.67 (4.83)	104.29, 109.57	
Line 7 (MT)	Direct	97.10-109.90	104.63 (3.59)	105.30 (5.48)	102.56, 106.70	0.764[a]
	Artec	96.16-109.72	104.77 (3.55)	104.94 (4.88)	102.72, 106.82	
	Lumio	97.60-111.65	105.59 (4.00)	106.74 (5.22)	103.28, 107.89	

[a] one-way ANOVA test

[k] Kruskul-Wallis test

IC = Intercanthal line, IA = Interalar line, IM = Intercommissural line, V = vertical line, LT = lateral canthus to tragus line, AT = Alar to tragus line, MT = Lip commissure to tragus line

Table 3 Distance deviation of the Artec and Lumio Groups from the direct measurement (Control Group).

Line	Deviation value	Mean (SD)	Min-Max	Median (IQR)	95 % CI (lower, upper)	*P* value
Line 1 (IC)	Artec (ΔA)	1.87 (1.06)	0.27-3.57	1.98 (1.97)	1.26, 2.47	0.182[P]
	Lumio (ΔL)	2.33 (1.63)	0.10-5.01	1.95 (3.02)	1.39, 3.27	
Line 2 (IA)	Artec (ΔA)	1.14 (0.81)	0.13-2.65	0.90 (1.42)	0.67, 1.60	0.595[P]
	Lumio (ΔL)	1.27 (0.87)	0.01-2.77	1.34 (1.62)	0.77, 1.77	
Line 3 (IM)	Artec (ΔA)	3.05 (1.10)	1.08-4.91	3.00 (1.35)	2.42, 3.68	0.807[P]
	Lumio (ΔL)	2.95 (1.18)	0.30-4.61	3.24 (1.63)	2.27, 3.63	
Line 4 (V)	Artec (ΔA)	2.11 (1.12)	0.11-3.58	2.13 (1.65)	1.46, 2.75	0.292[P]
	Lumio (ΔL)	1.71 (0.99	0.17-3.28	1.69 (1.72)	1.14, 2.28	
Line 5 (LT)	Artec (ΔA)	1.64 (0.93)	0.18-3.54	1.50 (1.31)	1.10, 2.17	0.810[P]
	Lumio (ΔL)	1.57 (1.02)	0.35-3.43	1.21 (1.86)	0.98, 2.16	
Line 6 (AT)	Artec (ΔA)	2.01 (1.58)	0.01-6.15	1.85 (1.33)	1.10, 2.92	0.925[W]
	Lumio (ΔL)	2.11 (2.03)	0.06-6.59	1.66 (2.64)	0.93, 3.28	
Line 7 (MT)	Artec (ΔA)	1.62 (0.84)	0.09-2.72	1.71 (1.27)	1.13, 2.10	0.826[W]
	Lumio (ΔL)	1.54 (1.53)	0.26-5.29	1.12 (1.45)	0.66, 2.42	

[P] paired-t test
[W] Wilcoxan-signed rank test
IC = Intercanthal line, IA=Interalar line, IM = Intercommissural line, V = vertical line, LT = lateral canthus to tragus line, AT = Alar to tragus line, MT = Lip commissure to tragus line

Discussion

Three-dimensional facial scanner is commonly employed, particularly for capturing and assessing the proportions of the face before and after surgery. Due to the abundance of brands and systems on the market, the accuracy, convenience, realistic pricing, and scanning time should all be considered as selection criteria.[7] The accuracy of each scanner is impacted by the operating system, manufacturing processes, light source, light propagation, and light reflection.[16]

Although direct facial measurements using tools like Vernier calipers and fine-scale rulers are still commonly used in many hospitals, they are increasingly considered less precise due to potential human error. Previous research has demonstrated that stereophotogrammetry and structured-light system offers the higher accuracy in facial scanning.[17,18] However, the high cost of these scanners limits their accessibility and widespread use. Therefore, identifying a more affordable and accurate alternative to the direct measurement method would be highly beneficial for clinical practice.

This study aimed to compare the accuracy of the Artec® Space Spider 3D and Lumio® 3D scanners in capturing human facial images. The findings indicate that there is no statistically significant difference in both distance and displacement measurements between the two scanners and direct measurements taken from

Table 4 Displacement deviation of the Artec and Lumio Groups from the direct measurement (Control Group).

Line	Deviation value	Mean (SD)	Min-Max	Median (IQR)	95 % CI (lower, upper)	*P* value
Line 1 (IC)	Artec (ΔA→)	0.82 (0.71)	0.16-2.92	0.78 (0.77)	0.41, 1.23	0.006[W]
	Lumio (ΔL→)	1.74 (0.97)	0.14-3.55	1.82 (1.52)	1.18, 2.30	
Line 2 (IA)	Artec (ΔA→)	1.39 (0.70)	0.01-2.37	1.65 (1.05)	0.99, 1.79	0.035[W]
	Lumio (ΔL→)	2.30 (1.22)	0.07-3.63	2.91 (1.99)	1.59, 3.00	
Line 3 (IM)	Artec (ΔA→)	1.53 (1.47)	0.06-5.66	1.36 (1.62)	0.68, 2.38	0.683[W]
	Lumio (ΔL→)	1.66 (1.40)	0.05-4.36	1.19 (2.74)	0.85, 2.46	
Line 4 (V)	Artec (ΔA→)	1.50 (2.31)	0.14-9.28	0.73 (1.26)	0.17, 2.84	0.972[W]
	Lumio (ΔL→)	1.51 (2.11)	0.16-8.55	0.85 (1.01)	0.30, 2.73	
Line 5 (LT)	Artec (ΔA→)	1.23 (0.88)	0.01-2.87	1.31 (1.20)	0.72, 1.74	0.152[W]
	Lumio (ΔL→)	0.75 (0.62)	0.07-1.83	0.52 (1.17)	0.40, 1.11	
Line 6 (AT)	Artec (ΔA→)	1.35 (0.88)	0.33-3.12	1.39 (1.46)	0.84, 1.86	0.753[P]
	Lumio (ΔL→)	1.45 (1.02)	0.28-3.79	1.22 (1.66)	0.86, 2.04	
Line 7 (MT)	Artec (ΔA→)	1.22 (0.83)	0.12-2.92	1.00 (1.23)	0.74, 1.70	0.605[P]
	Lumio (ΔL→)	1.41 (0.83)	0.06-2.93	1.45 (1.08)	0.93, 1.89	

[P] paired-*t* test
[W] Wilcoxan-signed rank test
IC = Intercanthal line, IA = Interalar line, IM = Intercommissural line, V = vertical line, LT = lateral canthus to tragus line, AT = Alar to tragus line, MT = Lip commissure to tragus line

the human face. The results of this study are consistent with those of Zhao et al.,[12] which found no significant differences in the accuracy of three different facial scanner types: line laser, stereophotogrammetry, and structured light. Conversely, Amornvit and Sanohkan., discovered that the best accuracy is provided by a structured-light scanner, with stereophotogrammetry coming in second.[15]

When comparing the scanner measurements with the direct method, this study found significant differences in displacement at line 1 (IC) and line 2 (IA), which correspond to the orbital and nasal regions, respectively. These discrepancies can be attributed to several factors that affect the accuracy of facial scanning. According to the study of Zhao et al., the skin's surface characteristics, skin texture, reflectivity, roughness, presence of hair follicles and pores, as well as micro-movements caused by breathing, muscle twitching, emotional expression, and facial asymmetries, can all impact scan accuracy. Additionally, the scanning technique particularly the lighting system used, may influence involuntary facial movements.[12]

LED light emitted during scanning has been reported to induce blinking and facial movement, potentially leading to distortion in the captured data.[19] Different scanning systems use varying light emission patterns, which may have differing impacts on patient response. For example, the Lumio® 3D scanner emits a single flash of light during image capture, minimizing prolonged visual stimulation. In contrast, the Artec® Space Spider emits continuous flashes throughout the entire scanning process, which may increase the likelihood of blinking or subtle facial movements. These involuntary responses can lead to distortions, particularly in dynamic facial regions such as the eyes, thereby reducing the accuracy and reliability of the final 3D facial model.

The orbital and nasal regions present greater anatomical complexity compared to other areas of the face. These regions contain multiple slopes, skin creases, and undercut areas, which can pose challenges for optical scanning systems. Such complexity may reduce scanning accuracy due to difficulties in light reflection and surface detection. In contrast, a study by Zhao et al., reported high accuracy in facial scanning when using stereophotogrammetry and structured-light systems, particularly in the midface region. This improved performance was attributed to the facial contours in that area, which facilitated better registration across multiple image captures.[12]

The scanning time is one of the factors that influences accuracy. The Artec® space spider requires approximately four times as much Lumio® 3D, according to the study. The prolonged scanning time could affect the patient's tendency to move during the scanning. However, this study did not evaluate the relation between scanning time and accuracy. Additionally, the handheld design, which requires the user to move around the object at a limited distance, occasionally results in many captures that overlap. In the global registration step, multiple captures diminish precision.[20,21] Furthermore, since no headrest or stabilization device was used during the scanning procedure, slight head movements may have occurred during data acquisition. This was particularly relevant for scanners with longer scanning durations, such as the Artec® Space Spider, which may have contributed to reduced accuracy. Despite this potential limitation, no significant differences were observed among the three groups.

The study was carried out by photographing a human face with the muscle of facial expression active at all times, depending on emotion and external stimulation.[22] This introduces potential confounding variables that may affect the accuracy and consistency of the scans. To minimize such variables, the 3D-printed solid facial models were proposed. These models provide a stable and repeatable surface for evaluation, helping to control for muscle movement and facial expression.[15] However, while this approach improves standardization, it may involve higher costs and lacks direct applicability in routine clinical settings.

The accuracy of facial scanning is crucial, particularly for 3D planning in orthognathic surgery. Since soft tissue simulation significantly impacts treatment outcomes which are the primary concern for patients. The misalignment of the facial surface scan and the soft tissue profile can lead to discrepancies affecting both planning and outcomes. Not only the surgical planning, but the accurate facial profile documentation is also important to assess the treatment of patients undergoing orthognathic surgery or orthodontic treatment alone. Unlike 2D photos, which lack of surface texture and three-dimensional shape, 3D imaging provides a more comprehensive assessment of soft tissue changes.[23] From our study, these two 3D facial scanners are the appropriate tools for the treatments mentioned above. However, despite significant differences in the orbital and nasal areas, users should be cautious, particularly when measuring the degree of asymmetry between these areas.

This study was conducted on subjects who were not orthognathic surgery patients and generally exhibited a skeletal Class I relationship. In contrast, clinical cases, particularly in orthodontic treatment and orthognathic surgery, often involve patients with abnormal jaw relationships, asymmetry, and other conditions such as cleft lip and palate or hemifacial microsomia. These variations could potentially influence the results of the study.

For more applicable findings in clinical treatment, future research should include patients with abnormal skeletal and soft tissue frameworks. Additionally, further studies should compare the soft tissue profiles obtained from CBCT with the underlying bone structure to validate the results of this study. Moreover, the scanners can be utilized as a tool in research to evaluate treatment, particularly in orthodontic and orthognathic procedures.

Conclusion

Artec® space spider and Lumio® 3D scanners showed no significant difference in facial scanning accuracy compared to the direct measurement method. However, significant discrepancies were noted in the eye and nose region, likely due to anatomical complexity and movement. These areas may require special attention for improved scanning precision.

Author contributions

DS: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data Curation, Writing-Review & Editing, Visualization, Project administration, Funding acquisition; TW: Validation, Writing-Review & Editing, Visualization, Supervision; NT: Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing-Original Draft, Funding acquisition; KS: Writing-Review & Editing, Visualization

Ethical statement

The research protocol was approved by the Ethics Committee of the Faculty of Dentistry, Prince of Songkla University (No. EC6402-013).

Disclosure statement

The authors have no conflict of interest.

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References

1. Berlin NF, Berssenbrügge P, Runte C, Wermker K, Jung S, Kleinheinz J, et al. Quantification of facial asymmetry by 2D analysis - a comparison of recent approaches. J Craniomaxillofac Surg 2014;42(3):265-71.
2. Xia JJ, Shevchenko L, Gateno J, Teichgraeber JF, Taylor TD, Lasky RE, et al. Outcome study of computer-aided surgical simulation in the treatment of patients with craniomaxillofacial deformities. J Oral Maxillofac Surg 2011;69(7):2014-24.
3. Troulis MJ, Everett P, Seldin EB, Kikinis R, Kaban LB. Development of a three-dimensional treatment planning system based on computed tomographic data. Int J Oral Maxillofac Surg 2002;31(4):349-57.
4. Swennen GR, Schutyser F. Three-dimensional cephalometry: spiral multi-slice vs cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2006;130(3):410-6.
5. Scarfe WC, Li Z, Aboelmaaty W, Scott SA, Farman AG. Maxillofacial cone beam computed tomography: essence, elements and steps to interpretation. Aust Dent J 2012;57 Suppl 1:46-60.
6. Mangano C, Luongo F, Migliario M, Mortellaro C, Mangano FG. Combining intraoral scans, cone beam computed tomography and face scans: the virtual patient. J Craniofac Surg 2018;29(8):2241-6.
7. Javaid M, Haleem A, Kumar L, Current status and applications of 3D scanning in dentistry. Clin Epidemiol Glob Health 2019;7(2):228-33.

8. Petrides G, Clark JR, Low H, Lovell N, Eviston TJ. Three-dimensional scanners for soft-tissue facial assessment in clinical practice. J Plast Reconstr Aesthet Surg 2021;74(3):605-14.

9. Artopoulos A, Buytaert JA, Dirckx JJ, Coward TJ. Comparison of the accuracy of digital stereophotogrammetry and projection moiré profilometry for three-dimensional imaging of the face. Int J Oral Maxillofac Surg 2014;43(5):654-62.

10. Marić I, Šiljeg A, Domazetović F, Precision assessment of artec space spider 3D handheld scanner for quantifying tufa formation dynamics on small limestone plates (PLs). In proceedings of the 8th international conference on geographical information systems theory, applications and management; Science and Technology Publications, Lda; 2022.p.27-29.

11. Chalearnthongtakul S, Arunjaroensuk S, Kaboosaya B, Dhanesuan K, Tunwatatanapong B, Pimkhaokham A, The accuracy and precision of twelve-angle camera facial scan system for measurement of facial soft tissue. J Dent Assoc Thai 2023;73(2):145-52.

12. Zhao YJ, Xiong YX, Wang Y. Three-dimensional accuracy of facial scan for facial deformities in clinics: a new evaluation method for facial scanner accuracy. PLoS One 2017;12(1):e0169402.

13. Rudolph H, Salmen H, Moldan M, Kuhn K, Sichwardt V, Wöstmann B, et al. Accuracy of intraoral and extraoral digital data acquisition for dental restorations. J Appl Oral Sci 2016;24(1):85-94.

14. Piedra-Cascón W, Meyer MJ, Methani MM, Revilla-León M. Accuracy (trueness and precision) of a dual-structured light facial scanner and interexaminer reliability. J Prosthet Dent 2020;124(5):567-74.

15. Amornvit P, Sanohkan S. The accuracy of digital face scans obtained from 3D scanners: an in vitro study. Int J Environ Res Public Health 2019;16(24):5061.

16. Ebrahim MA. 3D laser scanners' techniques overview. Int J Sci Res 2015;4(10):323-31.

17. Ye H, Lv L, Liu Y, Liu Y, Zhou Y. Evaluation of the accuracy, reliability, and reproducibility of two different 3D face-scanning systems. Int J Prosthodont 2016;29(3):213-8.

18. Quinzi V, Polizzi A, Ronsivalle V, Santonocito S, Conforte C, Manenti RJ, et al. Facial scanning accuracy with stereophotogrammetry and smartphone technology in children: a systematic review. Children (Basel) 2022;9(9):1390.

19. Lin CC, Hung JH, Huang YH. Immediate ocular changes after light-emitting diode displays exposure-a preliminary study. Front Med (Lausanne). 2022;9:848794.

20. Buck U, Buße K, Campana L, Schyma C. Validation and evaluation of measuring methods for the 3D documentation of external injuries in the field of forensic medicine. Int J Legal Med 2018;132(2):551-61.

21. Popan IA, Balc N, Popan A, Carean A. Experimental study on reverse engineering in case of composite materials cut by water jet cutting. InMATEC 2018;178:03004.

22. Özsoy U, Sekerci R, Hizay A, Yildirim Y, Uysal H. Assessment of reproducibility and reliability of facial expressions using 3D handheld scanner. J Craniomaxillofac Surg 2019;47(6):895-901.

23. Plooij JM, Maal TJ, Haers P, Borstlap WA, Kuijpers-Jagtman AM, Bergé SJ. Digital three-dimensional image fusion processes for planning and evaluating orthodontics and orthognathic surgery. A systematic review. Int J Oral Maxillofac Surg 2011;40(4):341-52.

Systematic review and meta-analysis

Comparison of Heat Generation Between Manual Metal Strips and Motor Stripping Discs for Interproximal Reduction: A Systematic Review and Meta-Analysis

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Abstract

Background: Interproximal reduction (IPR) is a widely used orthodontic procedure that reduces the mesiodistal thickness of teeth to alleviate crowding and achieve optimal occlusion. It involves contouring tooth surfaces using manual or motor instruments. Despite being commonly used, there are concerns about the potential thermal impact on dental pulp caused by friction during the procedure. **Objective:** To conduct a systematic review and meta-analysis comparing the temperature changes, measured in degrees Celsius, between manual metal strips and motor stripping discs during IPR in a non-clinical setting. **Materials and methods:** A comprehensive literature search was conducted using four databases: Embase, PubMed, Scopus, and Google Scholar. The risk of bias in the identified studies was assessed using the QUIN tool. Meta-analysis and subgroup analysis were performed, while publication bias was evaluated using Egger's test. A sensitivity analysis was also conducted. **Results:** Four in vitro studies met the inclusion criteria, showing a low to moderate risk of bias. The meta-analysis, which included data from 354 tooth surfaces, found that motor stripping discs generated higher temperatures than manual metal strips, with a mean difference of 2.57°C (95 % confidence interval = −3.89, −1.26). A subgroup analysis of premolar teeth showed similar results. Sensitivity analysis confirmed the robustness of the findings. **Conclusion:** Both manual and motor IPR methods generate mild heat. Clinicians should be aware of overheating risks and employ intermittent stripping with water coolants to reduce temperature increases. The predominance of in vitro studies highlights the need for more clinical trials to enhance generalizability.

Keywords: Heat, Interproximal reduction, Metal strip, Stripping disc, Temperature

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Introduction

Interproximal reduction (IPR) is a dental technique used to reduce the mesiodistal thickness of teeth, applicable to both the labial and buccal segments. IPR is also referred to using other terms, including interproximal enamel reduction, reproximation, slenderization, and stripping.[1,2] Ballard initially introduced the stripping technique on the proximal surfaces of the lower anterior teeth to address tooth size discrepancies.[3] The IPR concept originates from Begg's research on aboriginal groups, where natural occlusal and interproximal wear patterns, influenced by non-refined abrasive diets, allowed sufficient space for third molars to erupt without dental crowding.[4] IPR can be utilized with fixed appliance therapy or as part of removable appliance therapy, such as clear aligners.[2] It is typically indicated for resolving mild to moderate crowding to create 3–4 mm of space, potentially avoiding the need for tooth extraction[5]; correcting Bolton tooth size discrepancies to achieve normal overjet, overbite, and proper occlusion[6]; and enhancing dental aesthetics by reshaping individual teeth.[7] It can also improve long-term stability by reshaping contact points.[8]

IPR can be conducted using manual or mechanical methods.[1] Introduced by Hudson, using handheld abrasive strips is time-consuming and hardly applicable to posterior teeth.[9] Hand-operated strips are typically used for minor enamel removal cases or as introductory or finishing stripping procedures.[1] Due to limitations in interproximal access, performing IPR with manual instruments is recommended during the initial phase of treatment when crowding has not been sufficiently alleviated. After the teeth are reasonably aligned, clinicians usually perform IPR with motor instruments, as they can be parallelized to the long axis of the tooth.[10] Motor stripping discs, or the recently developed segment discs, have gained popularity due to less hand fatigue and time consumption. Disc guards, fitting over the handpiece or contra-angle mounted stripping discs, can be employed to shield adjacent tissues.[1]

IPR offers several advantages. Studies have shown that IPR does not increase the risk of tooth decay on treated surfaces; in fact, the occurrence of cavities was comparable between IPR-treated and untreated surfaces.[11] IPR also does not cause periodontal changes or dental sensitivity when used cautiously. The spaces created by IPR can shorten the duration of orthodontic treatment, especially in non-extraction cases, compared to procedures involving dental extractions.[12] However, the friction from removing the tooth structure during dental procedure generates heat that is transferred to the dentine-pulp complex. Heat transferred to the pulp can induce various histopathological changes, potentially resulting in irreversible injury. The thermal behavior of teeth involves a process of heat conduction coupled with physiological processes such as dentinal fluid flow and pulpal blood flow. The injury mechanisms encompass protoplasm coagulation, expansion of liquid within dentinal tubules, increased outflow from the tubules, vascular injuries, and tissue necrosis.

The significance of temperature differences between manual and motor IPR techniques lies in their potential to affect the health of dental pulp. Elevated temperatures during dental procedures can lead to irreversible pulpitis, a condition where the dental pulp becomes inflamed and can result in pain and the need for further dental treatment.[13] Zach and Cohen demonstrated that increasing pulp temperatures by 5.50°C and 11.10°C in Macaca Rhesus monkeys resulted in irreversible pulpitis in 15 % and 60 % of cases, respectively.[14] Therefore, even slight differences in temperature elevation between techniques could have significant clinical implications.

Despite knowing the threshold temperature increase that can cause pulpitis, it is essential to determine whether the temperature changes induced by different IPR techniques remain within safe limits. The typical method for assessing heat generation involves continuous monitoring of temperature using thermocouples such as J-type or K-type, which are considered reliable without significantly affecting temperature measurements in dental settings or materials.[13]

Many studies have compared the temperature changes in the pulp chamber resulting from various IPR techniques, including both manual and motor techniques. These studies consistently found that all IPR techniques increase pulpal temperature; however, the results and methodologies of each study differ. Since IPR is a common procedure in dental practice, understanding the temperature changes is crucial for dental pulp health. To our knowledge, no published systematic review and meta-analysis has compared heat generation between manual and motor IPR techniques. Therefore, this study examines the temperature differences when performing IPR with motor stripping discs and manual metal strips. By conducting a systematic review and meta-analysis, this study aims to provide a comprehensive and unbiased synthesis of the available evidence, offering clearer insights into the thermal impacts of these techniques and guidance for clinical practice.

Objective

This study aimed to systematically review the temperature differences, measured in degrees Celsius, when performing IPR with manual metal strips and motor stripping discs in a non-clinical setting. It also aimed to compare these temperature differences between motor stripping discs and manual metal strips through meta-analysis.

Material and methods

Registration and literature search

This systematic review and meta-analysis was registered in the PROSPERO database (CRD42024531664). Four electronic databases were searched to identify relevant articles: Embase, PubMed, Scopus, and Google Scholar. The search terms combined subject terms and free terms. No language restrictions were applied. Studies in languages other than English were identified using their keywords or abstracts. Once identified and selected based on the inclusion criteria, these studies were translated into English using the AI tool DeepL Translate to extract their details.[15] The search considered articles published from the inception of each database until April 30, 2024.

Inclusion and exclusion criteria

The inclusion criteria were as follows: 1) Populations: human permanent teeth, 2) Intervention: motor stripping discs, 3) Comparison: manual metal strips, 4) Outcome: Mean difference in temperature change of each group, and 5) Study design: both in vivo and in vitro studies conducted in clinical and non-clinical settings.

The exclusion criteria were as follows: 1) Animal studies, case reports, letters, and conference abstracts; 2) studies lacking clear data on pulpal temperature changes or full-text availability were excluded after three unsuccessful attempts to contact the authors for relevant data.

Literature selection and data extraction

After two researchers (PK and CC) had completed the literature selection, data were extracted, and quality was assessed independently according to the specific inclusion and exclusion criteria. Inter-reviewer reliability was assessed using Cohen's kappa (κ) coefficient to evaluate the consistency between two independent reviewers in literature selection and data extraction. Cohen's κ assesses agreement beyond chance, with values interpreted as follows: $\kappa \leq 0.20$ indicating poor agreement, $0.21 \leq \kappa \leq 0.40$ indicating fair agreement, $0.41 \leq \kappa \leq 0.60$ indicating moderate agreement, $0.61 \leq \kappa \leq 0.80$ indicating substantial agreement, and $\kappa > 0.80$ indicating almost perfect agreement. A Cohen's κ of 0.90 was obtained, indicating perfect agreement between the reviewers. Any discrepancies between the two researchers were resolved through open discussion and consensus. In cases where disagreement persisted, a third researcher (NN) was consulted to facilitate resolution. In addition to recording the outcomes of interest (mean difference in temperature change of each group), information on study design, types of teeth, and stripping procedures was extracted to construct a table of the characteristics of the included studies.

Risk of bias assessment of the included studies

The risk of bias in individual studies included in this systematic review and meta-analysis was evaluated using relevant tools specific to the study type. The QUIN tool was utilized for in vitro studies, assessing potential bias across 12 domains.[16]

Statistical analysis

Meta-analysis

The meta-analysis process involved systematic steps to synthesize and analyze data on temperature differences resulting from IPR with manual metal strips and motor stripping discs in non-clinical settings. It was guided by the following principles:

1. Data Extraction and Synthesis: The data extracted from eligible studies included standardized mean differences (SMDs), 95 % confidence intervals (CI), and sample sizes. These data were pooled using STATA software (version 18; StataCorp LLC, College Station, TX, USA) to calculate overall effect sizes.
2. Heterogeneity Assessment: Heterogeneity among studies was assessed using the Q test and the I^2 statistic. The Q test evaluates whether observed variations in effect sizes are compatible with chance alone, with a significant *P* value (< 0.05) indicating substantial heterogeneity. The I^2 statistic quantifies the percentage of total variation across studies due to heterogeneity rather than chance, with 25 %, 50 %, and 75 % indicating low, moderate, and high heterogeneity, respectively.
3. Statistical Models: The statistical model used depended on the level of heterogeneity observed. The fixed effects model was used when I^2 was < 50 % and the Q test had a non-significant *P* value (> 0.10), assuming a common effect size across studies due to minimal heterogeneity. The random effects model was used when I^2 was ≥ 50 % and/or the Q test had a significant *P* value (≤ 0.10), accounting for potential variability in effect sizes across studies.
4. Subgroup Analysis: Subgroup analyses were conducted based on tooth type to explore potential sources of heterogeneity and to assess whether specific study characteristics influenced the observed temperature differences between manual metal strips and motor stripping discs.
5. Forest Plot: A forest plot was created to visually represent the meta-analysis results, displaying individual study effect sizes (SMDs) and their 95 % CIs, providing a comprehensive overview of the pooled estimates and their variability.
6. Statistical Significance: Results were considered statistically significant at a threshold of $P < 0.05$, indicating temperature differences between the two techniques that were unlikely to occur by chance alone.

Assessment of publication bias

Publication bias was evaluated based on asymmetry in the funnel plot. Egger's linear regression quantitative test was also used to objectively assess publication bias.

Sensitivity analysis

The effect size after removing individual studies was analyzed to evaluate the reliability of the combined results and decrease heterogeneity among studies.

Results

Study selection and characteristics

The literature search yielded 1,204 articles. After removing duplicates and screening titles and abstracts against the eligibility criteria, the full texts of the remaining articles were evaluated. Ultimately, four in vitro studies were included (Figure 1).[17-20]

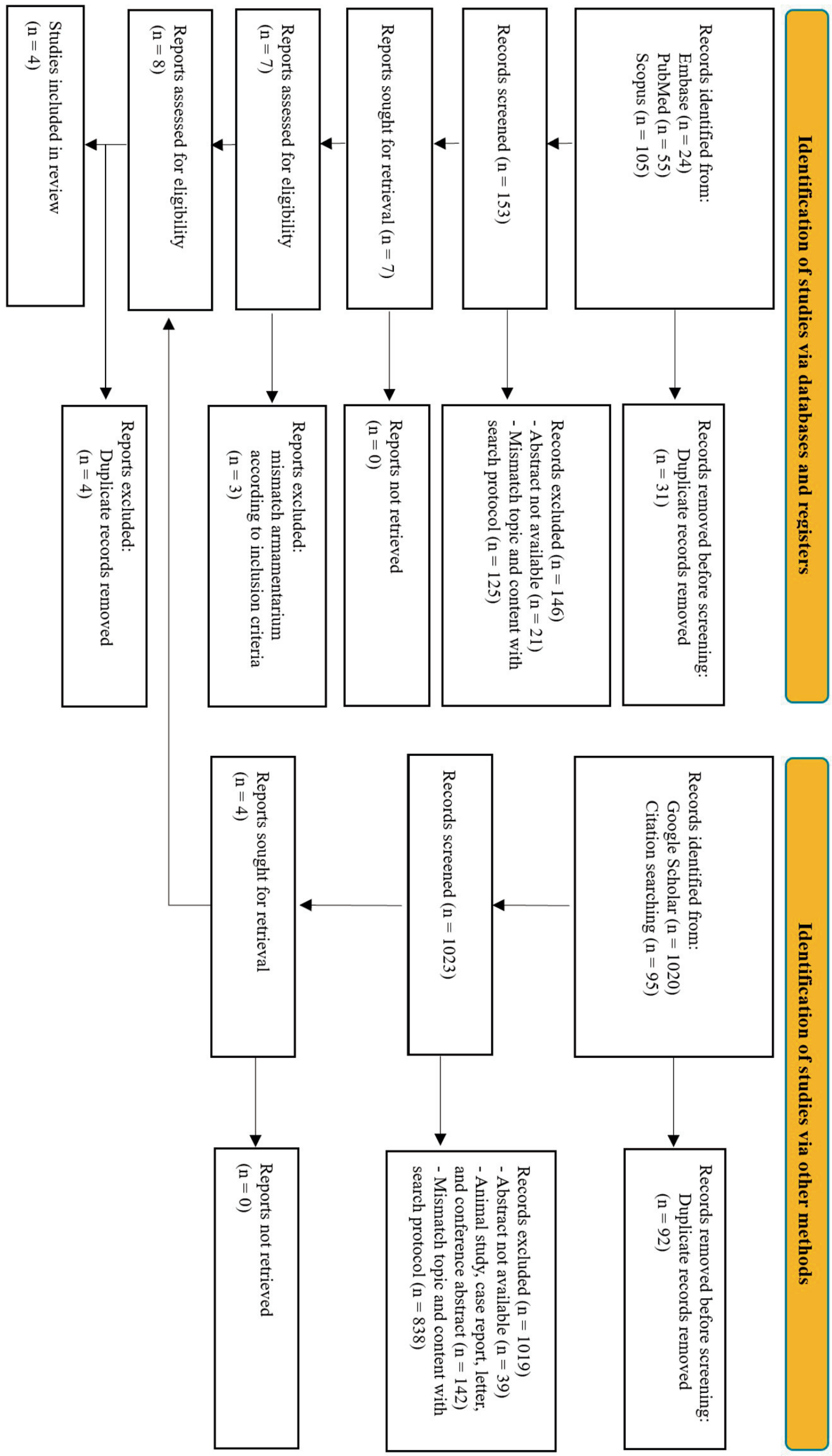

Figure 1 PRISMA flowchart of the selection of eligible studies

Table 1 Characteristics of the included studies

No.	Author, year	Study design	Thermocouple type	Armamentarium	Procedure	Tooth type	Temperature change (°C)		
							N (sides)	Mean difference	Standard deviation
1	Baysal et al.	In vitro	J type	Metal handheld stripper (double side 6 mm; GH Company, Hanover, Germany)	20 strokes on the mesial and distal of each tooth without any type of coolant.	Incisor	20	1.21	1.48
						Canine	20	1.30	1.30
						Premolar	20	−0.18	0.97
				Perforated stripping disc (8934 A.220; Komet, Lemgo, Germany)	Low speeds (< 15,000 rpm) with a contra-angle handpiece for 10 seconds each without any type of coolant.	Incisor	20	2.37	1.31
						Canine	20	2.51	1.25
						Premolar	20	3.84	2.21
2	Pereira et al.	In vitro	J type	Metal handheld stripper (single-sided 6 mm; KG Sorensen, São Paulo, Brazil)	Stripping to 0.50 mm of interproximal enamel without any type of coolant.	Incisor	13	1.24	0.30
						Premolar	13	0.96	0.39
						First molar	13	0.92	0.18
				Two-sided perforated stripping disc (KG Sorensen, São Paulo, Brazil)	Low-speed stripping to 0.50 mm of interproximal enamel without any type of coolant.	Incisor	13	2.58	0.27
						Premolar	13	2.64	0.29
						First molar	13	2.48	0.38
3	Omer and Sanea	In vitro	K type	Manual metal strip (Not specifying type and brand)	Striping for 20 seconds without any type of coolant.	Premolar	24	0.27	0.16
				One-sided diamond stripping disc (RaintreeEssix, Inc., Metairie, CA, USA)	The lowest recommended speed (8,500 rpm) for 20 seconds without any type of coolant.	Premolar	24	1.37	0.75
					The highest recommended speed (12,000 rpm) for 20 seconds without any type of coolant.	Premolar	24	0.77	0.47
4	Dara et al.	In vitro	K type	Metal handheld stripper (type and brand not specified)	Stripping to 1 mm of interproximal enamel without any type of coolant.	Premolar	42	2.52	0.63
				Diamond stripping disc (Strauss, Ra'anana, Israel)	Low speeds (below 15,000 rpm) stripping to 1 mm of interproximal enamel without any type of coolant.	Premolar	42	4.31	0.56

The characteristics of the included studies were extracted according to the use of motor stripping discs and manual metal strips (Table 1).

Risk of bias assessment

The QUIN tool was used to evaluate the risk of bias in all four in vitro studies across 12 domains.[16] The overall risk of bias in the included studies was assessed to be low to medium (Table 2).

Meta-analysis

The meta-analysis included data from 354 tooth surfaces with reported temperature differences in degrees Celsius (Figure 2). The SMD and a random-effects model were used to analyze the data.

Table 2 Risk of bias in the included studies

Quality assessment of the in vitro studies using the QUIN tool														
Study	1. Clearly Stated Aims/Objectives	2. Sample Size Calculation	3. Explanation of Sampling Technique	4. Comparison Group	5. Methodology	6. Operator Details	7. Randomization	8. Method of Measurement of Outcome	9. Outcome Assessor Details	10. Blinding	11. Statistical Analysis	12. Presentation of Results	Final score	Risk of Bias*
Pereira et al.	2	2	2	2	2	0	2	2	0	0	2	2	75 %	Low
Omer and Sanea	2	0	2	2	2	0	2	2	0	0	2	2	66.67 %	Medium
Baysal et al.	2	0	1	2	2	1	0	2	0	0	2	2	58.33 %	Medium
Dara et al.	2	0	2	2	2	1	2	2	0	0	2	2	70.83 %	Low

* Score: adequately specified = 2; inadequately specified = 1; not specified = 0.
Final score = (total score × 100) / (2 × number of criteria applicable); > 70 % = low risk of bias; 50 %–70 % = medium risk of bias; and < 50 % = high risk of bias.

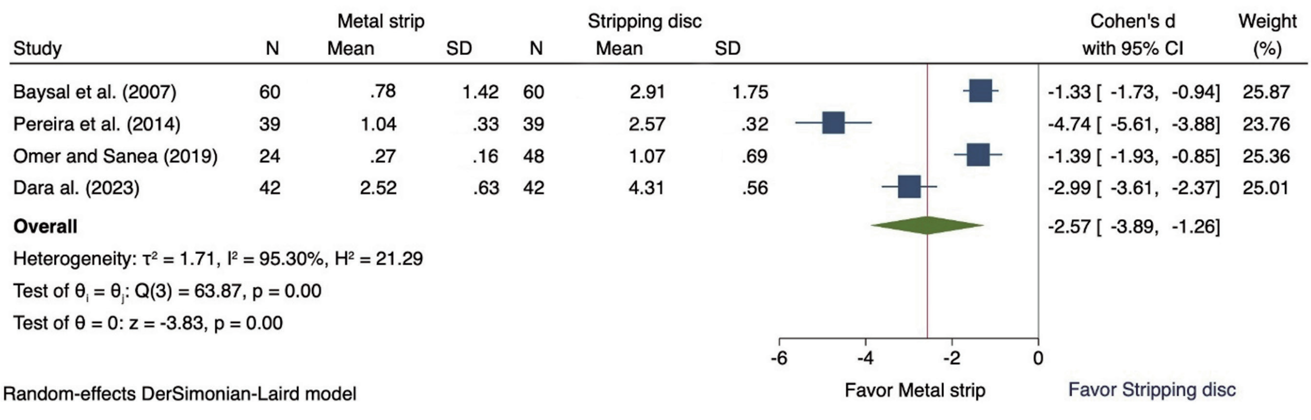

Figure 2 Forest plot of temperature change differences across all tooth types

Subgroup analysis

A subgroup analysis was conducted to reduce heterogeneity by analyzing only premolar teeth (Figure 3).

Publication bias

Egger's test was statistically significant, suggesting that some publication bias may be attributed to factors such as heterogeneity in the included studies, influencing the asymmetric shape of the funnel plot (Figure 4).

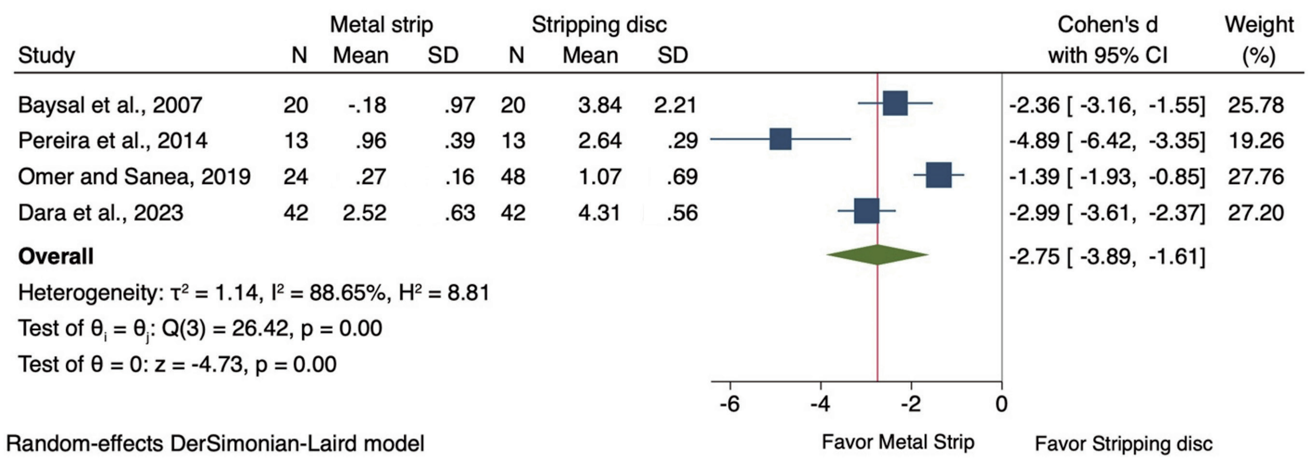

Figure 3 Forest plot of temperature change differences for premolar teeth

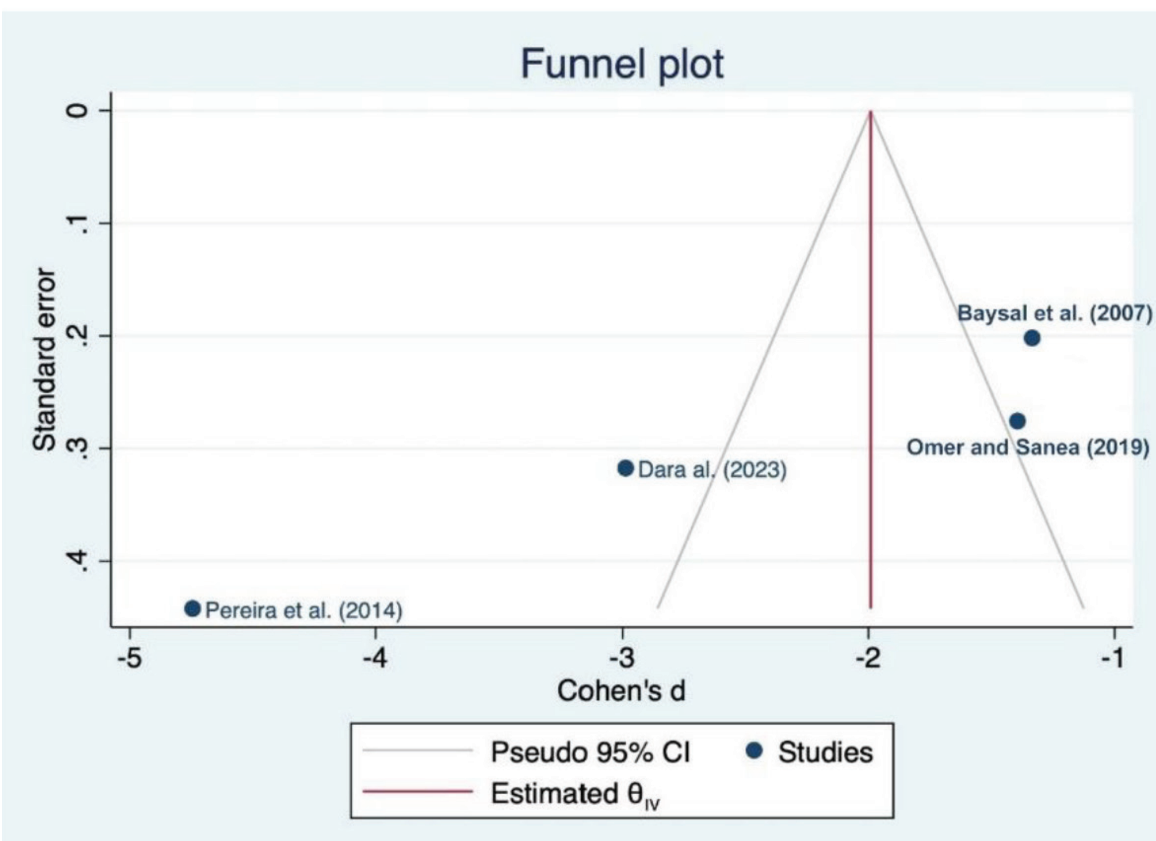

Figure 4 Funnel plot of the meta-analysis to assess publication bias

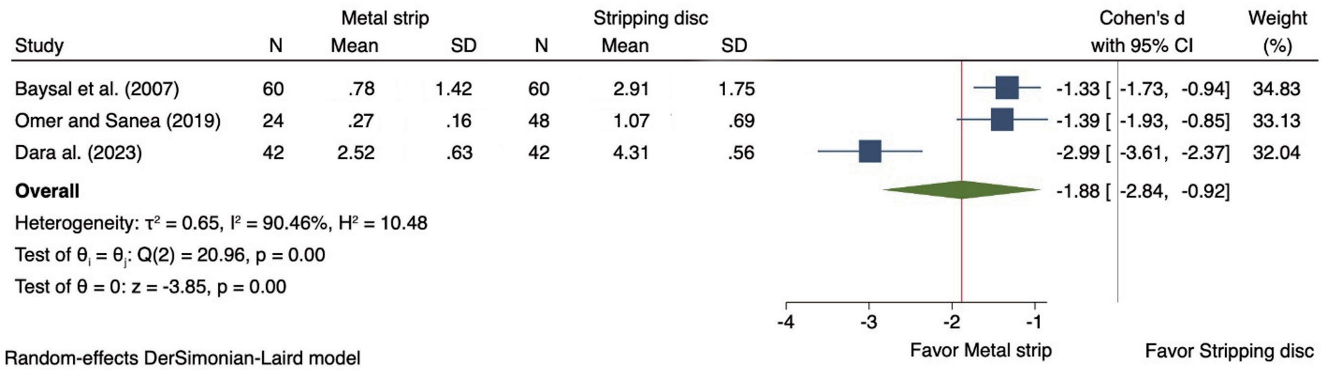

Figure 5 Forest plot of sensitivity analysis

Sensitivity analysis

A sensitivity analysis was conducted, excluding the study of Pereira et al., as it was an outlier in the publication bias analysis (Figure 5). However, this analysis still yielded similar results favoring metal strips (MD = −1.88, 95% CI = −2.84, −0.92) with high heterogeneity (I^2 = 90.46 %).

Discussion

This systematic review and meta-analysis is the first to compare temperature differences in degrees Celsius between motor stripping discs and manual metal strips during IPR, aiming to include all strong study designs for a comprehensive comparison. Despite its broad inclusion criteria, the search primarily yielded in vitro studies. In vivo studies, particularly clinical research involving human participants, were unavailable. Consequently, while this review offers valuable insights, it has inherent limitations when using its findings in clinical settings.

This systematic review and meta-analysis included 354 tooth surfaces from four studies retrieved from four databases, adhering to the PRISMA workflow, with a low to moderate risk of bias. In the included studies, using manual metal strips caused temperature rises between −0.18°C and 2.52°C, while using motor stripping discs caused temperature rises between 0.77°C and 4.31°C.[17-20] The temperature rise did not exceed the 5.50°C threshold that may cause irreversible pulpitis, as reported by Zach and Cohen,[14] in both procedures. Therefore, these procedures were found to be safe for performing IPR. However, Amuk et al. reported different results; they reported that motor stripping discs raised temperatures between 5.54°C and 7.30°C. However, this study was not included in our review as it did not meet the inclusion criteria, which required the use of manual metal strips.[21]

A random-effects model was used due to variations in IPR procedures across studies. The findings of our meta-analysis favored metal strips in terms of temperature rise. It showed that motor stripping discs generated more heat than manual metal strips by around 2.57°C, based on all tooth types (95 % CI = −3.89, −1.26, I^2 = 95.30 %). Our subgroup analysis included only premolar teeth due to variations in tooth thickness across tooth types. Residual dentin thickness was the key factor affecting the rise in intrapulpal temperature. Tooth thickness, especially enamel thickness, varies among tooth types. Premolars and molars generally have thicker enamel than mandibular central incisors. The enamel on the distal aspect was thicker than the enamel on the mesial aspect by an average of 0.10 mm (95 % CI = 0.09, 0.12).[22] The results showed similar trends, and heterogeneity decreased but remained high (MD = −2.75°C, 95 % CI = −3.89,

−1.61; I^2 = 88.65 %). Egger's test was statistically significant, suggesting that some publication bias may be attributed to factors such as heterogeneity in the included studies, influencing the shape of the funnel plot. The sensitivity analysis, excluding the outlier study by Pereira et al.,[18] showed similar results favoring metal strips (MD = −1.88°C, 95 % CI = −2.84, −0.92), with high heterogeneity. This study showed the trend in temperature changes, with motor-driven procedures generating more heat than manual procedures.

Regarding the implications of our findings, friction from mechanical procedures generates heat.[23] While our findings show that both manual and motor IPR techniques increase the pulpal temperature within safe limits, Amuk et al. reported contrasting results, indicating that motor stripping discs can raise the temperature by up to 7.30°C, exceeding the 5.50°C threshold. This discrepancy likely arises from variations in methods, such as different types of motor stripping discs, shorter stripping durations, or tooth types. The conflicting findings emphasize the need for standardized research protocols to ensure the comparability and reliability of results. The study by Amuk et al. was not included in our review due to a mismatch in the armamentarium, specifically the use of metal strips according to our inclusion criteria.[21] Understanding these methodological differences is crucial for determining the thermal safety of IPR procedures in clinical practice.[21]

The recommendation for IPR, especially motor-driven procedures, is intermittent stripping because heat dissipation can occur during rest periods, resulting in a lower temperature rise.[24] Moreover, air coolant is insufficient; water coolant should be used to prevent harmful critical temperature changes.[25] Studies have compared temperature changes during IPR and found that using a diamond bur with water cooling results in lower temperature changes than with air cooling.[19,21,26]

Our systematic review and meta-analysis had several limitations. Firstly, it included only in vitro studies, which may not reflect actual clinical environments due to the absence of blood circulation typical of the vital pulp. Its absence contributes significantly to heat dissipation and leads to a risk of overestimating pulp temperature changes due to the lack of blood and dentine fluid flow and periodontal tissues.[27] Consequently, the generalizability of our findings to vital human dentition may be limited.

Secondly, heterogeneity remained high in both the subgroup and sensitivity analyses despite efforts to investigate its sources. This variability may arise from factors such as variations in tooth types, procedures, and instruments. Therefore, careful consideration is advised when interpreting our findings. The various types of teeth have different thicknesses. Even in the same tooth type, the age of the teeth may influence their mineral content and the size of their pulp chamber.[28] In addition, differences in the armamentarium, procedure, and thermal measurement, such as one-sided or two-sided strippers, grit size, thickness, design, duration, and stroke of the procedure, as well as the amount of tooth reduction, are important factors.[13] Future research should focus more on clinical trials.

Thirdly, Banga et al. reported the only in vivo study examining temperature change during IPR performed on patients for whom extraction of premolars had been advised using an airotor handpiece and bur, handheld metal strip, and orthodontic IPR kit. They found that all three methods were safe, and using coolant, either water or air, could reduce the heat generated by the dental procedure.[29] Future studies should include various tooth types because many past studies have mainly focused on premolars. The variation in armamentariums and procedures should be considered. Moreover, many thermal measurement devices, such as thermocouples or thermal cameras, can be explored.[30]

Conclusion

The temperature change is greater with motor stripping discs than with manual metal strips by around 2.57°C (95 % CI = −3.89, −1.26). A subgroup analysis of premolars supported this finding, with motor stripping discs causing a greater temperature change by around 2.75°C (95 % CI = −3.89, −1.61).

Author contributions

PK: Validation, Formal analysis, Investigation, Resources, Data Curation, Writing-Original Draft, Writing-Review & Editing, Visualization, Project administration; CC: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Supervision; NV: Writing-Review & Editing, Supervision; NS: Conceptualization, Methodology, Validation, Resources, Writing-Original Draft, Writing-Review & Editing, Supervision, Project administration.

Disclosure statement

The authors have no conflicts of interest.

References

1. Livas C, Jongsma AC, Ren Y. Enamel reduction techniques in orthodontics: a literature review. Open Dent J 2013;7:146–51.
2. Pindoria J, Fleming PS, Sharma PK. Inter-proximal enamel reduction in contemporary orthodontics. Br Dent J 2016;221(12):757–63.
3. Ballard ML. Asymmetry in tooth size: a factor in the etiology, diagnosis and treatment of malocclusion. Angle Orthod 1944;14(3):67–70.
4. Begg PR. Stone age man’s dentition: with reference to anatomically correct occlusion, the etiology of malocclusion, and a technique for its treatment. Am J Orthod 1954;40(4):298–312.
5. Chudasama D, Sheridan JJ. Guidelines for contemporary air-rotor stripping. J Clin Orthod 2007;41(6):315–20.
6. Bolton WA. Disharmony in tooth size and its relation to the analysis and treatment of malocclusion. Angle Orthod 1958;28(3):113–30.
7. Zachrisson BU. JCO/interviews Dr. Bjorn U. Zachrisson on excellence in finishing. Part 1. J Clin Orthod 1986;20(7):460–82.
8. Aasen TO, Espeland L. An approach to maintain orthodontic alignment of lower incisors without the use of retainers. Eur J Orthod 2005;27(3):209–14.
9. Hudson AL. A study of the effects of mesiodistal reduction of mandibular anterior teeth. Am J Orthod 1956;42(8):615–24.
10. Suwanwitid P, Changsiripun C, Jaruprakorn T, Komolpis R, Chengprapakorn S, Kanpittaya P. Interproximal enamel reduction: what clinicians should know. SWU Dent J 2022;15(2):102–10.
11. Koretsi V, Chatzigianni A, Sidiropoulou S. Enamel roughness and incidence of caries after interproximal enamel reduction: a systematic review. Orthod Craniofac Res 2014;17(1):1–13.
12. Gómez-Aguirre JN, Argueta-Figueroa L, Castro-Gutiérrez MEM, Torres-Rosas R. Effects of interproximal enamel reduction techniques used for orthodontics: a systematic review. Orthod Craniofac Res 2022;25(3):304–19.
13. Lau XE, Liu X, Chua H, Wang WJ, Dias M, Choi JJE. Heat generated during dental treatments affecting intrapulpal temperature: a review. Clin Oral Investig 2023;27(5):2277–97.
14. Zach L, Cohen G. Pulp response to externally applied heat. Oral Surg Oral Med Oral Pathol 1965;19:515–30.
15. Sebo P, de Lucia S. Performance of machine translators in translating French medical research abstracts to English: a comparative study of DeepL, Google Translate, and CUBBITT. PLoS One 2024;19(2):e0297183.
16. Sheth VH, Shah NP, Jain R, Bhanushali N, Bhatnagar V. Development and validation of a risk-of-bias tool for assessing in vitro studies conducted in dentistry: The QUIN. J Prosthet Dent 2024;131(6):1038–42.
17. Baysal A, Uysal T, Usumez S. Temperature rise in the pulp chamber during different stripping procedures. Angle Orthod 2007;77:478–82.
18. d’Ornellas Pereira JC, Jr., Weissheimer A, de Menezes LM, de Lima EM, Mezomo M. Change in the pulp chamber temperature with different stripping techniques. Prog Orthod 2014;15(1):55.
19. Omer ABA, Sanea JA. A comparison of thermal changes among four different interproximal reduction systems in orthodontics. J Contemp Dent Pract 2019;20(6):738–42.
20. Dara A, Datla PKV, Priya CVP, Manda A, Kandikatla P, Polineti P. Evaluation and comparison of thermal changes in the pulp chamber in different inter proximal reduction techniques: an in-vitro study. Uttar Pradesh J Zool 2023;44(24):303–10.
21. Gul Amuk N, Kurt G, Cakmak G, Er O. Evaluation of time-dependent temperature changes during different interdental stripping procedures by thermal imaging: an in vitro study. Oral Health Prev Dent 2019;17(6):591–8.
22. Kailasam V, Rangarajan H, Easwaran HN, Muthu MS. Proximal enamel thickness of the permanent teeth: a systematic

review and meta-analysis. Am J Orthod Dentofacial Orthop 2021;160(6):793–804.e3.

23. Cavalcanti BN, Otani C, Rode SM. High-speed cavity preparation techniques with different water flows. J Prosthet Dent 2002;87(2):158–61.
24. Ottl P, Lauer HC. Temperature response in the pulpal chamber during ultrahigh-speed tooth preparation with diamond burs of different grit. J Prosthet Dent 1998;80(1):12–9.
25. Farah RI. Effect of cooling water temperature on the temperature changes in pulp chamber and at handpiece head during high-speed tooth preparation. Restor Dent Endod 2019;44(1):e3.
26. Sehgal M, Sharma P, Juneja A, Kumar P, Verma A, Chauhan V. Effect of different stripping techniques on pulpal temperature: in vitro study. Dental Press J Orthod 2019;24(1):39–43.
27. Kells BE, Kennedy JG, Biagioni PA, Lamey PJ. Computerized infrared thermographic imaging and pulpal blood flow: Part 1. A protocol for thermal imaging of human teeth. Int Endod J 2000;33(5):442–7.
28. Daubert DM, Kelley JL, Udod YG, Habor C, Kleist CG, Furman IK, et al. Human enamel thickness and ENAM polymorphism. Int J Oral Sci 2016;8(2):93–7.
29. Banga K, Arora N, Kannan S, Singh A, Malhotra A. Evaluation of temperature rise in the pulp during various IPR techniques—An in vivo study. Prog Orthod 2020;21:40.
30. Kus A, Isik Y, Cakir MC, Coşkun S, Özdemir K. Thermocouple and infrared sensor-based measurement of temperature distribution in metal cutting. Sensors 2015;15(1):1274–91.

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Case report

Orthodontic Space Closures with Canine Substitution for Bilateral Congenitally Missing Maxillary Lateral Incisors: A Case Report

Sutti Malaivijitnond*

Abstract

Missing maxillary lateral incisors creates an esthetic and functional issue that necessitates unique orthodontic and restorative considerations. Consequently, various patient-specific factors, in particular patient satisfaction, should be meticulously evaluated prior to determining whether to close the space with canine substitution or open the space with tooth replacement. This case report describes successful space closure and canine repositioning used in the orthodontic treatment of a 25-year-old female patient with Class I malocclusion with bimaxillary dental protrusion and bilateral congenitally missing maxillary lateral incisors. Enhancing a patient's appearance and functionality requires minimizing the use of a prosthesis and improving the patient's facial profile, which includes the canine-like size, color, and shape of the maxillary first premolar. Orthodontic treatment was completed, with favorable results. The treatment time was 25 months. Although this case required some adjunctive procedures to improve the esthetics, the patient declined as she was very satisfied with the achieved results. After two years of follow-up, a stable occlusion with a satisfactory facial profile and functional excursion without interference was achieved. Functionality and esthetics can be improved by choosing this approach, which is less invasive as well as more economical.

Keywords: Canine substitution, Missing maxillary lateral incisor, Orthodontic space closure

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Introduction

Permanent tooth agenesis is one of the most common developmental anomalies in humans[1] with an incidence ranging from 1.60 % to 9.60 %, excluding third molars, which occur in 20 % of the population.[2] The frequency of congenitally missing maxillary lateral incisors varies greatly between populations. The majority of reports in the literature show a variation between 1 % and 3 % for missing lateral incisors.[3] According to research by Kanchanasevee et al., 8.98 % of Thai people have tooth agenesis with the maxillary lateral incisor being the third most prevalent form of missing teeth after the mandibular second premolar and mandibular lateral incisor.[4] Dental agenesis is mostly caused by genetic factors[5] but it can also be caused by environmental factors, such as dentoalveolar trauma[6] and radiation therapy.[7] Agenesis of both maxillary lateral incisors is more common than agenesis of only one, and it occurs slightly more frequently in females.[8]

Concerns about how to manage agenesis instances, particularly those involving lateral incisors, have persisted in the fields of orthodontics and restorative dentistry. Thorough diagnostic and thorough multidisciplinary treatment planning are required to determine whether to open a lateral incisor space for a prosthesis or close the space with canine mesial movement. In either case, the best option of treatment for maxillary lateral incisor agenesis must be determined to achieve the optimal esthetic, occlusal (functional), and periodontal outcomes. When treating patients with either a space opening or closure because their maxillary lateral incisors are missing, there are a lot of considerations. These factors include the type of malocclusion, age of the patient, tooth-to-tooth connections, crowding/spacing, canine position, canine morphology, canine color, lip level, and the patient's expectations from treatment.[9,10] If these selection criteria are fulfilled, the patient can expect a functional and esthetically pleasing end result.[10]

This case report aims to present a successful orthodontic treatment for bilateral congenitally missing maxillary lateral incisors by space closure with repositioning the canines. The functionality and esthetics can improve by choosing this less invasive and less costly approach.

Case report

Case history and diagnosis

A 25-year-old Thai female came to the orthodontic clinic with the chief complaint of difficulty biting and the desire to improve the appearance of her protruding lips and her anterior teeth spacing. She was physically healthy, had no medical history, and her teeth had previously been straightened. She had facial symmetry with a convex profile, an acute nasolabial angle, upper and lower lips protrusion, incompetent lips during relaxation, hyperactive mentalis muscle, and a normal smile line. The intraoral examination presented Class I canine and molar relationships on both sides with clinical absence of the maxillary left and right lateral incisors. She was wearing circumferential retainers with bilaterally positioned maxillary lateral incisor pontics and a fixed lower 3-3 retainer to maintain her teeth and appearance. The patient also presented with reduced overjet and overbite. The maxillary and mandibular dental midlines were coincident with the facial midline. In addition, a tongue thrusting habit during swallowing was observed (Figure 1 and Figure 2).

A panoramic radiograph revealed missing maxillary lateral incisors and the presence of all third molars. The overall alveolar bone level was within normal limits (Figure 3). The cephalometric analysis indicated a skeletal Class II relationship with an ANB angle of 7° due to a slightly prognathic maxilla (SNA = 88°) and an orthognathic mandible (SNB = 81°). Vertically, the patient had a high-angle tendency (FMA = 33°) and hyperdivergent facial pattern. The dental relationshipevaluation indicated an acute interincisal angle (U1-L1 = 93°) due to both maxillary and

Figure 1 Pretreatment facial and intraoral photographs.

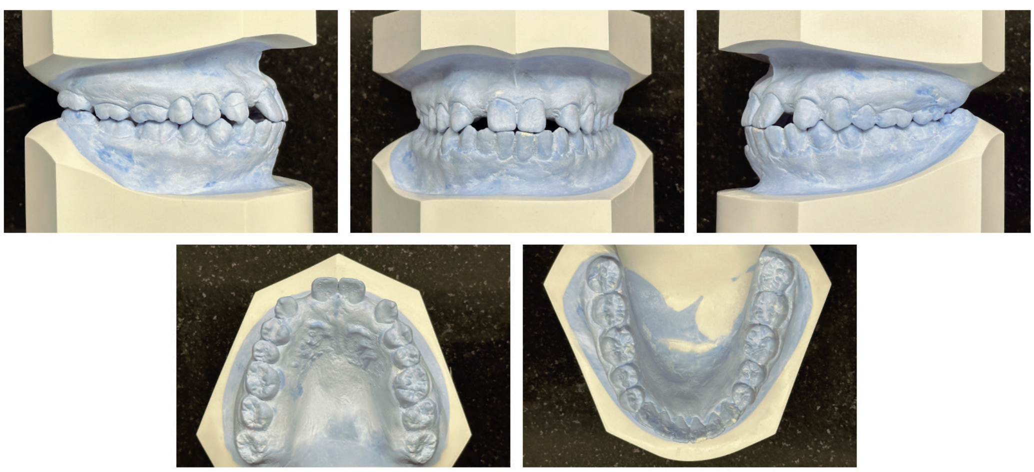

Figure 2 Pretreatment dental cast photographs.

mandibular incisors that were in forward positions and protruded. In relation to the E-line, the upper and lower lips protruded (Figure 4 and Table 1).

The diagnosis of this case according to the skeletal, dental, and soft tissue parameters was 1) skeletal Class II hyperdivergent pattern with prognathic maxilla and orthognathic mandible, 2) dental Class I malocclusion with bilateral congenitally missing maxillary lateral incisors, maxillary anterior teeth spacing and well-aligned mandibular anterior teeth, proclined and forward positioned maxillary and mandibular incisors with coinciding maxillary and mandibular dental midlines, and 3) convex facial profile and protruded upper and lower lips.

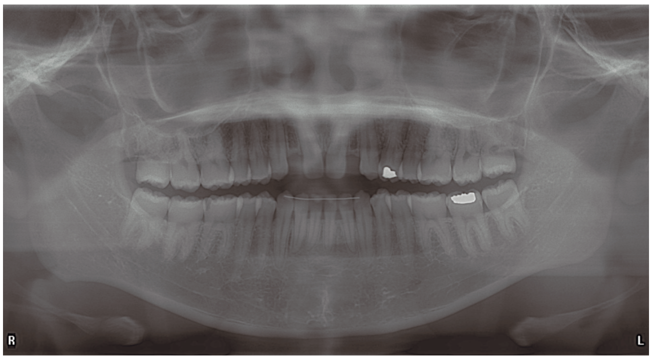

Figure 3 Pretreatment panoramic radiograph.

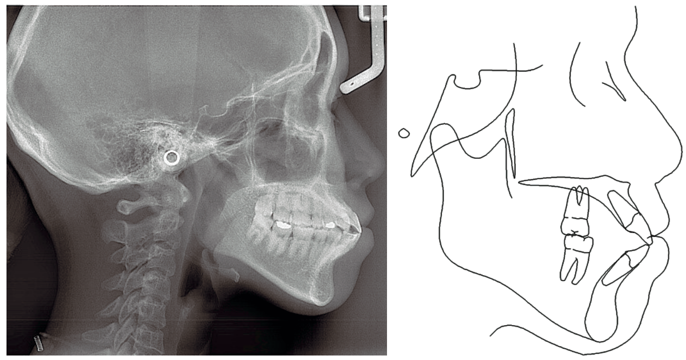

Figure 4 Pretreatment lateral cephalometric radiograph and tracing.

Table 1 Pretreatment cephalometric analysis (Thai norm).[11]

Area		Measurement	Norm Mean ± SD	Pretreatment	Interpretation
Reference line		FH-SN (degree)	6 ± 3	5	Normal cranial base inclination
Skeletal	Maxilla to cranial base	SNA (degree)	84 ± 4	88	Orthognathic maxilla
		SN-PP (degree)	9 ± 3	8	Normal inclination of maxilla
	Mandible to cranial base	SNB (degree)	81 ± 4	81	Orthognathic mandible
		SN-MP (degree)	29 ± 6	34	Normodivergent pattern
		SN-Pg (degree)	82 ± 3	81	Orthognathic mandible
		NS-Gn (degree)	68 ± 3	70	Normodivergent pattern
	Maxillo-mandibular	ANB (degree)	3 ± 2	7	Skeletal Class II
		Wits (mm)	−3 ± 2	0	Skeletal Class II
		MP-PP (degree)	21 ± 5	26	Normodivergent pattern
		FMA (degree)	23 ± 5	33	Hyperdivergent pattern
Dental	Maxillary dentition	U1 to NA (degree)	22 ± 6	26	Normal inclined upper incisor
		U1 to NA (mm)	5 ± 2	10	Forward position upper incisor
		U1 to SN (degree)	108 ± 6	118	Proclined upper incisor
	Mandibular dentition	L1 to NB (degree)	30 ± 6	47	Proclined lower incisor
		L1 to NB (mm)	7 ± 2	24	Forward position lower incisor
		L1 to MP (degree)	99 ± 5	110	Proclined lower incisor
	Maxillo-mandibular	U1 to L1 (degree)	125 ± 8	93	Acute interincisal angle
Soft tissue	Soft tissue	E line U. lip (mm)	−1 ± 2	2	Protruded upper lip
		E line L. lip (mm)	2 ± 2	7	Protruded lower lip
		Nasolabial angle (degree)	91 ± 8	113	Obtuse nasolabial angle
		H-angle (degree)	14 ± 4	19	Protruded upper lip

Treatment objectives

The treatment objectives were the following: 1) perform orthodontic space closures with canine substitution for bilateral congenitally missing maxillary lateral incisors; 2) obtain Class I canine (first premolar) and molar relationships with normal overjet and overbite; 3) create a good functional occlusion; 4) improve the facial esthetics; and 5) eliminate the tongue thrusting habit.

Treatment alternatives

In the case of a missing maxillary lateral incisor, the key question becomes one of treatment planning. Should the space be opened and a prosthesis placed or should the canine be moved forward and reshaped to simulate the missing lateral incisor? A comprehensive interdisciplinary approach is required for treatment planning[12] in addition to many factors that must be considered before making a decision. It seems reasonable to assume that both facial appearance and dental esthetics can be acceptable. Occlusal characteristics, such as overjet, overbite, and molar relationship, in addition to facial types and profile, arch length, and tooth size discrepancies are commonly influencing factors. Canine morphology, including size, shape, and color, may also influence the treatment modality.[13] Finally, patient compliance and expectations may influence the development of a treatment plan.

Following the data collection, the interdisciplinary team discussed treatment options with the patient who had a Class II skeletal jaw relationship with a hyperdivergent pattern and missing maxillary lateral incisors. She had already undergone orthodontic treatment and presented with a convex profile, an acute nasolabial angle, and bimaxillary dental protrusion. It was expected that the treatment strategy used to address the issue of missing lateral incisors would have an impact on the patient's soft tissue profile due to the planned treatment goals for facial esthetics and function. It was reported that the nasolabial angle significantly increased as a result of the retraction of the maxillary central incisors, and the upper lip also receded considerably.[14] Patients with convex profiles and missing the maxillary lateral incisor teeth can benefit from proper orthodontic treatment; however, it is required to extract both mandibular first premolars. The maxillary anterior teeth can be retracted using the following procedures. 1) Use the maxillary first premolars to take the position of the canines and close the lateral incisor spaces with canine mesial movement. After that, retract the maxillary anterior teeth by closing the spaces that remain, therefore minimizing the requirement for prosthetic restorations. The canine-like size, color, and shape of the maxillary first premolar are further enhanced by this treatment, which also makes the canines appear more like the maxillary lateral incisors. 2) To create spaces, remove the maxillary first premolars, retract the maxillary anterior teeth, and keep the spaces for the maxillary lateral incisors. Next, replace the lateral incisors at both sites with dental implants.

To achieve the treatment goals, the patient preferred canine mesialization and the use of maxillary first premolars to replace the canines and retract the maxillary anterior teeth, followed by canine reshaping to resemble the lateral incisor. In a long-term clinical and radiographic follow-up study by Thordarson and colleagues, the canines were ground to the shape of lateral incisors as part of the orthodontic treatment.[15] The patients were called back after 10 to 15 years for a clinical evaluation. The results, they said, were encouraging since reshaping the canines rather than using prosthetic devices to replace missing incisors can lead to better long-term esthetic outcomes and healthier periodontal status.

Completing the diagnostic wax-up is an important step in the patient selection process, as is evaluating the anterior tooth-size relationship when substituting canines for lateral incisors and using the maxillary first premolars to replace the canines (Figure 5). According to Bolton's analysis, the anterior ratio of this patient,

Figure 5 Set-up model.

which was 71 %, was less than normal. It is known that the optimal anterior ratio is 77.2 %. This indicates that the upper anterior tooth, measuring 4 mm, would be bigger than it should be. Therefore, it is frequently required to reduce the anterior tooth-size excess created in the maxillary arch in order to establish a normal overbite and overjet relationship.[16] This allows the orthodontist to assess the final occlusion, determine how much canine reduction is required, and determine whether an esthetic final result is achievable.[17]

Treatment progress

The patient was treated with preadjusted 0.022″ McLaughlin, Bennett, and Trevisi (MBT) prescription brackets after extraction of the mandibular first premolars, and both the maxillary and mandibular teeth were bonded. After the canines were moved mesially enough to allow adequate access to all proximal surfaces, the canines should have been reshaped but this was delayed until the end of treatment. To simulate the proper position of the canine eminence, the maxillary first premolar roots were torqued buccally while the canine roots were torqued palatally. The maxillary canine brackets on both sides were inverted for a +7° torque which nearly matched the torque of the maxillary lateral incisor tooth. The maxillary canine brackets were positioned slightly gingivally to match with the gingival line and proper contact point of the maxillary central incisors. The first premolar bracket was positioned slightly distal to hide the palatal cusp of the first premolars on both sides and to give a cervical prominence as that of a canine.

The arches were aligned using the following sequence of archwires: 0.014″ NiTi and 0.018″ NiTi, 0.016″ × 0.022″ SS. Later, 0.017″ × 0.025″ SS wire followed by 0:019 × 0:025″ SS wire was placed to level and express the prescription of the bracket. Consolidation of the anterior segment was achieved using an elastic chain. Retraction of the anterior teeth and using an elastic chain were employed to close all spaces left by sliding mechanics with a maximum anchorage situation. First-order bends were performed on the maxillary canines and "cuspid curves" were used on the first premolars to improve the interproximal contact points in the archwire design (Figure 6). Following the diagnostic wax-up, the patient was satisfied and was able to freely perform lateral movement. Therefore, the tip, canine convexity, and palatal cusp tip of the maxillary first premolars were not ground on the following visits. Bolton's analysis indicated that the anterior ratio was less than normal; however, the patient refused to have the maxillary canine teeth reduced. Therefore, the maxillary anterior teeth must be upright in order to provide a proper occlusion

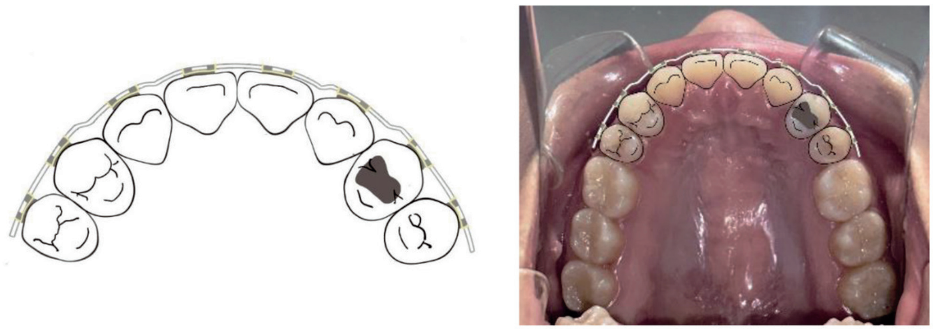

Figure 6 First-order (in-out) bends were performed on the maxillary canines, and "cuspid curves" were used on the first premolars to improve the interproximal contact points in the archwire design.

Figure 7 Posttreatment facial and intraoral photographs.

with an optimal overjet and overbite. From earlier research, it is clear that the canine is a larger tooth than the lateral incisor it would replace. The underlying dentin may start to show through the thin enamel if a substantial quantity of enamel is removed to make the right surface contours, which would reduce the esthetics.[18] In any case, Zachrisson showed that extensive grinding with diamond instruments and a lot of water spray cooling can be done on immature teeth without affecting their sensitivity over a long period of time. However, he found that for 1-3 days after grinding, temperature variations led to temporary increases in tooth sensitivity.[15,19] Finishing and detailing were done, and the appliance was debonded. The total treatment time was 25 months. In the retention phase, wrap around retainers were placed in both arches.

Treatment results

The post-treatment facial photographs exhibited a remarkable improvement of facial esthetics, and the patient's smile had improved. Intraorally, an optimal overbite and overjet relationship was established. A well-interdigitated buccal occlusion with class I molar relationship and a class I canine (first premolar)

Figure 8 Posttreatment dental cast photographs.

Table 2 Comparison of pretreatment and post-treatment dental cast analysis.

Parameters		Pretreatment	Post-treatment
Overjet		0.50 mm	2 mm
Overbite		0.50 mm	2 mm
Canine relationships	Right	Class I	Class I
	Left	Class I	Class I
Molar relationships	Right	Class I	Class I
	Left	Class I	Class I
Upper	Midline	Center	Center
	Arch form	Paraboloid-shaped	Paraboloid-shaped
	Intercanine width	35 mm	37.50 mm
	Intermolar width	54 mm	52 mm
Lower	Midline	Center	Center
	Arch form	Paraboloid-shaped	Paraboloid-shaped
	Intercanine width	29 mm	28 mm
	Intermolar width	52 mm	46 mm

relationship on both sides were achieved, as well as upper and lower dental midlines which coincided with the facial midline (Figures 7 and 8). According to a previous study, mandibular intercanine width tends to expand during treatment by 1-2 mm and contract postretention to approximately the original dimension.[20] In this case, the mandibular intercanine width was reduced slightly by 1 mm to avoid traumatic occlusion between the mandibular canine's cusp tip and the inclined plane of the buccal cusp of the maxillary first premolar. Since the maxillary first premolar is now used instead of the maxillary canine, the maxillary intercanine width increased slightly by 2.50 mm (Table 2). There was canine guidance

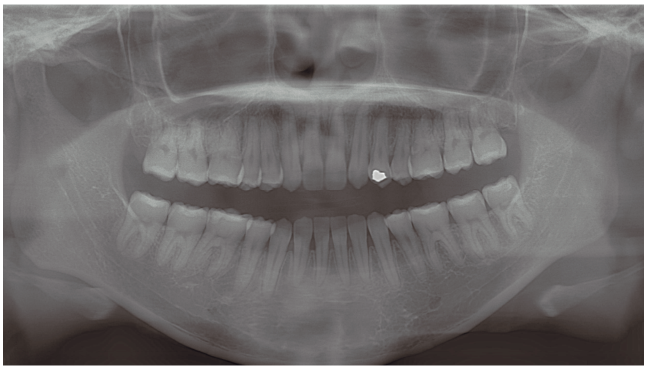

Figure 9 Posttreatment panoramic radiograph.

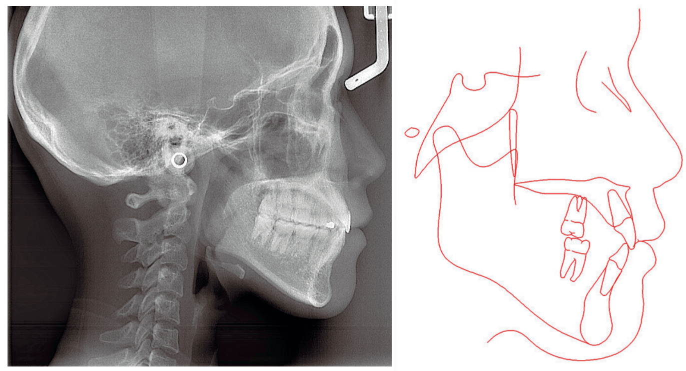

Figure 10 Posttreatment lateral cephalometric radiograph and tracing.

in lateral excursions with proper anterior guidance without balancing side interferences. The spaces left by missing maxillary lateral incisors were closed with canine mesialization. Contact of the canines, gingival line, and color in relation to the surrounding teeth should all be in acceptable condition. This case was completed with esthetically and functionally satisfactory results. Although this case required some adjunctive procedures to improve the esthetics, the patient decided she was very satisfied with the achieved results. Radiographs revealed parallelism of dental roots and no root resorption of the maxillary canines or other teeth (Figure 9). The post-treatment cephalometric radiograph (Figure 10) showed significant changes in the dental measurements after treatment. In particular, the measurements intended to decrease the protrusion of the anterior teeth (U1-NA, U1-SN, L1-NB, L1-MP, U1-L1).

Appropriate anchorage control was applied to both the maxillary and mandibular molars by adding a reverse curve of Spee on the main arch wires and bonding buccal tubes to the third molars for increased anchorage. In the lateral cephalometric analysis between the pretreatment and post-treatment stages, there was no increase in face height, but the technique significantly decreased the protrusion of the maxillary anterior teeth (Figure 11). Furthermore, both the maxillary and mandibular incisors had lingual inclinations with a 42° increase in the interincisal angle. According to the cephalometric superimposition, the skeletal measurement variables had not changed; however, the interincisal angle had increased. Furthermore, the soft tissue profile indicated that the upper and lower lip had moved backward with a 2 mm decrease in the U-lip to E-line and a 7 mm decrease in the L-lip to E-line.

Figure 11 Cephalometric superimpositions between the pretreatment and posttreatment stages: overall, maxilla, and mandible. The black and red lines showed pretreatment and post-treatment, respectively.

Table 3 Pretreatment, posttreatment, and postretention cephalometric analysis (Thai norm).

Area		Measurement	Norm Mean ± SD	Pretreatment	Posttreatment	Postretention
Reference line		FH-SN (degree)	6 ± 3	5	5	5
Skeletal	Maxilla to cranial base	SNA (degree)	84 ± 4	88	88	88
		SN-PP (degree)	9 ± 3	8	8	8
	Mandible to cranial base	SNB (degree)	81 ± 4	81	81	81
		SN-MP (degree)	29 ± 6	34	34	34
		SN-Pg (degree)	82 ± 3	81	81	81
		NS-Gn (degree)	68 ± 3	70	70	70
	Maxillo-mandibular	ANB (degree)	3 ± 2	7	7	7
		Wits (mm)	−3 ± 2	0	0	0
		MP-PP (degree)	21 ± 5	26	26	26
		FMA (degree)	23 ± 5	33	33	33
Dental	Maxillary dentition	U1 to NA (degree)	22 ± 6	26	13	14
		U1 to NA (mm)	5 ± 2	10	1	2
		U1 to SN (degree)	108 ± 6	118	99	100
	Mandibular dentition	L1 to NB (degree)	30 ± 6	47	25	26
		L1 to NB (mm)	7 ± 2	24	8	9
		L1 to MP (degree)	99 ± 5	110	84	85
	Maxillo-mandibular	U1 to L1 (degree)	125 ± 8	93	135	134
Soft tissue	Soft tissue	E line U. lip (mm)	−1 ± 2	2	0	0
		E line L. lip (mm)	2 ± 2	7	0	0
		Nasolabial angle (degree)	91 ± 8	113	117	117
		H-angle (degree)	14 ± 4	19	18	18

During the postretention phase, which occurred two years and two months after the end of active treatment, no significant changes in the facial profile or occlusion were observed. Also, stable occlusion with a satisfactory facial profile and functional excursion without interference were achieved. The maxillary canines and neighboring teeth were in good condition but the patient declined to reshape the maxillary canines to resemble lateral incisors and grind the lingual cusp of the maxillary first premolars (Figures 12-14). A comparison of post-treatment and postretention lateral cephalograms revealed only minor differences in the U1-NA, U1-SN, L1-NB, L1-MP, and interincisal angle (Figure 15 and Table 3). The patient maintained a stable occlusion without functional interference.

Figure 12 Postretention facial and intraoral photographs.

Figure 13 Postretention dental cast photographs.

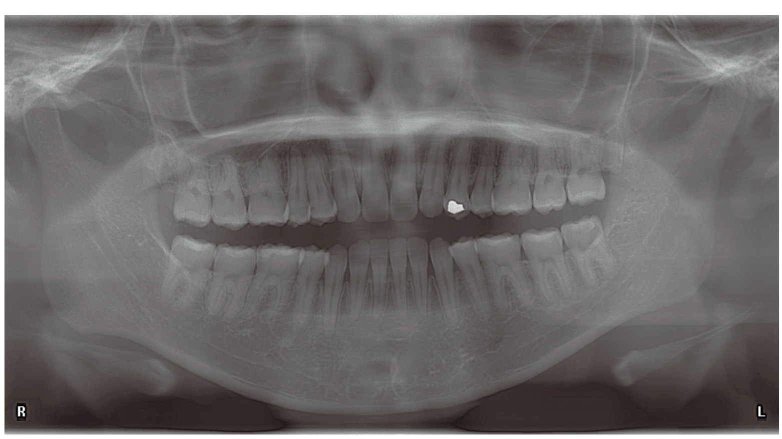

Figure 14 Postretention panoramic radiograph.

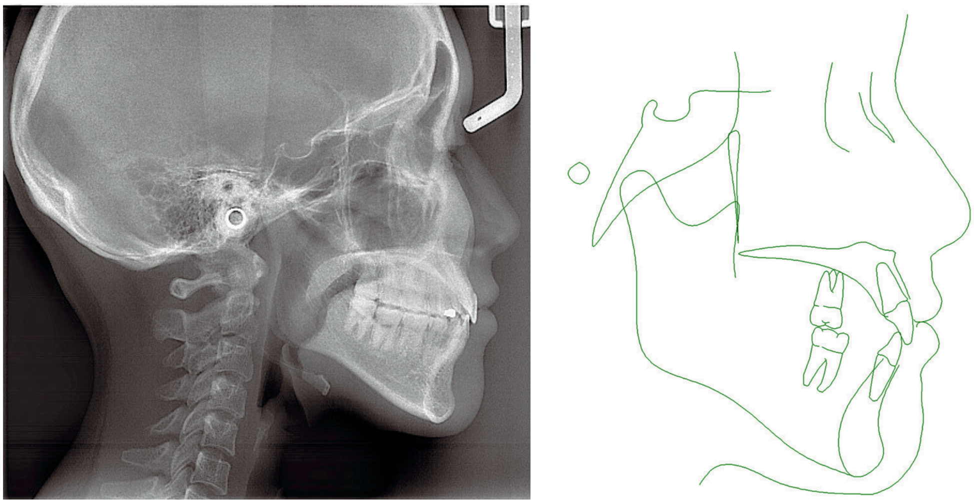

Figure 15 Postretention lateral cephalometric radiograph and tracing reveal a slight distinction between post-treatment and postretention.

Discussion

In many routine dental malocclusions, orthodontic treatment alone may not be sufficient to provide esthetic anterior teeth and correct agenesis. Therefore, patients must be informed of their total dental needs and not just those associated with a limited specialty. There are numerous difficulties in achieving and maintaining an ideal result, regardless of whether canine substitution, single implants, or tooth-supported restorations are the method of choice for patients with missing maxillary lateral incisors. Before closing the missing lateral incisor spaces by canine substitution, the degree of esthetic improvement varies depending on the shape and position of the canines and the clinician's ability to make these teeth resemble and function as lateral incisors.[21] A lack of color contrast between the canines and central incisors, as well as inappropriate reshaping of the canines can result in an unpleasant esthetic result.[19] Furthermore, the type of malocclusion determines whether the spaces are open or closed. If the anterior teeth protrude or crowd, Class I and II malocclusion is the ideal kind of occlusion because the space needs to be closed to allow for proper tooth alignment. Finally, patient satisfaction will influence the treatment plan.

The canines can be moved mesially to close the lateral spaces, which reduces the need for a prosthetic restoration, and the maxillary first premolars can be used to replace the canines. The maxillary anterior teeth can be retracted, which directly alters lip position and increases the nasolabial angle, which improves the facial profile. A canine-protected occlusion cannot be obtained when the canines are relocated mesially, although some clinicians advise against closing missing lateral incisor spaces because they consider achieving a canine-guided occlusion a mandatory orthodontic treatment goal.[22] However, after space closure, a functional occlusion can be obtained with lateral group function.[23] Others have found no significant differences in the adequacy of occlusal function between groups with space opening and those with mesial movement of the canines.[10,21] To improve occlusal stability, canine incisal edges should be reduced to eliminate premature contacts with the mandibular incisors.[24] Furthermore, grinding of the maxillary first premolars can be performed to limit cross-tooth balancing interferences.[18]

Over the past few decades, dental implants have emerged as one of the most popular biomaterials to replace one or more lost teeth;[25] however, not all patients can benefit from this. The replacement of a missing lateral incisor by an implant is a predictable treatment approach. However, it might best to defer an implant until dental maturity, at which time a dental implant can be accurately placed in a well-developed site through a multidisciplinary approach. Many patients may benefit from orthodontic space closure because it reduces the number of dental implants required. The study found that subjects who had orthodontic space closure felt more confident in the appearance of their teeth than patients who wore prosthetics.[10] Furthermore, while high implant survival rates are anticipated, biologic and technical complications are common and can manifest as unethical soft- and hard-tissue changes around implant-supported porcelain crowns in the anterior maxilla. These complications can occur in patients even after a few years.[26] With either approach, no significant differences in the prevalence in the signs and symptoms of temporomandibular dysfunction were observed between patients.[10,23]

Canines have a wide and long root, whereas lateral incisors frequently have a narrow alveolar bone area, which reflects the tooth's typical root shape. Placing a canine anteriorly to replace missing maxillary lateral incisors was reported to reduce the size of the maxillary arch, which resulted in a disharmonious smile and jeopardized facial balance.[27] Obviously, if a patient has bilateral agenesis of the maxillary lateral incisors, the maxillary bone volume is decreased.[24] Alveolar canine buttressing of the canine roots is visible anteriorly where the lateral incisors should be, and the dental arch narrows distally in the canine substitution case. Although the arch form appears to be condensed and constricted after canine mesialization, Gianelly[28] reported a similar conclusion that extraction treatments do not constrict arch form. However, even if the canines are reshaped esthetically, the dentoalveolar arch curvature cannot be changed. The patient in full smile displays the buccal corridor because the arch circumference is diminished with the closure of the lateral incisor spaces. There is less dentoalveolar bone to work with to create an esthetic smile.[15] In extraction cases, however, the buccal corridor can be eliminated by applying labial crown torque to lingually inclined canines and premolars during treatment.[10] In this case, to improve the interproximal contact points, decrease the buccal corridor, and diminish recontoured canines in the archwire design, first-order bends (in-out) were performed on the maxillary canines, and "cuspid curves" were incorporated on the maxillary first premolars.

Canines typically appear darker in color than lateral and central incisors, consequently orthodontists must take the extent of this color difference into consideration when determining whether to open or close missing maxillary lateral spaces.[29] Lack of color harmony between maxillary canines and neighboring teeth, according to Robertsson and Mohlin,[10] was a significant factor in patient dissatisfaction among individuals who received orthodontic treatment to close missing lateral incisor spaces. It is possible that the color difference between canines and central incisors will become even more pronounced due to the alteration in canine color degradation caused by labial enamel reduction, as well as the decrease in translucency and darker canine color given on by incisal edge recontouring.[18] The appearance of the canines in respect to the central incisors could be improved through bleaching techniques.[24] Although this patient's canines, maxillary central incisors, and first premolars all seemed to be the same color, the teeth's forms and sizes were remarkably different. Some canines have such a distinct appearance that it is difficult to reshape them into acceptable lateral incisor anatomy. They take various shapes that range from conical to trapezoidal, and reshaping is only possible within certain limits. The patient may find the esthetic outcome to be rather unpleasant when the canine shape imposes severe limits on reshaping, leading the clinician to seek a space opening to obtain better esthetics. In this present case, the patient was content with the images produced by the setup models and did not wish to reshape or recontour the teeth.

The ideal anterior gingival architecture has the central incisor and canine margins at the same level, while the lateral incisor gingival contour is approximately 1 mm more incisal.[30] In this present case of closing the missing lateral incisor spaces, the gingival margin of the natural canine should be positioned slightly incisal to the central incisor gingival margin. Also, the gingival margin of the first premolar was naturally positioned more coronally than the central incisor. This helped camouflage the substituted canine. Occasionally, a gingivectomy may be needed to properly position the gingival margin. As a result, space closure may result in an unsightly anterior gingival anatomy, particularly when combined with a high smile line.

When treating patients with canine substitution, proper bracket placement is critical. Canine brackets are typically placed at a distance from the gingival margin that allows the teeth to erupt into the appropriate lateral incisor vertical position. A thicker portion of the crown comes into contact with the mandibular incisors as they erupt. This frequently results in prematurities that must be adjusted on a regular basis during the alignment stage of orthodontic treatment. In this patient, we used inverted MBT canine brackets on the canines to deliver +7° of labial crown torque that nearly matched the torque of the lateral incisor on the contralateral side, and a 0.019″ × 0.025″ SS wire was used to level and express the prescription of the bracket. The advantage of using these techniques is that prior enameloplasty is not needed as the bracket base matches the surface contour of the tooth.

Selecting appropriate cases is essential to a treatment's success to achieve lasting results. The patient's desired type of occlusion, Class I malocclusion with bimaxillary dental protrusion, can be achieved by using the lateral incisor spaces to reduce the anterior teeth protrusion and avoid the need for prosthesis. In this current case, the post-treatment well-interdigitated occlusion, placement of all teeth in the appropriate bone housing, the patient's cooperation and attitude, and functional excursion without interference were all significant factors that contributed to the stable results.

Conclusion

Closing the space with canine mesial movement and replacing the canines with maxillary first premolars are possible treatment options in the case of Class I malocclusion with bimaxillary dental protrusion and bilateral congenitally missing maxillary lateral incisors. The treatment in this case established a stable occlusion and a pleasing facial appearance in a comparatively short amount of time without the need for a prosthesis. The main benefits of orthodontic space closure are the long-term nature of the outcome and the possibility to conclude treatment in early adulthood.

Author contributions

SM: Conceptualization, Methodology, Resources, Writing-Original Draft, Writing-Review & Editing, Visualization.

Disclosure statement

The author has no conflicts of interest.

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References

1. Shapiro SD, Farrington FH. A potpourri of syndromes with anomalies of dentition. In: Jorgenson RJ, editors. Dentition genetic effects. birth defects: original article series. New York: March of Dimes Birth Defects Foundation; 1983.p.129-40.
2. Graber LW. Congenital absence of teeth: a review with emphasis on inheritance pattern. J Am Dent Assoc 1978;96:266-75.

3. Alvesalo L, Portin P. The inheritance pattern of missing, peg-shaped and strongly mesio-distally reduced upper lateral incisors. Acta Odontol Scand 1969;27:563-75.
4. Kanchanasevee C, Theerapanon T, Intarak N, Pittayapat P, Porntaveetus T. Prevalence and pattern of tooth agenesis in non-syndromic Thai dental patients. RSU Int Res Conf 2019:36-44.
5. De Coster PJ, Marks LA, Martens LC, Huysseune A. Dental agenesis Genetic and clinical perspectives. J Oral Pathol Med 2009;38:1–17.
6. Schalk-van der Weide Y, Steen WH, Bsman F. Distribution of missing teeth and tooth morphology in patients with oligodon-tia. ASDC J Dent Child 1992;59(2):133–40.
7. Chung CJ, Han JH, Kim KH. The pattern and prevalence of hypodontia in Koreans. Oral Dis 2008;14:620–5.
8. Stamatiou J, Symons AL. Agenesis of the permanent lateral incisor: distribution, number and sites. J Clin Pediatr Dent 1991;15:244-6.
9. Kokich VO Jr. Congenitally missing teeth: orthodontic management in the adolescent patient. Am J Orthod Dentofacial Orthop 2002;121:594-5.
10. Robertsson S, Mohlin B. The congenital missing upper lateral incisor. A retrospective study of orthodontic space closure versus restorative treatment. Eur I Orthod 2000;22:697-710.
11. Dechkunakorn S, Chaiwat J, Sawaengkit P, Anuwongnukorh N, Taweesedt N. Thai adult norms in various lateral cephalometric analyses. J Dent Assoc Thai 1994;44(5):202-13.
12. Savarrio L, McIntyre GT. To open or to close space—that is the missing lateral incisor question. Dental Update 2005;32(1):16–25.
13. Wriedt S, Werner P, Wehrbein H. Tooth shape and color as criteria for or against orthodontic space closure in case of a missing lateral incisor. J Orofacial Orthop 2007;68(1):47–55.
14. Woodworth DA. Bilateral congenital absence of maxillary lateral incisors--a craniofacial and dental cast analysis. Am J Orthod 1985;87:280-93.
15. Thordarson A, Zachrisson BU, Mjor IA. Remodeling of canines to the shape of lateral incisors by grinding: a long-term clinical and radiographic evaluation. Am J Orthod Dentofacial Orthop 1991;100:123-32.
16. Kokich VG. Managing orthodontic-restorative treatment for the adolescent patient. In: McNamara JA, Brudon WL, editors. Orthodontics and dentofacial orthopedics. Ann Arbor, Michigan: Needham Press Inc; 2001.p.1-30.
17. BU, Rosa M. Integrating esthetic dentistry and space closure in patients with missing maxillary lateral incisors. J Clin Orthod 2001;35:221-34.
18. McNeill RW, Joondeph DR. Congenitally absent maxillary lateral incisors: treatment planning considerations. Angle Orthod 1973;43:24-9.
19. Sabri R. Management of missing lateral incisors. J Am Dent Assoc 1999;130:80-4.
20. Burke SP, Silveira AM, Goldsmith LJ, Yancey JM, Van Stewart A, Scarfe WC. A meta-analysis of mandibular intercanine width in treatment and postretention. Angle Orthod 1998;68(1):53-60.
21. Senty EL. The maxillary cuspid and missing lateral incisors: esthetics and occlusion. Angle Orthod 1976;46:365-71.
22. Henns RJ. The canine eminence. Angle Orthod 1974;44:326-8.
23. Nordquist GG, McNeill RW. Orthodontic versus restorative treatment of the congenitally absent lateral incisor-long term periodontal and occlusal evaluation. J Periodontol 1975;46:139-43.
24. Rosa M, Zachrisson BU. Integrating esthetic dentistry and space closure in patients with missing maxillary lateral incisors. J Clin Orthod 2001;35:221-34.
25. Guillaume B. Dental implants: a review. Morphologie. 2016;100(331):189-98.
26. Jemt T. Single implants in the anterior maxilla after 15 years of follow-up: comparison with central implants in the edentulous maxilla. Int J Prosthodont 2008;21:400-8.
27. Wheeler RC. Textbook of dental anatomy. Philadelphia: WB Saunders; 1965.p.315-27.
28. Gianelly AA. Arch width after extraction and nonextraction treatment. Am J Orthod Dentofacial Orthop 2003;123:25-8.
29. Shaw WC. The influence of children's dentofacial appearance on their social attractiveness as judged by peers and lay adults. Am J Orthod 1981;79:399-415.
30. Kokich VG, Nappen DL, Shapiro PA. Gingival contour and clinical crown length: their effect on the esthetic appearance of maxillary anterior teeth. Am J Orthod 1984;86:89-97.