E- ISSN: 2148-9505

TURKISH JOURNAL OF ORTHODONTICS

TJO

The Official Journal of Turkish Orthodontic Society

galenos Publishing House

Volume 38
Issue 02
June 2025

The Official Journal of Turkish Orthodontic Society

TURKISH JOURNAL OF ORTHODONTICS

TJO

Owner

Gökmen Kurt
Department of Orthodontics, Bezmialem Vakıf University Faculty of Dentistry, İstanbul, Türkiye

Editor in Chief

Çağla Şar
Department of Orthodontics, Istanbul Health and Technology University School of Dentistry, İstanbul, Türkiye
ORCID ID: 0000-0003-4966-9779

Associate Editors

Furkan Dindaroğlu
Department of Orthodontics, Ege University School of Dentistry, İzmir, Türkiye
ORCID ID: 0000-0003-4456-3115

Feyza Eraydın
Department of Orthodontics, İstanbul Gelişim University School of Dentistry, İstanbul, Türkiye
ORCID ID: 0000-0002-7791-6979

Seden Akan Bayhan
Department of Orthodontics, Yeditepe University School of Dentistry, İstanbul, Türkiye
ORCID ID: 0000-0001-7955-3086

galenos Publishing House

Publisher Contact
Address: Molla Gürani Mah. Kaçamak Sk. No: 21/1
34093 İstanbul, Türkiye
Phone: +90 (530) 177 30 97
E-mail: info@galenos.com.tr/yayin@galenos.com.tr
Web: www.galenos.com.tr
Publisher Certificate Number: 14521

Printing Date: July 2025
E-ISSN: 2148-9505
International scientific journal published quarterly.

TURKISH JOURNAL OF ORTHODONTICS

The Official Journal of Turkish Orthodontic Society

Editorial Board

Please refer to the journal's webpage (**https://turkjorthod.org/**) for "Ethical Policy", "Instructions to Authors" and "About Us".

The editorial and publication processes of the journal are shaped in accordance with the guidelines of the ICMJE, WAME, CSE,COPE, EASE, and NISO. Turkish Journal of Orthodontics is indexed in PubMed Central, Web of Science-Emerging Sources Citation Index, DOAJ, Scopus, CNKI, Gale, EBSCO and TUBITAK ULAKBİM TR Index.

The journal is published online.

Owner: Gökmen Kurt on behalf of the Turkish Orthodontic Society

Responsible Manager: Çağla Şar

Editor in Chief: Çağla Şar

Address: Sütlüce Mah. İmrahor Cad. No: 82 Beyoğlu, İstanbul/Türkiye

Phone: +90 (212) 416 61 13

E-mail: info@turkjorthod.org

The Official Journal of Turkish Orthodontic Society

TURKISH JOURNAL OF ORTHODONTICS

TJO

Contents

Original Articles

80 **Does LeFort I Surgery Have Any Influence on External Root Resorption?**
Ellen Kim, Ahmed A. Alsulaiman, Michael J. Gunson, Leslie A. Will, Marianne Saade, Melih Motro

89 **3-Dimensional Evaluation of Enamel Thickness to Guide Orthodontic Interproximal Reduction: A CBCT-Based Study Across Gender and Ethnicity**
Ezgi Cansu Fırıncıoğulları, Aslıhan Ertan Erdinç, Sercan Akyalçın

97 **Finite Element Method (FEM) Analysis of Dentoskeletal Changes on Temporary Anchorage Device (TAD)-Assisted Mandibular Advancement**
Nazleen Valerie Vas, Navaneethan Ramasamy, Sruthi Harikrishnan, Karthikeyan Ramalingam, Marco Di Blasio, Hande Uzunçıbuk, Marco Cicciù, Giuseppe Minervini

107 **Comparative Effects of Maxillary Advancement Alone and in Combination with Mandibular Setback on Airway Anatomy and Function in Class III Malocclusion: A Controlled Prospective Clinical Study**
Hatice Başaran Bal, Celal Irgın

116 **Impact of Camouflage Treatment with Class III Elastics on Temporomandibular Joint and Dentoskeletal Relationships: A Pilot CBCT and MRI-Based Clinical Trial**
Panjaree Panpitakkul, Teekayu Plangkoon Jorns, Warinthorn Phuttharak, Rajda Chaichit, Pipop Sutthiprapaporn

Reviews

128 **The Effect of Diabetes Mellitus on Mandibular Growth**
Nearchos Panayi, Apostolos Tsolakis, Dimitrios Konstantonis, Ioannis Tsolakis, Maria Kouri, Georgia Kotantoula, Ismene A. Dontas

133 **Clinical Outcomes of Skeletal Anchorage Versus Conventional Anchorage in the Class III Orthopaedic Treatment in Growing Patients: A Systematic Review and Meta-Analysis**
Rachele Podda, Francesca Imondi, Adriana Assunta De Stefano, Martina Horodynski, Roberto Antonio Vernucci, Gabriella Galluccio

TURKISH JOURNAL OF ORTHODONTICS

DOI: 10.4274/TurkJOrthod.2025.2024.135

Original Article

Does LeFort I Surgery Have Any Influence on External Root Resorption?

Ellen Kim[1], Ahmed A. Alsulaiman[2], Michael J. Gunson[1], Leslie A. Will[1], Marianne Saade[1], Melih Motro[1]

[1]Boston University, Henry M. Goldman School of Dental Medicine, Department of Orthodontics and Dentofacial Orthopedics, Boston, Massachusetts
[2]Imam Abdulrahman Bin Faisal University College of Dentistry, Department of Preventive Dental Sciences, Dammam, Saudi Arabia

Cite this article as: Kim E, Alsulaiman AA, Gunson MJ, Will LA, Saade M, Motro M. Does LeFort I surgery have any influence on external root resorption?. *Turk J Orthod.* 2025; 38(2): 80-88

Main Points

- LeFort I segmental osteotomy shows increases in root resorption at all time points.
- No statistically significant differences were found between the control and study groups except for a few variables.
- Changes in root length were all less than 1 mm.

ABSTRACT

Objective: The aim of our study was to evaluate root resorption on maxillary teeth neighboring osteotomy sites in response to segmental LeFort I osteotomy over time.

Methods: Eighteen subjects, aged 18 to 65 years with pre-surgery (T0), post-surgery (T1), and long-term follow-up (T2) CBCT records were included. Sixteen control subjects, aged 17.67 to 62.33 years, with pre-treatment (T0), progress (T1), and long-term progress orthodontic (T2) CBCT records were also used. Maxillary central incisor, canine, and first molar roots were segmented. The volume, surface area, and root length changes were analyzed using repeated measures ANOVA and mean differences across follow-up periods. Significance was set at $p<0.05$.

Results: The surgical group had an overall increase in the amount of root resorption in all time comparisons and variables with significance ($p<0.05$) in length, volume, and surface area. When comparing mean differences between the control and surgical groups, no significant differences were observed except for a few variables.

Conclusion: LeFort I segmental osteotomy in conjunction with orthodontic treatment, induces root resorption. However, except for a few variables, the differences compared to orthodontic treatment alone are not statistically significant. Moreover, these findings are clinically insignificant.

Keywords: LeFort I, root resorption, CBCT

INTRODUCTION

Root resorption is defined as the loss of dental hard tissues due to an inflammatory response following injury to the root surface and long-term stimulation.[1] Irreversible damage of tooth structure compromises the integrity and longevity of the tooth and may result in its early loss. Although a complex and multifactorial process, root

Corresponding author: Melih Motro, **e-mail:** mmotro@bu.edu
Received: September 26, 2024 **Accepted:** May 15, 2025 **Publication Date:** July 02, 2025

resorption is an undesired side effect of orthodontic tooth movement and treatment modalities.[2]

One of the most common surgical procedures used in conjunction with orthodontic therapy to correct dentofacial deformities is LeFort I osteotomy. This technique describes the osteotomy pattern that starts from the piriform aperture, continuing the cut above the roots of the teeth and through to the pterygomaxillary junction on both sides.[3,4] If the transverse dimension of the maxilla requires change, a segmental LeFort I osteotomy can be performed.[5] The interdental osteotomies are commonly placed between lateral incisors and canines or between the canines and first premolars. It has been noted that there is an increased risk for periodontal and root damage, specifically in cases where the interdental space is less than 2.5 mm and the subapical cuts are closer than 15 mm from the alveolar border in molar area.[6,7]

Recently, there has been an increased interest in the development of surgical techniques to take advantage of the regional acceleratory phenomeon (RAP) in orthodontics to accelerate tooth movement. The RAP is a physiologic healing response to noxious stimuli that accelerates the healing capacity of the affected hard and soft tissues.[8] Studies have found that interdental osteotomies and orthognathic surgery induce a regional inflammatory process, bone remodeling, and increase cellular activity in the dentoalveolus that lasts for approximately 3 to 4 months. This increased bone turnover leads to a high presence of clastic cellular activity inducing root resorption.[9-12]

External root resorption is a well-acknowledged concern in orthodontics. Recent studies using cone-beam computerized tomography (CBCT) have shown that the resorption affects all root surfaces and is not limited to the apex.[2,13] However, there is little evidence quantifying the effects of maxillary surgery on the teeth adjacent to subapical and interdental osteotomies over the long term.

The aim of this study was to assess the resorptive effects of maxillary osteotomies on the root surfaces of maxillary central incisors, canines, and first molars using CBCT images. The null hypothesis tested was that there were no differences in root resorption between patients who underwent combined orthodontic and segmental LeFort I osteotomy and those who received orthodontic treatment only.

METHODS

This retrospective study was conducted at the Department of Orthodontics, Boston University Henry M. Goldman School of Dental Medicine. CBCT records were acquired from the department repository (H-32515). Sample and control CBCT scans were taken on i-CAT machines (120kV, 5mA, voxel size 0.3 mm, Imaging Sciences International, Hatfield, PA, USA).

The surgical group was selected based on the following criteria: adults between 18 and 65 years of age who underwent segmental LeFort I osteotomy and had presurgical (T0), immediate post-surgical (T1), and long-term post-surgical or 1 month after removing the braces (T2) CBCT records. Individuals with more than two teeth with one-third of the root resorbed at baseline, incomplete or poor-quality radiographs, a history of craniofacial anomaly or syndromes, craniofacial trauma or surgery, and systemic diseases affecting bone quality were excluded. All studied teeth had fully intact roots with no visible damage. Interdental vertical osteotomies were performed at predetermined positions between the maxillary lateral incisors and canines, meeting the H-shaped para-median palatal osteotomy.

The sample size calculation was undertaken in G*Power 3.1.9.6 (Heinrich-Heine-University-Dusseldorf, Germany) using a repeated-measures ANOVA model with an estimated small effect size of 0.25, a correlation between repeated measures of 0.80, and a non-sphericity correction of 1. For an a priori α of 0.05 and 80% power, the total sample size required was at least 15 participants per group to demonstrate a difference of 0.5 mm in root resorption.[14]

The CBCT records for the control group were selected from the same repository. They were matched by sex, age, and duration of treatment, underwent conventional orthodontic therapy without any surgical intervention, and had pretreatment (T0), progress (T1), and long-term progress (T2) CBCT records, following the same exclusion criteria as the surgical group. Both control and study groups had Class II malocclusion. The surgical group included 18 subjects and 92 teeth (30 maxillary central incisors, 32 maxillary canines, and 30 maxillary first molars). Specific teeth immediately adjacent to or directly affected by surgical screws or temporary anchorage devices, and those with direct root damage from surgical instruments were excluded. Hence the numbers of teeth were not equal. The control group included 16 subjects and 91 teeth (29 maxillary central incisors, 31 maxillary canines, and 31 maxillary first molars) with similar inclusion and exclusion criteria. Some control teeth were excluded due to imaging artifacts in the region.

The maxillary central incisor, canine, and first molars roots were segmented, and the volume, surface area, and linear measurements were performed using Mimics™ v.22.0 Software (Materialise, Belgium) (Figures 1 and 2).[13,15]

Measurements were taken by one examiner (EK). Intraclass correlation (ICC) and paired t-test were used for intra-examiner reliability, utilizing a random sample (n=6). All measurements had an ICC value >0.90, and none were found to be statistically significantly different, indicating excellent reliability.

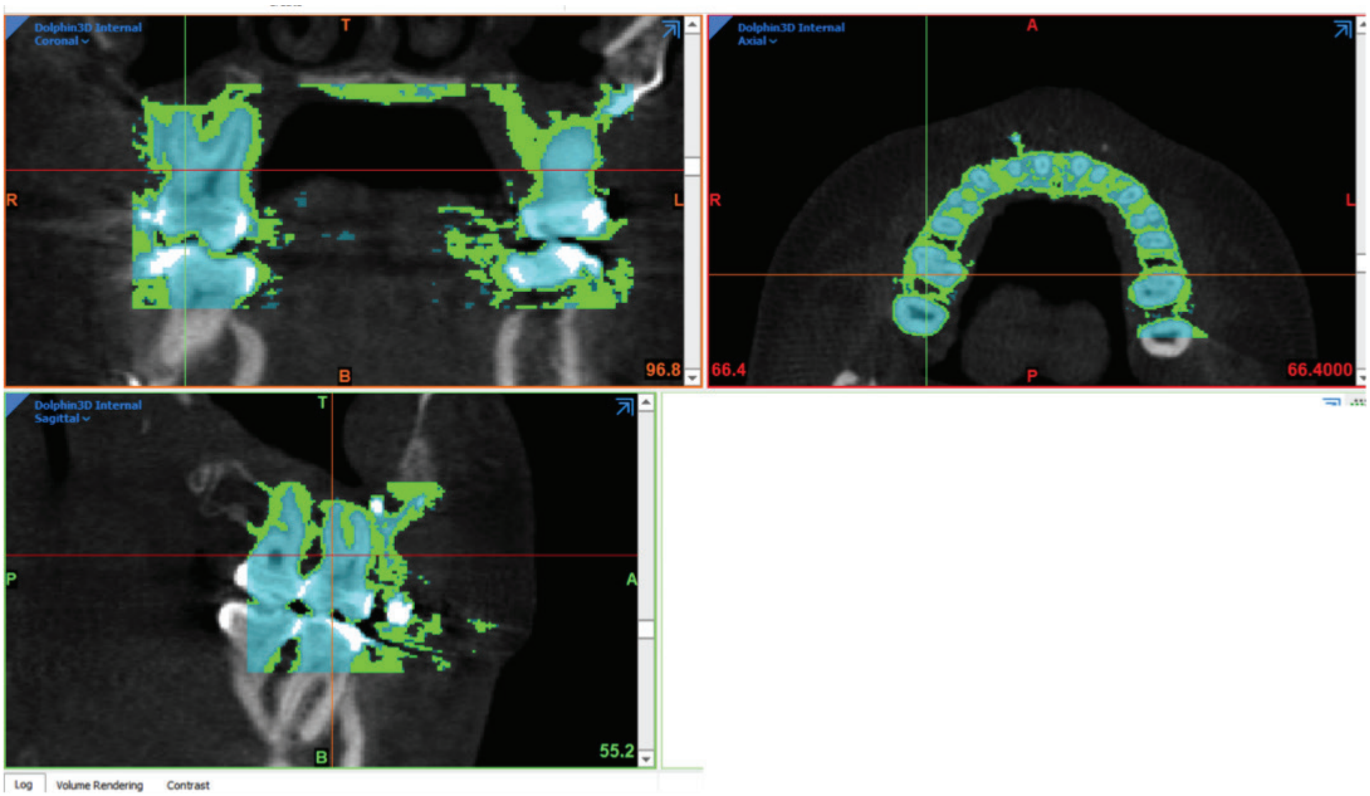

Figure 1. Custom threshold values were selected to create masks (1) include teeth and surrounding bone and periodontal ligament (PDL) and (2) space around teeth (bone and PDL). The 2 masks were subtracted with Boolean operation function to result in the segmented teeth/root mask.

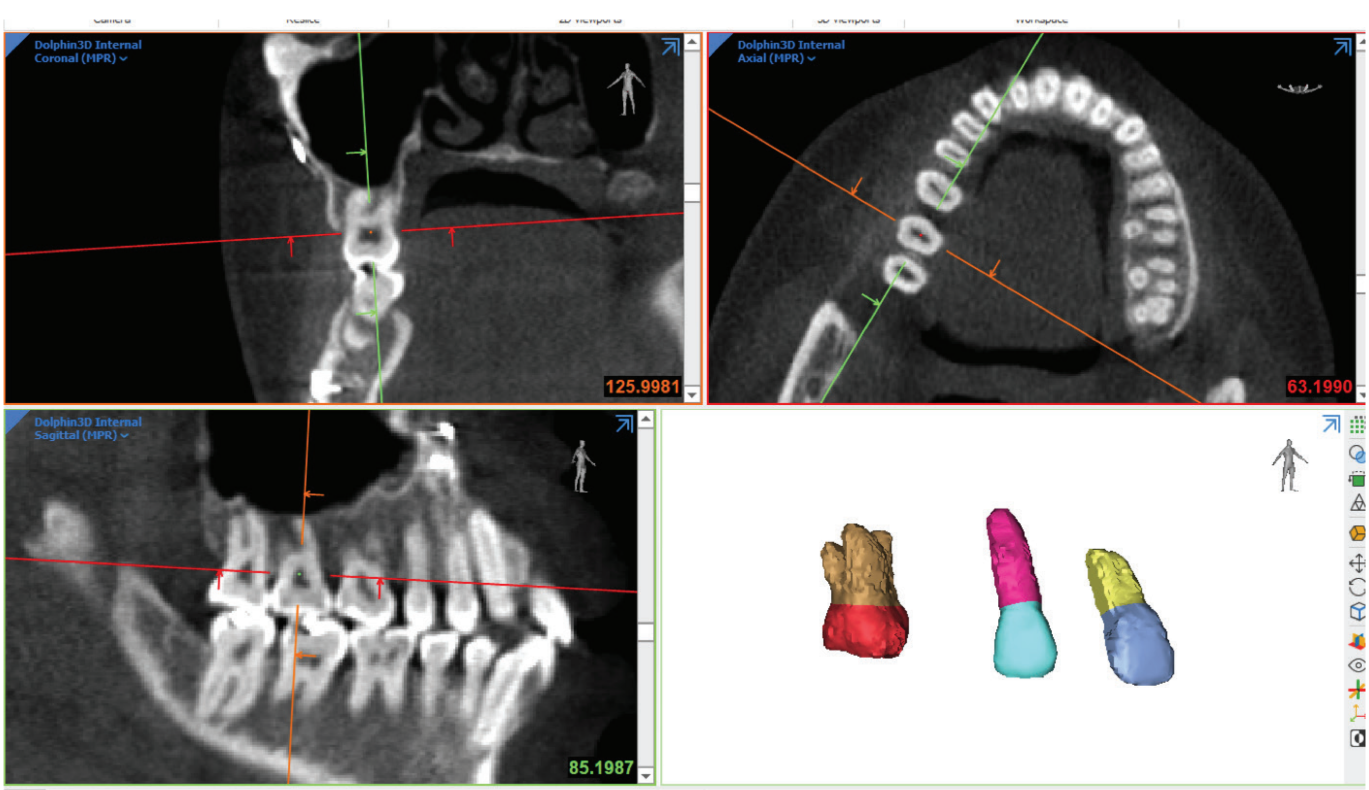

Figure 2. Interactive multiplanar reconstruction function was used to adjust the axial, coronal, and sagittal views for placing reference points. The axial, coronal, and sagittal planes were adjusted along the long axis of the tooth and to intersect at the center of the tooth. 3 reference points were marked to create the CEJ plane (buccal CEJ point, palatal CEJ point, and mesial CEJ point) to segment the crown from the root.

Statistical Analysis

The data was normally distributed as assessed by Shapiro-Wilk's test. Descriptive statistics were used, and results were analyzed using repeated-measures analysis of variance (ANOVA) for all variables. Additionally, chi-squared and Student's t-test were used to assess the mean differences between the surgical and control groups. All statistical analysis were performed using SAS Software Version 9.4 (SAS Institute Inc., Cary, NC, USA).

RESULTS

A chi-squared and paired t-test were performed, and no significant differences were found ($p>0.05$) between groups for sex, age, or time interval (T0 to T2) (Table 1).

Overall, the control and surgical groups showed an increasing trend in root resorption with variations in significance across some variables (Tables 2 and 3).

Surgical Group:

Between T0 and T2, there was significant ($p<0.05$) root resorption in all variables except for the maxillary left canine root volume. Additionally, there were more significant variables from T0-T1 compared to T1-T2 (eighteen and eleven variables, respectively).

Control Group:

Between T0 and T2, there was ~~a~~ significant ($p<0.05$) root resorption in all variables except for the maxillary right canine root volume and surface area. Moreover, the control group had nearly equal numbers of significant variables between T0-T1 compared to T1-T2 (seventeen and eighteen variables, respectively).

Surgical vs Control Group:

In the surgical group, more significant ($p<0.05$) mean differences in root resorption were noted in the time frame from T1 to T2 compared to T0-T2 and T0-T1, and more on the right-sided variables than the left-sided variables, including the maxillary right central incisor root volume (-11.39 mm^3, p=0.03), the maxillary right canine root volume (-46.72 mm^3, p<0.00), the maxillary right first molar root volume (-44.98 mm^3, p<0.00), the maxillary left central incisor root volume (-19.64 mm^3, p=0.01), the maxillary left first molar mesiobuccal root length (-0.65 mm, p=0.03) (Tables 4-6).

In the control group, only the maxillary left canine root volume was significantly lower ($p<0.05$) at T0-T1 and T0-T2.

DISCUSSION

Studies have noted the prevalence of root resorption after osteotomy; however, most have been based on empirical evidence and case reports, and infrequently use CBCT.[3,6] To the best of our knowledge, this study is the first to quantif y the influence of segmental LeFort I osteotomy in the long term using CBCT, compared to a non-surgical orthodontic group. It is widely accepted that root resorption is an undesired sequelae of orthodontic treatment.[16] Massler and Malone[17] found that 86.4% of orthodontic patients had root resorption. The results of our control group are consistent with previous studies indicating a correlation between orthodontic treatment and root resorption. The data imply that root resorption may not be as prevalent in the maxillary canines as suggested by Sameshima and Sinclair[18] possibly due to the association between root length and resorption. The variations in non-significance may be due to specific orthodontic treatment-related factors such as the amount and direction of tooth movement, the duration of treatment, or mechanical factors that could not be controlled for.[16,19-21]

The surgical group also exhibited a pattern of increased resorption in some variables. The literature reports that LeFort I osteotomy is a risk factor for apical root resorption.[22] A micro-CT study by Patterson et al.[10] showed that root resorption increased due to the presence of clastic cellular activity during increased bone turnover. Other articles did not find any association between root resorption and LeFort I osteotomy, piezocision-assisted movement, and corticotomy-facilitated movement.[11,23] These articles, however, relied on anecdotal findings, 2D imaging, had a short follow-up period, or were based on animal studies. On the other hand, a recent CBCT study found that three-piece LeFort I led to greater root resorption compared to other types of surgery, though the extent of resorption was considered minimal.[24]

From immediate post-surgery (T1) to long-term post-surgery (T2), less significant root resorption was noted when compared to presurgical (T0) to immediate post-surgery (T1). There can be several explanations for this finding. First, for patients undergoing surgery as part of their treatment,

Table 1. Demographics and characteristics of sample and control

		Subjects	Control	p-value
Characteristic		**n=18**	**n=16**	
Age, mean (SD), years		27.11 (9.89)	32.75 (14.73)	0.21
Sex, n (%) of patients				0.69
	Male	4 (22.22)	3 (18.75)	
	Female	14 (77.78)	13 (81.25)	
T0 - T2 (months difference)		15.28 (3.97)	14.13 (2.03)	0.29

*Significance at p<0.05

Table 2. Repeated measure ANOVA for root resorption changes from T0-T2 (Control)

Variable	T0		T1		T2		Multiple comparisons (p-value)								
							T0 vs T1			T0 vs T2			T1 vs T2		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	p<0.05	Mean	SD	p<0.05	Mean	SD	p-value
UR1 length (mm)	22.48	3.30	22.33	3.27	22.04	3.38	-0.15	0.18	0.01*	-0.44	0.30	<0.0001*	-0.28	0.29	0.00*
UR1 volume (mm^3)	258.89	79.29	249.95	78.91	239.94	76.04	-8.94	7.57	0.00*	-18.95	11.28	<0.0001*	-10.01	12.41	0.01*
UR1 SA (mm^2)	249.67	56.70	247.67	57.23	239.45	55.75	-2.00	7.98	0.35	-10.22	6.66	<0.0001*	-8.22	6.47	0.00*
UR3 length (mm)	26.04	2.91	25.85	2.85	25.54	2.91	-0.19	0.19	0.00*	-0.50	0.36	0.00*	-0.31	0.41	0.01*
UR3 volume (mm^3)	365.74	84.01	354.04	83.96	370.61	136.96	-11.70	13.38	0.00*	4.87	82.32	0.82	16.57	79.71	0.43
UR3 SA(mm^2)	330.68	58.69	330.31	57.87	326.16	60.47	-0.38	6.86	0.84	-4.52	8.65	0.06	-4.14	7.89	0.06
UR6 MB length (mm)	19.57	1.33	19.41	1.31	19.00	1.13	-0.16	0.17	0.00*	-0.57	0.52	0.00*	-0.41	0.49	0.00*
UR6 DB length (mm)	19.67	1.44	19.27	1.39	18.83	1.53	-0.40	0.48	0.00*	-0.84	0.69	0.00*	-0.43	0.51	0.00*
UR6 P length (mm)	20.86	1.22	20.58	1.27	20.25	1.39	-0.28	0.24	0.00*	-0.61	0.42	<0.0001*	-0.33	0.26	0.00*
UR6 volume (mm^3)	606.86	97.31	606.86	91.06	573.99	91.06	-23.41	18.93	0.00*	-32.86	22.68	<0.0001*	-9.45	13.91	0.02*
UR6 SA (mm^2)	577.82	79.47	576.24	80.62	568.51	82.05	-1.58	17.61	0.73	-9.30	14.82	0.02*	-7.73	18.03	0.11
UL1 length (mm)	22.26	3.14	22.02	3.19	21.90	3.17	-0.24	0.24	0.00*	-0.36	0.30	0.00*	-0.12	0.18	0.03*
UL1 volume (mm^3)	267.42	79.04	257.40	80.10	254.98	79.99	-10.02	9.53	0.00*	-12.44	11.20	0.00*	-2.42	9.70	0.37
UL1 SA (mm^2)	253.86	55.95	251.32	57.16	244.84	54.91	-2.54	7.02	0.20	-9.02	5.84	<0.0001*	-6.48	6.93	0.00*
UL3 length (mm)	26.00	2.39	25.61	2.28	25.33	2.20	-0.39	0.41	0.00*	-0.68	0.70	0.00*	-0.29	0.39	0.01*
UL3 volume (mm^3)	379.27	66.41	354.52	64.98	346.22	57.82	-24.75	27.32	0.00*	-33.05	32.93	0.00*	-8.30	15.58	0.05*
UL3 SA (mm^2)	343.45	49.01	335.52	45.17	327.36	44.04	-7.92	13.49	0.03*	-16.09	12.47	0.00*	-8.17	8.55	0.00*
UL6 MB length (mm)	20.02	1.50	19.86	1.46	19.67	1.48	-0.16	0.29	0.05*	-0.35	0.39	0.00*	-0.19	0.32	0.04*
UL6 DB length (mm)	19.69	1.59	19.53	1.57	19.28	1.63	-0.16	0.15	0.00*	-0.41	0.40	0.00*	-0.26	0.38	0.02*
UL6 P length (mm)	21.14	1.26	20.97	1.37	20.59	1.44	-0.17	0.21	0.01*	-0.55	0.52	0.00*	-0.38	0.53	0.01*
UL6 volume (mm^3)	604.01	100.40	584.27	95.96	571.88	106.01	-19.74	23.82	0.01*	-32.13	27.17	0.00*	-12.39	16.60	0.01*
UL6 SA (mm^2)	582.49	74.95	579.55	72.47	563.95	81.31	-2.94	15.50	0.47	-18.54	26.43	0.02*	-15.59	21.53	0.01*

*Significance at p<0.05; T0, pre-orthodontic treatment; T1, progress orthodontic treatment; T2, long-term progress orthodontic treatment. SD, standard deviation.

most tooth movements are done pre-surgery, leaving only the detailing and finishing tooth movements post-surgery to debond. Secondly, several studies have noted the healing capacity of the root following damage, with reparative cementum observed about 8 weeks after injury.[25,26] The T2 CBCT records were taken approximately one month after debonding, providing enough time for the root to heal post-surgery. Another possible explanation is the theory that the RAP effect decreases bone density and thereby decreases the likelihood of hyalinization necrosis during tooth movement.[23] Post-surgical orthodontic treatment typically lasts 4 to 6 months, with the RAP effect peaking in the first and second month. However, with typically minor tooth movements occurring post-surgery, it is difficult to determine if the accelerated bone remodeling truly decreases the risk of root resorption.[9] In contrast, Alqahtani et al. found significantly greater root remodeling after 1 and 2 years in the one-piece LeFort I surgery group compared to the bilateral sagittal split osteotomy group.[27]

We evaluated the impact of segmental LeFort I-induced root resorption while comparing it to root resorption induced by orthodontic treatment only. The comparison between the surgical and control groups showed no statistically significant differences, except for a few variables. Consequently, this study did not reject the null hypothesis.

Our results showed more significant surgical resorption on right-sided variables. This could suggest that the surgeon's handedness or position affects the surgical outcomes, thereby further stimulating the resorptive process more on one side than the other. An article analyzing the influence of clinicians' expertise on microimplant drilling also noted a right versus left-hand bias regarding root damage during drilling.[28] However, further studies are needed to evaluate the surgical outcomes of clinician hand preferences regarding teeth injury.

The literature has various methods of classifying the degree of external root resorption, many based on 2D radiographs with mild resorption classified as irregular root contouring or less than 2 mm of original root length, and the most severe resorption

Table 3. Repeated measure ANOVA for root resorption changes from T0-T2 (Subjects)

Variable	T0		T1		T2		Multiple comparisons (p-value)								
							T0 vs T1			T0 vs T2			T1 vs T2		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	p<0.05	Mean	SD	p<0.05	Mean	SD	p-value
UR1 length (mm)	21.53	1.72	21.15	1.92	20.75	2.01	-0.38	0.80	0.09	-0.78	0.97	0.01*	-0.40	0.60	0.02*
UR1 volume (mm^3)	237.43	64.12	218.16	53.47	216.03	65.92	-19.27	20.03	0.00*	-21.40	15.15	<.0001*	-2.12	20.89	0.70
UR1 SA (mm^2)	235.26	42.61	222.64	39.44	217.35	42.70	-12.62	11.04	0.00*	-17.91	11.08	<.0001*	-5.29	8.64	0.03*
UR3 length (mm)	23.71	2.00	23.23	2.05	22.88	2.13	-0.48	0.93	0.04*	-0.82	1.03	0.00*	-0.35	0.79	0.08
UR3 volume (mm^3)	324.87	84.15	304.45	63.13	294.72	63.77	-20.42	27.80	0.01*	-30.15	31.95	0.00*	-9.73	17.61	0.03*
UR3 SA (mm^2)	304.98	56.91	288.27	42.95	281.89	47.43	-16.71	18.92	0.00*	-23.09	19.09	<.0001*	-6.38	14.50	0.08
UR6 MB length (mm)	17.92	1.96	17.65	1.99	17.42	2.12	-0.27	0.32	0.01*	-0.50	0.59	0.01*	-0.22	0.46	0.08
UR6 DB length (mm)	17.22	1.86	16.98	2.01	16.49	2.18	-0.25	0.50	0.08	-0.73	1.01	0.01*	-0.48	0.94	0.07
UR6 P length (mm)	19.39	1.97	19.14	2.16	18.61	2.41	-0.25	0.63	0.15	-0.79	0.96	0.01*	-0.54	0.82	0.02*
UR6 volume (mm^3)	556.11	103.94	518.83	94.88	501.68	98.33	-37.28	41.47	0.00*	-54.43	47.38	0.00*	-17.15	23.37	0.01*
UR6 SA (mm^2)	540.75	74.37	519.35	73.08	502.18	76.33	-21.40	24.82	0.00*	-38.57	35.39	0.00*	-17.17	24.22	0.02*
UL1 length (mm)	21.50	1.91	21.17	2.01	20.94	1.96	-0.32	0.69	0.09	-0.56	0.86	0.02*	-0.23	0.52	0.10
UL1 volume (mm^3)	277.31	66.46	264.00	62.06	255.26	59.70	-13.31	16.75	0.01*	-22.05	22.81	0.00*	-8.74	26.22	0.22
UL1 SA (mm^2)	255.30	44.55	248.33	43.45	240.03	39.68	-6.97	11.66	0.04*	-15.27	16.63	0.00*	-8.30	15.69	0.06
UL3 length (mm)	23.59	1.96	23.27	1.70	22.94	1.76	-0.33	0.61	0.04*	-0.65	0.91	0.01*	-0.33	0.49	0.01*
UL3 volume (mm^3)	353.31	78.90	345.35	72.13	348.47	87.51	-7.96	12.63	0.02*	-4.83	29.03	0.49	3.12	29.46	0.66
UL3 SA (mm^2)	312.72	47.31	308.03	45.03	304.34	52.25	-4.68	15.57	0.00*	-8.37	16.74	0.05*	-3.69	15.57	0.33
UL6 MB length (mm)	17.95	1.67	17.66	1.67	17.11	2.01	-0.29	0.33	0.00*	-0.84	1.03	0.01*	-0.55	0.89	0.03*
UL6 DB length (mm)	17.24	1.50	16.99	1.73	16.42	2.30	-0.25	0.38	0.02*	-0.83	1.13	0.01*	-0.57	0.87	0.02*
UL6 P length (mm)	19.49	1.72	19.03	2.00	18.73	2.21	-0.46	0.48	0.00*	-0.75	0.87	0.00*	-0.30	0.59	0.07
UL6 volume (mm^3)	614.02	109.93	597.06	115.64	587.22	113.86	-16.96	29.98	0.05*	-26.81	29.50	0.00*	-9.85	16.15	0.03*
UL6 SA (mm^2)	568.13	77.37	551.14	79.46	539.01	85.97	-16.99	23.43	0.01*	-29.11	19.79	0.00*	-12.12	19.79	0.03*

*Significance at p<0.05; T0, presurgical; T1, immediate post-surgical; T2, long-term post-surgical. SD, standard deviation.

exceeding 4 mm or one-third of the original root length.[29] Our study revealed that the changes in root length were all less than 1 mm for all-time comparisons and variables. Similar findings were reported in a recent study evaluating root changes in patients who had undergone single- and double-jaw surgery.[30] In such cases, the long-term prognosis of the involved teeth may not be affected.

Sample and control CBCT scans were taken on i-CAT machines (120kV, 5mA, voxel size 0.3 mm, Imaging Sciences International, Hatfield, PA, USA). However, there is no clear consensus on the optimal voxel size for assessing root resorption. One study demonstrated that CBCT images with a 0.3 mm voxel size effectively detected external root resorption.[31] In contrast, another study found that CBCT with 300 µm underestimated volumetric measurements compared to smaller voxel sizes.[32] More recent research reported no significant differences in sensitivity and specificity among voxel sizes 120, 200, 250, and 300 µm.[33]

Study Limitations

This retrospective study has several potential limitations that should be highlighted. The data were obtained from a repository where subjects were treated by multiple providers using different treatment mechanics. Another limitation is that not all teeth were analyzed. Additionally, the sample size was relatively small. Further studies with larger cohorts and more standardized treatment protocols are needed to expand our understanding of the effect of segmental LeFort I osteotomy on root resorption.

CONCLUSION

This study aimed to quantify root resorption due to increased remodeling caused by segmental LeFort I osteotomy. Although the resorption observed was clinically insignificant, it occurred in both the surgical and control groups. With the exception of a few variables, no statistically significant differences in root resorption were found between the two groups.

Table 4. Repeated measure ANOVA for root resorption changes T0 vs T1 in Control group vs Surgical group

	T0 vs T1					
Variable	S-Mean	S-SD	C-Mean	C-SD	Mean difference	p-value
UR1 length (mm)	-0.38	0.80	-0.15	0.18	-0.23	0.29
UR1 volume (mm³)	-19.27	20.03	-8.94	7.57	-10.33	0.07
UR1 SA (mm²)	-12.62	11.04	-2.00	7.98	-10.62	0.01*
UR3 length (mm)	-0.48	0.93	-0.19	0.19	-0.29	0.25
UR3 volume (mm³)	-20.42	27.80	-11.70	13.38	-8.73	0.28
UR3 SA (mm²)	-16.71	18.92	-0.38	6.86	-16.34	0.00*
UR6 MB length (mm)	-0.27	0.32	-0.16	0.17	-0.12	0.24
UR6 DB length (mm)	-0.25	0.50	-0.40	0.48	0.16	0.40
UR6 P length (mm)	-0.25	0.63	-0.28	0.24	0.03	0.86
UR6 volume (mm³)	-37.28	41.47	-23.41	18.93	-13.87	0.24
UR6 SA (mm²)	-21.40	24.82	-1.58	17.61	-19.83	0.02*
UL1 length (mm)	-0.32	0.69	-0.24	0.24	-0.08	0.68
UL1 volume (mm³)	-13.31	16.75	-10.02	9.53	-3.29	0.53
UL1 SA (mm²)	-6.97	11.66	-2.54	7.02	-4.43	0.23
UL3 length (mm)	-0.33	0.61	-0.39	0.41	0.06	0.74
UL3 volume (mm³)	-7.96	12.63	-24.75	27.32	16.80	0.03*
UL3 SA (mm²)	-4.68	15.57	-7.92	13.49	3.24	0.52
UL6 MB length (mm)	-0.29	0.33	-0.16	0.29	-0.13	0.26
UL6 DB length (mm)	-0.25	0.38	-0.16	0.15	-0.10	0.40
UL6 P length (mm)	-0.46	0.48	-0.17	0.21	-0.29	0.04*
UL6 volume (mm³)	-16.96	29.98	-19.74	23.82	2.78	0.78
UL6 SA (mm²)	-16.99	23.43	-2.94	15.50	-14.05	0.06

*Significance at p<0.05; S-Mean, surgical group mean; S-SD, surgical group standard deviation; C-Mean, control group mean; C-SD, control group standard deviation.
SD, standard deviation.

Table 5. Repeated measure ANOVA for root resorption changes T1 vs T2 in Control group vs Surgical group

	T1 vs T2					
Variable	S-Mean	SD	C-Mean	SD	Mean difference	p-value
UR1 length (mm)	-0.78	0.97	-0.28	0.29	-0.50	0.07
UR1 volume (mm³)	-21.40	15.15	-10.01	12.41	-11.39	0.03*
UR1 SA (mm²)	-17.91	11.08	-8.22	6.47	-9.69	0.01*
UR3 length (mm)	-0.82	1.03	-0.31	-8.11	-0.52	0.79
UR3 volume (mm³)	-30.15	31.95	16.57	27.11	-46.72	0.00*
UR3 SA (mm²)	-23.09	19.09	-4.14	7.89	-18.95	0.00*
UR6 MB length (mm)	-0.50	0.59	-0.41	0.49	-0.09	0.65
UR6 DB length (mm)	-0.73	1.01	-0.43	0.51	-0.30	0.30
UR6 P length (mm)	-0.79	0.96	-0.33	0.26	-0.46	0.07
UR6 volume (mm³)	-54.43	47.38	-9.45	13.91	-44.98	0.00*
UR6 SA (mm²)	-38.57	35.39	-7.73	18.03	-30.85	0.00*
UL1 length (mm)	-0.56	0.86	-0.12	0.18	-0.44	0.07
UL1 volume (mm³)	-22.05	22.81	-2.42	9.70	-19.64	0.01*
UL1 SA (mm²)	-15.27	16.63	-6.48	6.93	-8.80	0.08
UL3 length (mm)	-0.65	0.91	-0.29	0.39	-0.37	0.15
UL3 volume (mm³)	-4.83	29.03	-8.30	15.58	3.46	0.67
UL3 SA (mm²)	-8.37	16.74	-8.17	8.55	-0.20	0.97
UL6 MB length (mm)	-0.84	1.03	-0.19	0.32	-0.65	0.03*
UL6 DB length (mm)	-0.83	1.13	-0.26	0.38	-0.57	0.07
UL6 P length (mm)	-0.75	0.87	-0.38	0.53	-0.37	0.17
UL6 volume (mm³)	-26.81	29.50	-12.39	16.60	-14.42	0.11
UL6 SA (mm²)	-29.11	19.79	-15.59	21.53	-13.52	0.08

*Significance at p<0.05; S-Mean, surgical group mean; S-SD, surgical group standard deviation; C-Mean, control group mean; C-SD control group standard deviation.
SD, standard deviation.

Table 6. Repeated measure ANOVA for root resorption changes T0 vs T2 in Control group vs Surgical group

	T0 vs T2					
Variable	**S-Mean**	**SD**	**C-Mean**	**SD**	**Mean Difference**	**p-value**
UR1 length (mm)	-0.78	0.97	-0.44	0.30	-0.35	0.21
UR1 volume (mm^3)	-21.40	15.15	-18.95	11.28	-2.44	0.62
UR1 SA (mm^2)	-17.91	11.08	-10.22	6.66	-7.69	0.03*
UR3 length (mm)	-0.82	1.03	-0.50	0.36	-0.33	0.26
UR3 volume (mm^3)	-30.15	31.95	-21.80	25.22	-8.36	0.42
UR3 SA (mm^2)	-23.09	19.09	-4.52	8.65	-18.57	0.00*
UR6 MB length (mm)	-0.50	0.59	-0.57	0.52	0.07	0.73
UR6 DB length (mm)	-0.73	1.01	-0.84	0.69	0.11	0.72
UR6 P length (mm)	-0.79	0.96	-0.61	0.42	-0.17	0.50
UR6 volume (mm^3)	-54.43	47.38	-32.86	22.68	-21.57	0.11
UR6 SA (mm^2)	-38.57	35.39	-9.30	14.82	-29.27	0.01*
UL1 length (mm)	-0.56	0.86	-0.36	0.30	-0.20	0.42
UL1 volume (mm^3)	-22.05	22.81	-12.44	11.20	-9.62	0.17
UL1 SA (mm^2)	-15.27	16.63	-9.02	5.84	-6.25	0.19
UL3 length (mm)	-0.65	0.91	-0.68	0.70	0.02	0.92
UL3 volume (mm^3)	-4.83	29.03	-33.05	32.93	28.22	0.01*
UL3 SA (mm^2)	-8.37	16.74	-16.09	12.47	7.72	0.14
UL6 MB length (mm)	-0.84	1.03	-0.35	0.39	-0.49	0.10
UL6 DB length (mm)	-0.83	1.13	-0.41	0.40	-0.41	0.19
UL6 P length (mm)	-0.75	0.87	-0.55	0.52	-0.20	0.45
UL6 volume (mm^3)	-26.81	29.50	-32.13	27.17	5.32	0.61
UL6 SA (mm^2)	-29.11	19.79	-18.54	26.43	-10.58	0.23

*Significance at $p<0.05$; S-Mean surgical group mean, S-SD surgical group standard deviation; C-Mean, control group mean; C-SD, control group standard deviation.
SD, standard deviation.

Ethics

Ethics Committee Approval: The study was reviewed and approved by the Boston University Institutional Review Board (approval no.: H-32515, date: 14.09.2019).

Informed Consent: Informed consent was obtained from all patients.

Footnotes

Author Contributions: Concept - M.J.G., L.A.W., M.M.; Design - M.M.; Data Collection and/or Processing - E.K., M.J.G., M.M.; Analysis and/or Interpretation - E.K., A.A.A., M.S.; Literature Search - E.K.; Writing - E.K., A.A.A., M.J.G., L.A.W., M.S., M.M.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: This study did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

REFERENCES

1. Garg N, Garg A. Root Resorption. In: Textbook of Endodontics; 2019:483-483. [CrossRef]
2. Patel S, Kanagasingam S, Pitt Ford T. External cervical resorption: a review. *J Endod.* 2009;35(5):616-625. [CrossRef]
3. Bell WH. Le Forte I osteotomy for correction of maxillary deformities. *J Oral Surg.* 1975;33(6):412-426. [CrossRef]
4. Buchanan EP, Hyman CH. LeFort I osteotomy. *Semin Plast Surg.* 2013;27(3):149-154. [CrossRef]
5. Marchetti C, Pironi M, Bianchi A, Musci A. Surgically assisted rapid palatal expansion vs. segmental Le Fort I osteotomy: transverse stability over a 2-year period. *J Craniomaxillofac Surg.* 2009;37(2):74-78. [CrossRef]
6. Hartlev J, Klit Pedersen T, Nørholt SE. Cone beam computed tomography evaluation of tooth injury after segmental Le Fort I osteotomy. *Int J Oral Maxillofac Surg.* 2019;48(1):84-89. [CrossRef]
7. Bendrihem R, Vacher C, Fohlen A, Pelage JP. Anatomic basis of Le Fort 1 impaction osteotomy: a radiological study. *Surg Radiol Anat.* 2017;39(11):1209-1214. [CrossRef]
8. Frost HM. The regional acceleratory phenomenon: a review. *Henry Ford Hosp Med J.* 1983;31(1):3-9. [CrossRef]
9. Liou EJW, Chen PH, Wang YC, Yu CC, Huang CS, Chen YR. Surgery-first accelerated orthognathic surgery: Postoperative rapid orthodontic tooth movement. *J Oral Maxillofac Surg.* 2011;69(3):781-785. [CrossRef]
10. Patterson BM, Dalci O, Papadopoulou AK, et al. Effect of piezocision on root resorption associated with orthodontic force: a microcomputed tomography study. *Am J Orthod Dentofacial Orthop.* 2017;151(1):53-62. [CrossRef]
11. Dibart S, Yee C, Surmenian J, et al. Tissue response during Piezocision-assisted tooth movement: a histological study in rats. *Eur J Orthod.* 2014;36(4):457-464. [CrossRef]
12. Teng GYY, Liou EJW. Interdental osteotomies induce regional acceleratory phenomenon and accelerate orthodontic tooth movement. *J Oral Maxillofac Surg.* 2014;72(1):19-29. [CrossRef]

13. Forst D, Nijjar S, Flores-Mir C, Carey J, Secanell M, Lagravere M. Comparison of in vivo 3D cone-beam computed tomography tooth volume measurement protocols. *Prog Orthod* 2014;15:69. [CrossRef]
14. Kim SY, Lim SH, Gang SN, Kim HJ. Crown and root lengths of incisors, canines, and premolars measured by cone-beam computed tomography in patients with malocclusions. *Korean J Orthod*. 2013;43(6): 271-278. [CrossRef]
15. Sang YH, Hu HC, Lu SH, Wu YW, Li WR, Tang ZH. Accuracy assessment of three-dimensional surface reconstructions of in vivo teeth from cone-beam computed tomography. *Chin Med J (Engl)* 2016;129(12):1464-1470. [CrossRef]
16. Brezniak N, Wasserstein A. Orthodontically induced inflammatory root resorption. Part II: the clinical aspects. *Angle Orthod*. 2002;72(2):180-184. [CrossRef]
17. Massler M, Malone AJ. Root resorption in human permanent teeth: a roentgenographic study. *Am J Orthod*. 1954;40(8):619-633. [CrossRef]
18. Sameshima GT, Sinclair PM. Predicting and preventing root resorption: part I. Diagnostic factors. *Am J Orthod Dentofacial Orthop*. 2001;119(5):505-510. [CrossRef]
19. Vlaskalic V, Boyd RL, Baumrind S. Etiology and sequelae of root resorption. *Semin Orthod*. 1998;4(2):124-131. [CrossRef]
20. Linge L, Linge BO. Patient characteristics and treatment variables associated with apical root resorption during orthodontic treatment. *Am J Orthod Dentofacial Orthop*. 1991;99(1):35-43. [CrossRef]
21. Currell SD, Liaw A, Blackmore Grant PD, Esterman A, Nimmo A. Orthodontic mechanotherapies and their influence on external root resorption: A systematic review. *Am J Orthod Dentofacial Orthop*. 2019;155(3):313-329. [CrossRef]
22. Alqahtani KA, Shaheen E, Morgan N, Shujaat S, Politis C, Jacobs R. Impact of orthognathic surgery on root resorption: a systematic review. *J Stomatol Oral Maxillofac Surg*. 2022;123(5):e260-e267. [CrossRef]
23. Abbas NH, Sabet NE, Hassan IT. Evaluation of corticotomy-facilitated orthodontics and piezocision in rapid canine retraction. *Am J Orthod Dentofacial Orthop*. 2016;149(4):473-480. [CrossRef]

24. Alqahtani KA, Jacobs R, Da Costa Senior O, Politis C, Shaheen E. Recommendations to minimize tooth root remodeling in patients undergoing maxillary osteotomies. *Sci Rep*. 2024;14(1):13686. [CrossRef]
25. Ghanbarzadeh M, Heravi F, Abrishamchi R, et al. Cementum and dentin repair following root damage caused by the insertion of self-tapping and self-drilling miniscrews. *J Orthod Sci*. 2017;6(3):91-96. [CrossRef]
26. Kim H, Kim T-W. Histologic evaluation of root-surface healing after root contact or approximation during placement of mini-implants. *Am J Orthod Dentofacial Orthop*. 2011;139(6):752-760. [CrossRef]
27. Alqahtani KA, Shaheen E, Politis C, Jacobs R. Three-dimensional assessment of root changes after Le Fort I osteotomy. *Int J Oral Maxillofac Surg*. 2025;54(1):57-64. [CrossRef]
28. Cho UH, Yu W, Kyung HM. Root contact during drilling for microimplant placement: affect of surgery site and operator expertise. *Angle Orthod*. 2010;80(1):130. [CrossRef]
29. Feller L, Khammissa RAG, Thomadakis G, Fourie J, Lemmer J. Apical external root resorption and repair in orthodontic tooth movement: biological events. *Biomed Res Int*. 2016;2016. [CrossRef]
30. Erdem ME, Irgın C. Does orthognathic surgery affect tooth root length and volume: a retrospective cohort study. *Angle Orthod*. 2025;95(2):188-198. [CrossRef]
31. Liedke GS, da Silveira HE, da Silveira HL, Dutra V, de Figueiredo JA. Influence of voxel size in the diagnostic ability of cone beam tomography to evaluate simulated external root resorption. *J Endod*. 2009;35:233-235. [CrossRef]
32. Maret D, Telmon N, Peters OA, et al. Effect of voxel size on the accuracy of 3D reconstructions with cone beam CT. *Dentomaxillofac Radiol*. 2012;41(8):649-655. [CrossRef]
33. Nikneshan S, Valizadeh S, Javanmard A, Alibakhshi L. Effect of voxel size on detection of external root resorption defects using cone beam computed tomography. *Iran J Radiol*. 2016;13(3):e34985. [CrossRef]

DOI: 10.4274/TurkJOrthod.2025.2025.36

TURKISH JOURNAL OF
ORTHODONTICS

Original Article

3-Dimensional Evaluation of Enamel Thickness to Guide Orthodontic Interproximal Reduction: A CBCT-Based Study Across Gender and Ethnicity

Ezgi Cansu Fırıncıoğulları[1], Aslıhan Ertan Erdinç[2], Sercan Akyalçın[3]

[1]University of Nebraska Medical Center, Department of Growth and Development, Omaha, NE, USA
[2]Ege University Faculty of Dentistry, İzmir, Türkiye
[3]Harvard School of Dental Medicine, Department of Orthodontics, Boston, USA

Cite this article as: Fırıncıoğulları EC, Ertan Erdinç A, Akyalçın S. 3-dimensional evaluation of enamel thickness to guide orthodontic interproximal reduction: a CBCT-based study across gender and ethnicity. *Turk J Orthod.* 2025; 38(2): 89-106

Main Points

- Enamel thickness varies significantly between Caucasian and Somalian populations, regardless of tooth location(anterior/posterior, distal/mesial).
- Gender does not appear to influence enamel thickness across different ethnic backgrounds.
- In the posterior regions of both arches, distal surfaces generally have greater enamel thickness than mesial surfaces, making them safer for interproximal reduction.

ABSTRACT

Objective: This study aimed to explore variations in enamel thickness to provide guidelines for optimal interproximal enamel reduction in an untreated population using cone-beam computed tomography (CBCT).

Methods: CBCT scans of 100 orthodontic patients (51 Caucasian, 49 patients of Somalian descent; aged (12-18) were analyzed retrospectively. Enamel thickness was measured at the mesial and distal contact points of teeth from the second molar to the central incisor in both the maxillary and mandibular arches. Linear mixed models were employed to assess the effects of ethnicity, gender, anterior-posterior region, and mesial-distal proximal surfaces on enamel thickness. Fixed effects were estimated using the Kenward-Roger method, and a random intercept with an unstructured covariance matrix was included to account for within-subject variability. Ethnicity-specific residual variances were also modeled. Statistical significance was set at $p<0.05$.

Results: Enamel thickness varied significantly between Caucasians and Somalians in both the maxilla and mandible ($p<0.001$), with greater thickness observed in Caucasians. Gender-related differences were minimal; however, in the maxilla, distal surfaces of posterior teeth had greater enamel thickness in females compared to males ($p=0.0478$). Enamel thickness was consistently greater on distal surfaces of posterior teeth ($p<0.001$), while no significant differences were observed between mesial and distal surfaces in anterior teeth ($p>0.05$).

Conclusion: Posterior teeth, particularly distal proximal surfaces of premolars and molars hold a great potential for enamel reduction, offering clinicians the most optimal site in orthodontic interventions.

Keywords: Enamel thickness, interproximal reduction, cone-beam computed tomography, orthodontics, gender differences, ethnic variations

Corresponding author: Ezgi Cansu Fırıncıoğulları, **e-mail:** ezgicansu.erul@gmail.com
Received: February 26, 2025 **Accepted:** April 07, 2025 **Publication Date:** July 02, 2025

INTRODUCTION

A critical aspect of orthodontic treatment planning is accurately identifying the direction and magnitude of dental movements required within each arch quadrant. In many instances, achieving the desired dental movements necessitates the creation of adequate space to address the malocclusion. One of the most widely utilized techniques for gaining additional space is interproximal enamel reduction (IPR) which has been gaining popularity in clinical practice, particularly through the advocates of aligners and non-extraction treatment.[1] This method mimics the natural physiological process of interdental attrition, which occurs as part of normal aging.[2] Many practitioners rely on the strategic use of IPR to manage mild to moderate tooth-size discrepancies without the need for extractions.[3] Therefore, accurate assessment of enamel thickness across different sections is of critical importance in optimizing treatment outcomes.

The expanding body of literature has explored enamel thickness at interproximal surfaces and, the extent of how much IPR could safely be performed depends mostly on the enamel thickness and other patient-related factors.[4,5] According to Frindel,[6] the maximum recommended reduction is 0.3 mm for upper incisors, 0.2 mm for lower incisors, and 0.6 mm for both upper and lower posterior teeth. Sheridan and Ledoux[7] further suggested that the total space gained through IPR for the premolar region could reach up to 6.4 mm. Additionally, it has been proposed that up to 50% of interproximal enamel can be safely removed with IPR.[8]

The increasing popularity of IPR is closely related to the growing demand for orthodontic treatment among adults.[9] Challenges encountered in space closure for adult patients, the risk of reopening extraction spaces after extraction treatments, and the ability of IPR to provide just enough space by removing only the required enamel[10] make it an attractive alternative for cases with mild to moderate crowding (4-8 mm).[11] However, IPR is not used exclusively for space creation. Other common applications include resolving black triangles, managing Bolton discrepancies, and more.[12,13] Nearly every orthodontic patient has the potential to benefit from IPR. Therefore, orthodontists require evidence-based data on how the amount of IPR varies based on gender, mesiodistal surface, anterior-posterior region, and racial differences.

Recently, patient-centered treatment principles have led to the limitation of extraction-based treatments to severe malocclusion cases. In simpler cases, faster and less invasive treatment options have become more popular.[10] Consequently, methods like distalization, expansion, and IPR have become more widely adopted, with increasing attention in the literature. According to an epidemiological study in the United States, severe crowding (≥7 mm), which may necessitate extractions, is observed in only 16.8% of the adult population.[14] From a clinical perspective, the findings in the literature indicate that IPR could provide more opportunity for non-extraction treatment in individuals with treatment objectives centering around no major change for the incisor position.

Given the clinical relevance of enamel thickness variations in IPR applications, our study aimed to quantify enamel thickness using cone-beam computed tomography (CBCT) to provide the clinicians with further evidence and guidance across genders, ethnic origins, groups and proximal surfaces of teeth. Although the body of evidence suggested that IPR within recognized limits would have no iatrogenic harm to the teeth and supporting structures,[15] the current study investigated the effects of multiple factors in enamel thickness variation. We aim to provide further supplementary data to the clinicians for optimizing their treatment decisions. The null hypothesis was that enamel thickness would not reveal any differences between different ethnic groups, sex, location and sites of teeth.

METHODS

The study was reviewed and approved by the Institutional Review Board (Tufts University #2018-11181). The CBCT records of 100 orthodontic patients (n=51 Caucasian and n=49 Somalian) were uploaded to *InVivo* (Anatomage, San Jose, CA) for volume rendering and sectioning. Axial and frontal slices of the maxillary and mandibular dentition, extending from the second molar to the contralateral second molar, were obtained for measurement purposes. Enamel thickness was assessed at the mesial and distal proximal surfaces of each tooth at the contact points within each quadrant. The mean enamel thickness was then calculated for each tooth. The inclusion criteria for the evaluation consisted of an age range of 12-18, fully erupted first and second molars, absence of any wear, absence of grinding or clenching. Patients with a history of prior orthodontic treatment, interproximal restorations, any kind of missing teeth or agenesis, tooth shape and size anomalies (macrodontia, peg laterals, twinning, etc.), craniofacial anomalies, necessitated exclusion from the study.

CBCT images were opened in *InVivo* (Anatomage, San Jose, CA). Axial (Figure 1a) and frontal (Figure 1b) slices of maxillary and mandibular teeth from the second molar to the central incisor were generated for the measurements. The thickness of the enamel on the proximal surfaces was measured directly from the mesial and distal contact points on the shortest line possible to the dentin and enamel junction perpendicular to the long axis of the tooth.

For the purposes of the study, central incisors, lateral incisors, and canines were grouped as the anterior teeth, while premolars, first molars, and second molars were labeled as the posterior teeth. A linear mixed model (LMM) was employed to evaluate the effects of ethnicity (Groups: Caucasian vs. Somalian), gender (male vs. female), tooth position [anterior vs. posterior (ant_post)], and surface [mesial vs. distal (DM)] on enamel thickness.

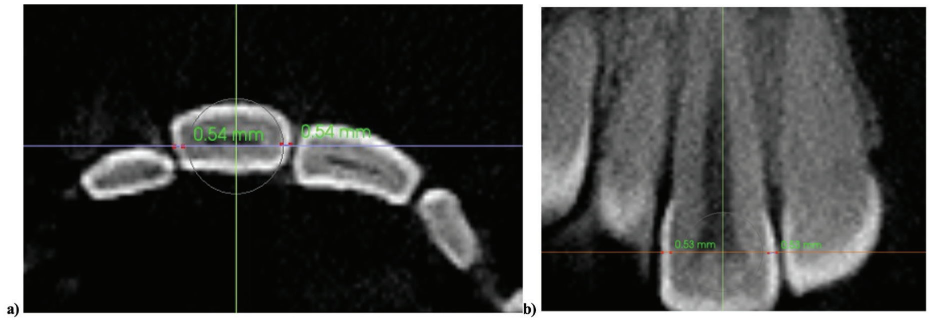

Figure 1. Axial and frontal view of a maxillary right central incisor. Enamel thickness measurements are made on mesial and distal proximal aspects at the contact point

Statistical Analysis

The enamel thickness was used as the dependent variable to achieve a normalized data distribution. The model included all main effects and their interactions. Fixed effects were estimated using the Kenward-Roger method to adjust degrees of freedom. A random intercept was included to account for within-subject variability, utilizing an unstructured covariance matrix. Additionally, ethnicity-specific residual variances were incorporated to account for heterogeneity at the ethnicity level.

In analyzing the results for the mandible, only the DM × ant_post interaction was significant (Table 1), while for the maxilla, gender × ant_post and DM × ant_post interactions were significant (Table 2). Interaction analyses were conducted using least squares mean differences to explore the effects further. The results of the least squares mean differences were used to evaluate specific subgroup interactions and to identify differences within the data that might not be apparent in the main effects analysis. For each comparison, the Tukey-Kramer adjustment was applied to control for multiple testing and provide adjusted p-values.

Statistical significance was set at p<0.05. LMMs were performed using SAS software (version 9.3; procedure: PROC MIXED; SAS Institute, Cary, NC, USA). Graphics were generated using R software (version 4.0.5; package: ggplot2, R Foundation for Statistical Computing, Vienna, Austria).

Table 1. Results of mixed-effects model of mandible: type III fixed effects

Test statistics	Den DF	F value		p-value
Groups	1	96.4	18.37	<0.0001
Gender	1	96.4	1.13	0.2898
Groups*Gender	1	96.4	0.25	0.6148
DM	1	1280	15.31	<0.0001
Groups*DM	1	1280	2.45	0.1179
Gender*DM	1	1280	0	0.9910
Groups*Gender*DM	1	1280	0.01	0.9283
ant_post	1	1280	482.28	<0.0001
Groups*ant_post	1	1280	1.77	0.1839
Gender*ant_post	1	1280	0.09	0.7636
Groups*Gender*ant_post	1	1280	0.09	0.7593
DM*ant_post	1	1280	5.96	0.0148
Groups*DM*ant_post	1	1280	0.14	0.7067
Gender*DM*ant_post	1	1280	0	0.9849
Group*Gender*DM*ant_post	1	1280	0	0.9469

ant_post: anterior vs. posterior, DM: mesial vs. distal

RESULTS

In the mandible, a significant difference in mean enamel thickness was found between two groups (Caucasians and Somalians) (p<0.001; Table 1). This difference was not affected by gender, anterior-posterior region, or DM surfaces. Similarly, no significant difference in enamel thickness was observed between genders (p=0.2898; Table 2, Figure 2), (Table 1).

The only statistically significant interaction was between DM surface and anterior-posterior region (p=0.0148).

In the posterior region, the distal surface exhibited a higher mean enamel thickness compared to the mesial surface (adjusted p<0.001). Conversely, no significant differences between surfaces were observed in the anterior region (adjusted p=0.7644). Both distal and mesial surfaces demonstrated a higher mean enamel thickness in the posterior region compared to the anterior region (Table 3, for both, adjusted p<0.001).

In the maxilla, like findings in the mandible, a significant difference in mean enamel thickness was observed between two ethnic groups (p<0.001; Table 2, Figure 3). This difference was not influenced by gender, anterior-posterior region, or DM surfaces interactions between DM surface and anterior-posterior region, as well as between gender and anterior-posterior region, were statistically significant (p=0.004 and p=0.0478, respectively; Table 2).

Consistent with findings in the mandible, the posterior region's distal surface demonstrated a higher mean enamel thickness compared to the mesial surface (adjusted p<0.001). In contrast, no significant difference was observed between surfaces in the anterior region (adjusted p=0.8180).

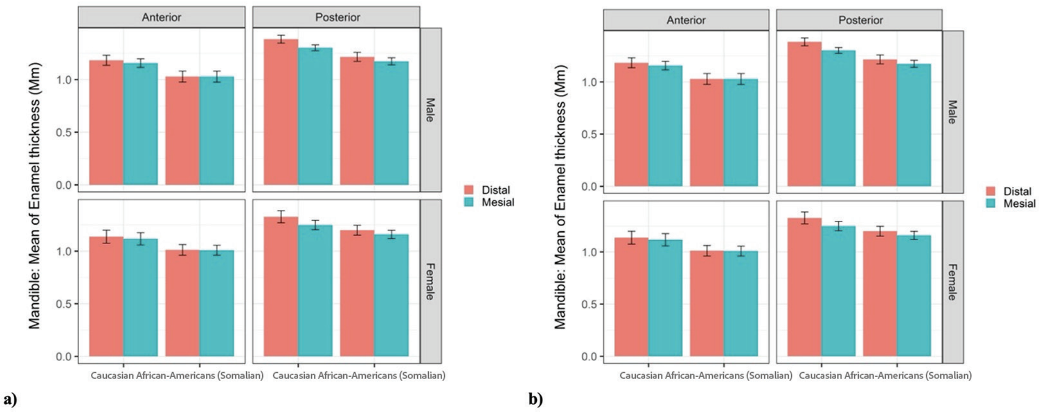

Figure 2. Mean enamel tickness and mean enamel tickness in log transformation of mandibular anterior and posterior teeth
Note: The Somalian group does not represent the full diversity of individuals categorized as African American.

Table 2. Results of mixed-effects model of maxilla: type III fixed effects

Test statistics	Den DF	F value	p-value
Groups	96.7	17.29	<0.0001
Gender	96.7	0.44	0.5086
Groups*Gender	96.7	0	0.9836
DM	1255	17.67	<0.0001
Groups*DM	1255	0.07	0.7985
Gender*DM	1255	0.21	0.6458
Groups*Gender*DM	1255	0.01	0.9239
ant_post	1255	1.57	0.2110
Groups*ant_post	1255	0.01	0.9144
Gender*ant_post	1255	3.92	0.0478
Groups*Gender*ant_post	1255	0.3	0.5846
DM*ant_post	1255	8.3	0.0040
Groups*DM*ant_post	1255	0.73	0.3943
Gender*DM*ant_post	1255	0.7	0.4030
Groups*Gender*DM*ant_post	1255	0.04	0.8368

No significant differences were found between genders in either region (anterior: p=0.6683; posterior: p=0.9990). Among females, the mean enamel thickness in the posterior region was higher on the distal surface, and among males, the mean enamel thickness in the anterior region was higher on the mesial surface; however, these differences were not statistically significant (Table 3 and 4, adjusted p=0.2487 and adjusted p=0.1872, respectively).

DISCUSSION

IPR is an effective method orthodontists use to create space by reducing the mesiodistal dimension of teeth. This procedure involves the removal of enamel material from the proximal surfaces of teeth, which can be performed using manual or automatic systems.[10] Despite various opinions in the literature about the maximum amount of IPR, individual differences in enamel thickness have been emphasized.[5,16-18] Understanding the variations in enamel thickness across different genders, ethnic backgrounds, tooth surfaces, and regions is critical for performing safe and effective IPR in orthodontic treatment. Despite the growing use of IPR, especially with the rise of clear aligner therapy, there remains limited evidence-based guidance tailored to individual patient characteristics. This study aimed to provide clinically relevant enamel thickness data using CBCT imaging to support more personalized and informed IPR protocols.

The literature contains diverse perspectives on the amount of space that can be gained with IPR. Recent studies highlight the importance of determining enamel thickness before the procedure, as it varies among individuals.[18,19] This study is distinguished by its specific age range selection, which was designed to minimize potential variations in interdental attrition across different age groups, thereby enhancing the reliability of enamel thickness comparisons. It is well-documented that interdental attrition occurs with age, transforming contact points into contact surfaces.[20] Attrition related changes could mean that enamel thickness and tooth width in the same individual differ at different ages. Therefore, our study measured only enamel thickness rather than overall tooth dimensions. Although there is a high correlation between tooth size and enamel thickness,[18,21] focusing on enamel thickness alone allowed for the acquisition of precise mesial and distal enamel thickness.

Results of this research showed that, similar to the findings of Moss and Moss-Salentijn,[22] the enamel thickness of mandibular canines in males was greater than that in females in both groups. Enamel thicknesses in the maxillary posterior region did not change between genders, consistent with the findings of Stroud et al.[5] Mandibular lateral incisors demonstrated greater enamel thickness compared to mandibular central incisors like Hall et al.'s[18] results. In line with findings reported in the literature, which indicate that enamel thickness is greater on distal surfaces than on mesial surfaces, this study showed similar findings exclusively for maxillary and mandibular posterior teeth and upper central incisors.[17] However, no

Table 3. Mean±standard deviation of enamel thickness

			Caucasian		Somalian	
			Distal	Mesial	Distal	Mesial
Maxilla	Male	Anterior	1.30±0.23	1.30±0.24	1.18±0.23	1.17±0.24
		Posterior	1.34±0.23	1.25±0.17	1.19±0.22	1.13±0.16
	Female	Anterior	1.28±0.27	1.27±0.25	1.15±0.23	1.12±0.21
		Posterior	1.33±0.26	1.26±0.19	1.19±0.24	1.14±0.22
Mandible	Male	Anterior	1.18±0.24	1.16±0.21	1.03±0.23	1.03±0.23
		Posterior	1.38±0.22	1.30±0.16	1.22±0.22	1.17±0.17
	Female	Anterior	1.14±0.22	1.12±0.21	1.01±0.21	1.01±0.20
		Posterior	1.33±0.24	1.25±0.18	1.20±0.22	1.16±0.19

significant differences were observed between mesial and distal surfaces in anterior teeth similar to Sarig et al.[10] and Konstantinidou et al.[23] The variations in these[24] findings can be attributed to differences in the methodologies employed, as Sarig et al.[10] study. Enamel thickness was measured at the mesial and distal contact points in this study and the referenced work. In contrast, Macha et al.[25] and Fernandes et al.[26] focused solely on the maximum enamel thickness, while Stroud et al.[4,5] assessed enamel thickness using radiographic techniques. Consistent with previous studies,[4,5,18] no gender-related differences in enamel thickness were observed in the mandibular anterior and posterior teeth. In the maxilla, no differences in enamel thickness were found between genders in anterior teeth. In contrast, in posterior teeth, the mean enamel thickness on distal surfaces was greater in females than in males.

The locations where enamel thickness was measured vary significantly across studies. Some measured the enamel thickness at mesial and distal contact areas, while others measured the greatest enamel thickness.[12] In this study, measurements were taken directly at the contact points on CBCT scans, as IPR is typically performed clinically starting from the contact points. This choice ensures the amount of enamel removed is calculated precisely at these locations, rather than at the areas of thickest enamel. A meta-analysis in 2021 recommended using 3D evaluation methods, for assessing enamel thickness to guide clinicians.[12] This study used CBCT instead of 2D evaluation methods reducing potential errors from magnification and angles. The right and left sides were not evaluated separately, as the literature indicates that the symmetry of the right and left teeth is nearly perfect, with a very high correlation.[12]

Clinicians use IPR less in the posterior region due to its distance from the anterior region, despite evidence indicating a progressive increase in enamel thickness from anterior to posterior teeth.[16] The findings of this study have important clinical implications, particularly for orthodontic treatment planning involving IPR. The observed variations in enamel thickness across ethnicities and genders highlight the necessity for individualized treatment protocols. For instance, the consistently greater enamel thickness observed in Caucasians compared to Somalians and the thicker enamel found in posterior teeth, particularly on distal surfaces irrespective of ethnicity, indicate that Caucasians and distal surfaces of posterior teeth may tolerate more aggressive enamel reduction without compromising dental integrity. Clinicians can use this evidence to optimize IPR procedures, minimizing risks while maximizing space creation in cases of mild to moderate crowding. Comparatively, this study aligns with prior research indicating significant regional and surface-specific differences in enamel thickness but provides additional granularity by incorporating ethnicity and gender as variables. Unlike earlier studies that focusing primarily on radiographic assessments or gross enamel thickness, this research utilized CBCT to achieve precise, localized measurements.

In addition to the main effects, a significant interaction between DM surface and anterior-posterior region was observed in both arches, indicating that surface-related differences in enamel thickness are influenced by the location of the tooth. Specifically, in the posterior region, distal surfaces consistently demonstrated greater enamel thickness than mesial surfaces, while no such difference was observed in the anterior region. This highlights the importance of considering both surface and region simultaneously in clinical decision-making. Moreover, a significant interaction between gender and anterior-posterior region was found in the maxilla. Although overall gender-related differences in enamel thickness were not statistically significant, this interaction suggests that the relationship between gender and enamel thickness may vary depending on the tooth region. Post-hoc comparisons did not reveal significant pairwise differences; however, the presence of the interaction indicates a pattern that may become more apparent with larger sample sizes and should be explored in future studies.

In this study, all individuals in the Somalian group were classified under the broader racial category of African American,[27] while the Caucasian group included individuals from a range of ethnic backgrounds.[28] Recognizing this, referring to the comparison solely as one between racial groups could lead to scientific

Table 4. Minimum, maximum, mean and standard deviation of enamel thickness (mm) for each tooth on mesial and distal surfaces, categorized by ethnicity, gender, and arch (maxilla and mandible)

	Caucasian n=51 (Female n=17, Male n=34)									Somalian n=49 (Female n=23, Male n=26)							
	Maxillary					Mandibular				Maxillary				Mandibular			
Gender	Tooth no and surface	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation
Male	7D	1.12	1.93	1.5841	0.20440	1.15	2.17	1.5815	0.22600	1.21	1.86	1.4037	0.18321	1.00	1.96	1.3765	0.20887
	7M	1.06	1.84	1.3456	0.18599	1.01	1.59	1.3443	0.13970	1.02	1.64	1.2138	0.13985	1.04	1.44	1.2171	0.11001
	6D	0.98	1.69	1.4015	0.16742	0.98	1.78	1.3878	0.18972	0.95	1.76	1.2271	0.21203	0.96	1.71	1.2435	0.21521
	6M	0.98	1.55	1.2969	0.15489	0.98	1.59	1.2859	0.15267	0.96	1.60	1.1717	0.15238	1.07	1.64	1.2165	0.15105
	5D	0.86	1.47	1.2088	0.14761	0.94	1.68	1.2574	0.14111	0.85	1.43	1.0658	0.13344	0.86	1.48	1.1242	0.16677
	5M	0.87	1.42	1.1643	0.12764	0.95	1.75	1.2715	0.17193	0.81	1.40	1.0617	0.13900	0.96	1.61	1.1260	0.16006
	4D	0.91	1.49	1.1834	0.13615	0.93	1.76	1.3103	0.18393	0.87	1.50	1.0719	0.16254	0.88	1.57	1.1202	0.19386
	4M	0.88	1.48	1.1966	0.15145	0.92	1.89	1.3059	0.18594	0.84	1.56	1.0715	0.16935	0.85	1.68	1.1352	0.22650
	3D	0.94	1.94	1.4419	0.22121	0.89	1.90	1.4272	0.23415	0.96	1.95	1.2404	0.25215	0.97	1.90	1.2165	0.25672
	3M	0.92	2.25	1.4369	0.26471	0.95	1.81	1.3587	0.20449	1.01	2.29	1.2573	0.29508	0.99	1.86	1.2183	0.26887
	2D	0.87	1.41	1.1482	0.14885	0.78	1.38	1.1012	0.14111	0.86	1.50	1.0831	0.15972	0.74	1.37	0.9519	0.15050
	2M	0.91	1.47	1.1626	0.16218	0.81	1.33	1.0776	0.13237	0.87	1.55	1.0613	0.13155	0.75	1.35	0.9415	0.14236
	1D	0.99	1.89	1.3181	0.21289	0.81	1.26	1.0235	0.10294	0.98	1.86	1.2221	0.23933	0.75	1.36	0.9185	0.13875
	1M	0.92	1.82	1.3046	0.18987	0.82	1.26	1.0346	0.10536	0.93	1.86	1.1888	0.22641	0.76	1.36	0.9260	0.13548
Female	7D	1.20	1.98	1.5665	0.25136	1.19	1.87	1.5268	0.22461	1.15	1.91	1.4180	0.20013	1.07	1.92	1.3833	0.21062
	7M	1.09	1.65	1.3468	0.18240	1.14	1.67	1.3185	0.15253	0.94	1.85	1.2615	0.22707	0.94	1.60	1.2283	0.17115
	6D	1.11	1.83	1.4185	0.22775	1.00	1.69	1.3429	0.20627	0.93	1.77	1.2015	0.20907	0.92	1.62	1.1952	0.17500
	6M	0.99	1.83	1.3568	0.20599	1.00	1.57	1.2768	0.18760	0.95	1.82	1.1909	0.20268	0.92	1.63	1.1904	0.16952
	5D	1.00	1.40	1.1903	0.12626	0.84	1.45	1.2174	0.17131	0.90	1.61	1.0654	0.17848	0.85	1.71	1.1037	0.20844
	5M	0.95	1.37	1.1529	0.12804	0.90	1.45	1.2003	0.16139	0.86	1.58	1.0535	0.17877	0.87	1.69	1.1111	0.20353
	4D	0.95	1.48	1.1256	0.14121	0.84	1.56	1.2200	0.20943	0.90	1.62	1.0611	0.18314	0.85	1.66	1.1165	0.19556
	4M	0.97	1.40	1.1735	0.13121	0.87	1.58	1.1971	0.21022	0.86	1.63	1.0698	0.19729	0.86	1.69	1.1098	0.19911
	3D	1.06	2.04	1.4609	0.30462	1.02	1.66	1.3032	0.18892	0.86	1.77	1.1935	0.24838	0.87	1.87	1.1520	0.25017
	3M	1.02	2.04	1.4650	0.28432	1.01	1.74	1.2856	0.20830	0.97	1.69	1.1659	0.18434	0.84	1.63	1.1357	0.22219
	2D	0.82	1.34	1.1094	0.13882	0.79	1.55	1.0803	0.21385	0.79	1.51	1.0393	0.15917	0.76	1.35	0.9528	0.15756
	2M	0.89	1.29	1.1109	0.12492	0.81	1.31	1.0424	0.15025	0.78	1.43	1.0261	0.14687	0.77	1.26	0.9443	0.14319
	1D	0.99	1.62	1.2653	0.20390	0.80	1.38	1.0306	0.15579	0.92	1.92	1.2037	0.25190	0.79	1.24	0.9337	0.14499
	1M	0.98	1.61	1.2224	0.17748	0.79	1.31	1.0235	0.15622	0.92	1.75	1.1822	0.24434	0.76	1.32	0.9443	0.16390

D: Distal surface, M: Mesial surface, 7: Second molar, 6: First molar, 5: Second premolar, 4: First premolar, 3: Canine, 2: Lateral incisor, 1: Central incisor, 7D: Distal surface of second molar

inaccuracy. Rather, this study involved a comparison between a specific ethnic subgroup (Somalian) and a racially defined but ethnically heterogeneous group (Caucasian). This distinction is important, as it underscores the need for caution in generalizing the findings to broader populations. The Somalian group does not represent the full diversity of individuals categorized as African American, and the Caucasian group comprises participants from different ethnic origins. Therefore, clinicians and researchers should interpret these results with care, particularly when applying enamel thickness data across different ethnic subgroups within the same racial classification.

Schwartz[24] suggested that enamel thickness is related to occlusal function; areas subjected to greater occlusal forces tend to have thinner enamel. A limitation of this study is that the participant group represents a specific age range, without standardized criteria to compare or evaluate occlusal function. However, it is important to note that patients with significant occlusal or proximal attrition were excluded. Another limitation of the study is the potential disadvantages associated with the use of CBCT, primarily due to its high ionizing radiation dose. Although CBCT is considered the gold standard for evaluating structures, it is not appropriate for use at frequent intervals.[29,30] Furthermore, in studies aiming to assess enamel thickness, the prospective acquisition of CBCT scans solely for research purposes may raise ethical concerns. Therefore, when evaluating enamel thickness in human subjects using CBCT, the only ethically acceptable approach is to conduct a retrospective analysis of previously acquired CBCT data. Future research should expand these findings by exploring additional ethnic groups and broader age ranges to enhance generalizability. Moreover, longitudinal studies assessing the long-term impact of IPR on enamel health and patient outcomes are necessary to further validate its safety and efficacy. Such studies would provide clinicians robust, evidence-based guidelines for personalized orthodontic care.

CONCLUSION

Clinicians should be cautious when performing IPR across different ethnicities, such as Caucasian and Somalian populations, due to variations in enamel thickness that are independent of gender, anterior-posterior region, or DM surfaces. Enamel thickness was generally similar between genders across different ethnic groups. In the posterior region of both arches, clinicians may perform IPR more safely on the distal surface than on the mesial surface due to greater enamel thickness.

Ethics

Ethics Committee Approval: The study was reviewed and approved by the institutional review board (Tufts Univ. #2018-11181).

Informed Consent: The study was approved by the Institutional Review Board with an "Expedited" status, and therefore, no patient consent form was required.

Footnotes

Author Contributions: Concept - A.M.E., S.A.; Design - E.C.F., S.A.; Data Collection and/or Processing - E.C.F.; Analysis and/or Interpretation - A.M.E., S.A.; Literature Search - E.C.F., A.M.E., S.A.; Writing - E.C.F., A.M.E., S.A.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: This study did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

REFERENCES

1. Güleç Ergün P, Arman Özçırpıcı A, Atakan Kocabalkan A, Tunçer Nİ. Evaluation of the consistency of two interproximal reduction methods in clear aligner therapy: a preliminary study. Turk J Orthod. 2024;37(1):1-6. [CrossRef]
2. Begg P. 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;40:298-312. [CrossRef]
3. Germeç D, Ugur Taner T. Ortodontide interproksimal mine aşındırması. *Turk J Orthod*. 2008;21(1):67-79. [CrossRef]
4. Stroud JL, Buschang PH, Goaz PW. Sexual dimorphism in mesiodistal dentin and enamel thickness. *Dentomaxillofac Radiol*. 1994;23(3):169-171. [CrossRef]
5. Stroud JL, English J, Buschang PH. Enamel thickness of the posterior dentition: its implications for nonextraction treatment. *Angle Orthod*. 1998;68(2):141-146. [CrossRef]
6. Frindel C. Clear thinking about interproximal stripping. *J Dentofacial Anom Orthod.* 2010;13(2):187-199. [CrossRef]
7. Sheridan JJ, Ledoux PM. Air-rotor stripping and proximal sealants. An SEM evaluation. *J Clin Orthod*. 1989;23(12):790-794. [CrossRef]
8. Sheridan JJ. Air-rotor stripping update. *J Clin Orthod*. 1987;21(11):781-788. [CrossRef]
9. Germeç D, Taner TU. Effects of extraction and nonextraction therapy with air-rotor stripping on facial esthetics in postadolescent borderline patients. *Am J Orthod Dentofacial Orthop*. 2008;133(4):539-549. [CrossRef]
10. Sarig R, Vardimon AD, Sussan C, et al. Pattern of maxillary and mandibular proximal enamel thickness at the contact area of the permanent dentition from first molar to first molar. *Am J Orthod Dentofacial Orthop*. 2015;147(4):435-444. [CrossRef]
11. Pindoria J, Fleming PS, Sharma PK. Inter-proximal enamel reduction in contemporary orthodontics. *Br Dent J*. 2016;221(12):757-763. [CrossRef]
12. 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. [CrossRef]
13. Fırıncıoğulları EC, Erdinç AM. Interproximal enamel reduction (stripping) techniques in orthodontic treatment. *Int Arch Dent Sci.* 2023;44(2):173-179. [CrossRef]
14. Buschang PH, Shulman JD. Incisor crowding in untreated persons 15-50 years of age: United States, 1988-1994. *Angle Orthod*. 2003;73(5):502-508. [CrossRef]
15. Zachrisson BU, Minster L, Ogaard B, Birkhed D. Dental health assessed after interproximal enamel reduction: caries risk in posterior teeth. *Am J Orthod Dentofacial Orthop*. 2011;139(1):90-98. [CrossRef]
16. Iplinsky NT, Gandini Junior LG, Gandini AS, et al. Radiographic evaluation of enamel thickness of permanent teeth: relevance and applicability. *Dental Press J Orthod*. 2024;29(3). [CrossRef]
17. Harris EF, Hicks JD. A radiographic assessment of enamel thickness in human maxillary incisors. *Arch Oral Biol*. 1998;43(10):825-831. [CrossRef]
18. Hall NE, Lindauer SJ, Tüfekçi E, Shroff B. Predictors of variation in mandibular incisor enamel thickness. *J Am Dent Assoc*. 2007;138(6):809-815. [CrossRef]
19. Danesh G, Hellak A, Lippold C, Ziebura T, Schafer E. Enamel surfaces following interproximal reduction with different methods. *Angle Orthod*. 2007;77(6):1004-1010. [CrossRef]
20. Atsu SS, Aka PS, Kucukesmen HC, Kilicarslan MA, Atakan C. Age-related changes in tooth enamel as measured by electron microscopy: implications for porcelain laminate veneers. *J Prosthet Dent*. 2005;94(4):336-341. [CrossRef]
21. Peck S, Peck H. Crown dimensions and mandibular incisor alignment. *Angle Orthod*. 1972;42(2):148-153. [CrossRef]
22. Moss ML, Moss-Salentijn L. Analysis of developmental processes possibly related to human dental sexual dimorphism in permanent and deciduous canines. *Am J Phys Anthropol*. 1977;46(3):407-413. [CrossRef]

23. Konstantinidou E, Araujo E, Mccray J, Ueno H, Schneider PP, Foley PF. Evaluation of enamel thickness of mandibular incisors. *Dental Press J Orthod*. 2023;28(2). [CrossRef]

24. Schwartz GT. Enamel thickness and the helicoidal wear plane in modern human mandibular molars. *Arch Oral Biol*. 2000;45(5):401-409. [CrossRef]

25. Macha A de C, Vellini-Ferreira F, Scavone-Junior H, Ferreira RI. Mesiodistal width and proximal enamel thickness of maxillary first bicuspids. *Braz Oral Res*. 2010;24(1):58-63. [CrossRef]

26. Fernandes SA, Vellini-Ferreira F, Scavone-Junior H, Ferreira RI. Crown dimensions and proximal enamel thickness of mandibular second bicuspids. *Braz Oral Res*. 2011;25(4):324-330. [CrossRef]

27. Abdi CM. The newest African-Americans?: Somali struggles for belonging. In: Armila P, Kananen M, Kontkanen Y. (eds) The contexts of diaspora citizenship. International perspectives on migration, vol 17. Springer, Cham. [CrossRef]

28. The Editors of Encyclopaedia Britannica (2021, February 11). *Caucasian peoples*. Encyclopedia Britannica. [CrossRef]

29. Çelik A, Ersan N, Selvi-Kuvvetli S. Evaluation of maxillary sinus pathologies in children and adolescents with cleft lip and palate using cone beam computed tomography: a retrospective study. *Cleft Palate Craniofac J*. 2025 Feb 9:10556656241306834. Online ahead of print [CrossRef]

30. Dindaroğlu F, Fırıncıoğulları EC, Duran GS. Three-dimensional evaluation of social smile asymmetry in patients with unilateral impacted maxillary canine: a 3D stereophotogrammetry study. *Clin Oral Investig*. 2023;27(11):6915-6924. [CrossRef]

DOI: 10.4274/TurkJOrthod.2025.2024.105

TURKISH JOURNAL OF ORTHODONTICS

Original Article

Finite Element Method (FEM) Analysis of Dentoskeletal Changes on Temporary Anchorage Device (TAD)-Assisted Mandibular Advancement

Nazleen Valerie Vas[1], Navaneethan Ramasamy[1], Sruthi Harikrishnan[1], Karthikeyan Ramalingam[2], Marco Di Blasio[3], Hande Uzunçıbuk[4], Marco Cicciù[5], Giuseppe Minervini[6,7]

[1]SIMATS Deemed University, Saveetha Institute of Medical and Technical Sciences, Saveetha Dental College and Hospitals, Department of Orthodontics and Dentofacial Orthopaedics, Chennai, India
[2]SIMATS Deemed University, Saveetha Institute of Medical and Technical Sciences, Saveetha Dental College and Hospitals, Department of Oral Pathology and Microbiology, Chennai, India
[3]University of Milan, Department of Biomedical, Surgical and Dental Sciences, Milan, Italy
[4]Trakya University, Faculty of Dentistry, Department of Orthodontics, Edirne, Türkiye
[5]Catania University, Department of Biomedical and Surgical and Biomedical Sciences, Catania, Italy
[6]SIMATS Deemed University, Saveetha Institute of Medical and Technical Sciences, Saveetha Dental College and Hospitals, Chennai, India
[7]University of Campania "Luigi Vanvitelli", Multidisciplinary Department of Medical-Surgical and Odontostomatological Specialties, Naples, Italy

Cite this article as: Vas NV, Ramasamy N, Harikrishnan S, et al. Finite element method (FEM) analysis of dentoskeletal changes on temporary anchorage device (TAD)-assisted mandibular advancement. *Turk J Orthod.* 2025; 38(2): 97-106

Main Points

- Finite element analysis revealed that Class II elastics combined with interconnected implants produce significant skeletal stress in the posterior ramus of the mandible and the lateral nasal aperture of the maxilla, with minimal dental stress
- The observed stress patterns indicate a tendency toward maxillary distalization and mandibular advancement, which reflects a greater contribution of skeletal displacement compared to dental movement.
- The findings support the potential of this approach in achieving skeletal correction, but further clinical validation under dynamic loading conditions is necessary.

ABSTRACT

Objective: Temporary anchorage devices (TADs) enhance the efficiency of fixed functional appliances (FFAs) by providing stable anchorage, improving skeletal and dental corrections, optimizing vertical control, and enhancing treatment outcomes for Class II and III malocclusions. TADs also help prevent the proclination of the lower incisors and the distalization of the molars, which are commonly observed with FFAs lacking skeletal anchorage. This study aims to analyze the displacement and stress distribution patterns generated in craniofacial structures and dentition using conjoined implants and intermaxillary elastics for growth modification in growing Class II patients.

Methods: Finite element analysis was conducted using cone-beam computed tomography data from an 11-year-old patient with Class II Division 1 malocclusion. Mini-implants and miniplates were designed and assembled in SolidWorks, meshed using HyperMesh, and analyzed in Abaqus 6.14 to evaluate stress and displacement patterns under a 450 g orthopedic force applied via Class II elastics.

Results: In the mandible, the highest principal and von Mises stresses were observed on the posterior surface of the ramus, whereas in the maxilla, stress concentrations were noted lateral to the nasal aperture. Additional stress concentrations were identified in the region posterior to the glenoid fossa. The mandible was displaced anteroinferiorly as a whole, while the maxilla exhibited posterosuperior displacement. Dental movements included maxillary expansion with intrusion of the anterior teeth, and anterior displacement of the mandibular dentition, primarily resulting from bodily movement.

Corresponding author: Marco Di Blasio, **e-mail:** marco.diblasio@unimi.it
Received: July 06, 2024 **Accepted:** April 22, 2025 **Publication Date:** July 02, 2025

Conclusion: The use of Class II elastics in combination with Temporary Anchorage Devices (TADs) produces greater stress and displacement in skeletal structures compared to the dentition. As a result, this treatment approach is more likely to produce substantial skeletal changes than dental alterations.

Keywords: Anchorage devices, biomechanics, bone remodeling, Class II, displacements, retrognathic mandible, temporary anchorage devices

INTRODUCTION

Growth plays a significant role in modulating treatment plans for skeletal and dental corrections. Fixed functional therapy with fixed functional appliances (FFAs) is a primary method for correcting Class II skeletal discrepancies due to a retrognathic mandible in growing patients. Class II malocclusion is often characterized by mandibular retrusion, and a variety of functional appliance modalities have been developed to optimize mandibular positioning in both the sagittal and vertical dimensions.[1]

FFAs are considered "non-compliant Class II inter-arch correctors" and achieve significant growth modification. These appliances promote mandibular advancement by mitigating dental interference and consolidating the dental arches, leading to craniofacial orthopedic, soft tissue, and orthodontic changes.[2-7] However, research has shown undesirable dental effects, including forward tipping of the lower incisors, backward tipping of the upper incisors, and a decrease in the interincisal angle, which can prolong treatment time.[8] Increased lower incisor inclination reduces the amount of skeletal correction achievable and increases the risk of relapse. Additionally, external root resorption has been reported as statistically significant in cases treated with the Forsus Fatigue Resistant Device (FFRD) and the Herbst appliance, with resorption of up to 0.81 mm and 1.55 mm, respectively.[9-11]

Skeletal anchorage is the most effective method for reinforcing anchorage, regardless of the type of planned tooth movement in orthodontics. To this end, many appliances have been modified to include Temporary Anchorage Devices (TADs) to improve anchorage.[12] The use of TADs in conjunction with FFAs has been shown to augment anchorage and prevent the adverse effects associated with FFAs alone.[13] For instance, Ince-Bingol et al.[14] found that the relapse rate one year post-treatment was not significantly different between cases managed with a combination of FFAs and TADs compared to those treated with FFAs alone. Bakdach and Hadad[15] reported that the Forsus appliance combined with bilateral miniplates enhanced skeletal and dental corrections in Class II growing patients, with treatment effects being largely dentoalveolar and a reduction in proclination of the lower incisors.

The miniplate-supported Forsus FRD appliance has been found to significantly retract both the maxillary and mandibular incisors compared to the effects observed with the activator appliance and untreated control groups. The authors suggested that the results might differ if the force were applied through skeletal anchorage in both jaws.[16] In 2016, Al-Dumaini et al.[17] described a treatment approach for Class II skeletal correction in growing patients using miniplate-based skeletal anchorage in conjunction with Class II elastics delivering up to 450 g of force bilaterally. However, a disadvantage of miniplates is that they provide indirect anchorage from the bone surface, and their placement in children is invasive. While miniscrews engage the bone directly, their stability is compromised when high forces are applied.[18] Connecting two miniscrews with a miniplate can enhance the stability of the anchorage system.[19-21]

Protraction of the mandible generates forces that produce stress and strain in various parts of the orofacial complex and the temporomandibular joint, thereby influencing biological changes. The application of elastics introduces an additional layer of complexity to the patterns of stress distribution and bone remodeling. The finite element method provides a unique analytical framework for examining stress patterns, deformations, and displacements in systems with irregular geometries and non-homogeneous material properties. Finite element analysis (FEA) can quantify stress levels at specific points within the teeth, periodontal ligaments, alveolar bone, and craniofacial structures. It also facilitates in vitro simulation of the oral environment and graphical representation of displacements caused by applied forces.[22]

The authors of the present study developed a model to correct Class II skeletal malocclusions in growing patients. In this model, extraoral elastics delivering a force of 450 g are applied from a hook on a miniplate—supporting a pair of mini-implants placed in the attached gingiva of the mandibular molar region—to a miniplate hook located in the maxillary canine region. Finite element analysis (FEA) was used to evaluate the displacement and stress patterns induced in the maxilla, mandible, condyle, and maxillary-mandibular dentition by the application of 450 g orthopedic forces through elastics connected between implants in the maxillary canine and mandibular molar regions.

METHODS

This research was designed and conducted at Saveetha Dental College the Institution in Chennai, India Ethics Committee approved the study protocol SRB/SDC/ORTHO-2102/23/231. Prior to enrollment, informed consent was obtained from the participant. An 11-year-old female patient with protrusive maxillary incisors, exhibiting Angle's Class II Division 1 malocclusion—characterized by a normal upper jaw, a retrognathic lower jaw, average growth pattern, favorable facial esthetics, well-aligned lower dentition, and no signs of temporomandibular joint disorder—was selected for this investigation. Comprehensive pre-treatment records, including study models, photographs, and cone-beam computed tomography (CBCT) scans, were collected for this patient.

For clarity, the methodology may be divided into the following steps:

1. File Conversion and Design

The CBCT acquired in Digital Imaging and Communications in Medicine (DICOM) format was converted to Standard Tessellation Language (STL) format using Geomagic Freeform software (3D Systems). SolidWorks Software (Dassault Systèmes) was used to design the miniplate and mini-implants. The dimensions of the mini-implants were 8 × 1.5 mm. Mini-implants were placed in the interradicular areas - between upper lateral incisor and the upper canine and, between upper canine and upper first premolar - their positioned 10 mm apical to the cementoenamel junction. The miniscrews were connected to each other with a miniplate bearing a hook to serve as the point of force application. A similar arrangement was designed in the lower arch, with the mini-implants were placed mesial and distal to the mesiobuccal root of the first molar.

2. Computer-Aided Design Modelling

The CBCT data, along with the designed miniplate and miniscrews, were imported in Standard Tessellation Language (STL) format into SolidWorks software (Dassault Systèmes) for computer-aided design (CAD) modeling. The STL model underwent geometric corrections and fine-tuning. The finalized CAD model is shown in Figure 1.

3. Pre-processing

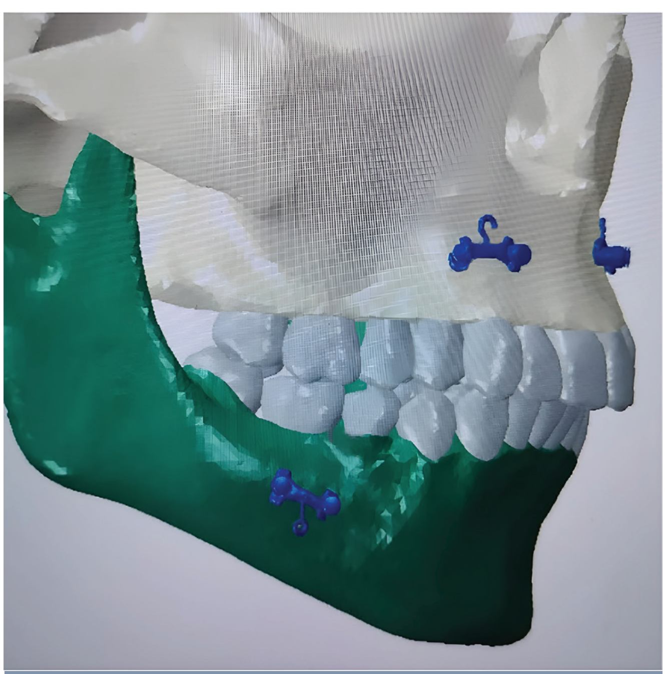

Figure 1. The CAD model with designed conjoined miniscrews
CAD, computer-aided design

Finite element meshing was performed using Altair HyperMesh 14.0.120, as illustrated in Figure 2, to generate a finite element model (FEM). Cortical and trabecular bone, along with the teeth, were modeled as homogeneous linear elastic materials. A thickness of 1 mm covering the surface areas of the jawbones where the teeth were located was defined as cortical bone, with the underlying region modeled as trabecular bone. The miniplate and miniscrews were then assembled onto the finite element model. Table 1 lists the material properties assigned to each component, and Table 2 provides the number of nodes and elements in the FEM.[23-28]

Boundary conditions were applied to constrain the maxilla, and contact interactions were defined. To simulate the intermaxillary elastics hooked between the maxillary and mandibular anchors, a pulling force of 450 g was applied.

4. Solving

Once the FEM was completed, the model was data-checked and prepared for analysis. Linear static analysis was performed for the applied load using Abaqus 6.14 software. Once the analysis is completed, the results were post-processed using the Abaqus Viewer. Stress values were expressed in megapascals (MPa). The color scale on the left side of each figure indicates the corresponding stress levels. Statistical analysis was not performed, as the study did not include multiple patient groups. The assessed outcomes included principal stresses, von Mises stresses, and displacements.

RESULTS

Principal Stresses and Von Mises Stresses

For the applied load on the FE model, the calculated stresses are reported in Table 3 and illustrated in Figure 2. The maximum stress recorded in the FE model was observed in the maxilla and mandible, with values of approximately 7 MPa. While the maxilla and mandible exhibited similar von Mises stress values, principal stresses in the maxilla (10.2 MPa) were higher than those in the mandible (7.1 MPa). In the maxilla, the highest stress concentration was observed around the miniscrew insertion site, in the region latero-inferior to the nasal aperture and posterior to the glenoid fossa. In the mandible, however, the greatest stress concentration was located on the posterior surface of the ramus. The miniplate exhibited significantly

Table 1. Material properties used in the study

Name	Young's Modulus (Mpa)	Poisson's Ratio
Maxilla	2,000	0.3
Mandible	7,000	0.3
Teeth	20,000	0.3
PDL	5	0.3
Implant	2,00,000	0.3
Miniplate	200000	0.3

PDL, periodontal ligament

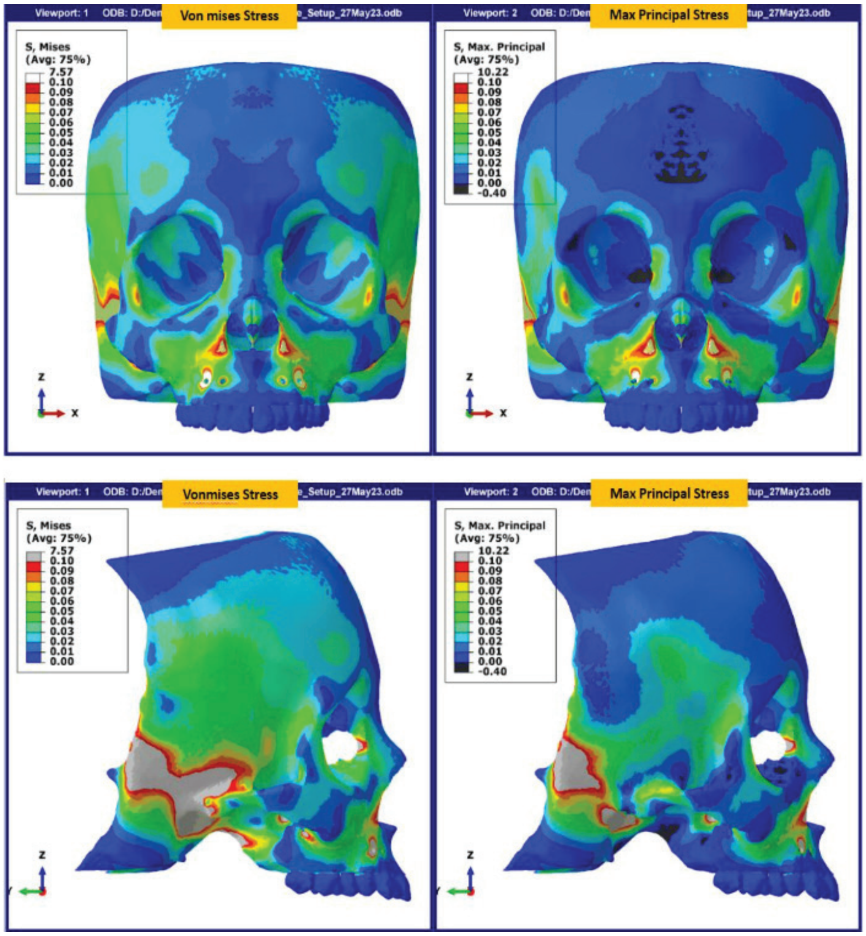

Figure 2. Stress distribution in the maxilla in frontal and lateral view

Table 2. The number of nodes and elements in the FE model

	Model	
Name	**No. of Nodes**	**No. of Elements**
Maxilla	115113	526770
Mandible	23036	98969
Maxillary teeth	25020	107293
Mandibular teeth	23265	99164
Maxillary PDL	2194	4146
Mandibular PDL	3136	5991
Implant	14500	55940
Miniplate	27216	113932
Total	233480	1012205

PDL, periodontal ligament; FE, finite element

greater stress than the miniscrew.

Displacements in the Finite Element Model

Displacements were recorded in all three spatial dimensions and are displayed in Figure 3. The X-axis represents displacements in the transverse plane, the Y-axis corresponds to the sagittal plane, and the Z-axis to the vertical plane. In the maxilla, the observed displacement occurred primarily along the X-axis, indicating transverse expansion. In the mandible, a forward displacement of the coronoid process followed by the condyle was observed, along with posterior displacement of the mental region. A superior displacement of the anterior portion of the mandible was also observed, with its magnitude decreasing in the anteroposterior direction.

Table 3. Summary of stresses generated in the model

Maximum Stress Result Summary (MPa)		
Name	**Von Mises**	**Max Principal**
Maxilla	7.57	10.218
Mandible	7.379	7.191
Maxillary teeth	0.81	0.776
Mandibular teeth	1.827	2.067
Maxillary PDL	0.006419	0.003725
Mandibular PDL	0.013126	0.014975
Implant	105.696	88.529
Miniplate	334.294	271.893

PDL, periodontal ligament

Displacements in the dentition were observed both en masse and in relation to the alveolar bone. As depicted in Figure 4, in the maxillary dentition, the highest displacements in the transverse plane were recorded for the first molars, followed by the second molars and premolars. In the sagittal plane, a mesial displacement was noted for the anterior teeth up till the premolars. In the vertical plane, intrusion of the anterior teeth and extrusion of the second molars were recorded. In the mandibular arch, the greatest expansion was observed in

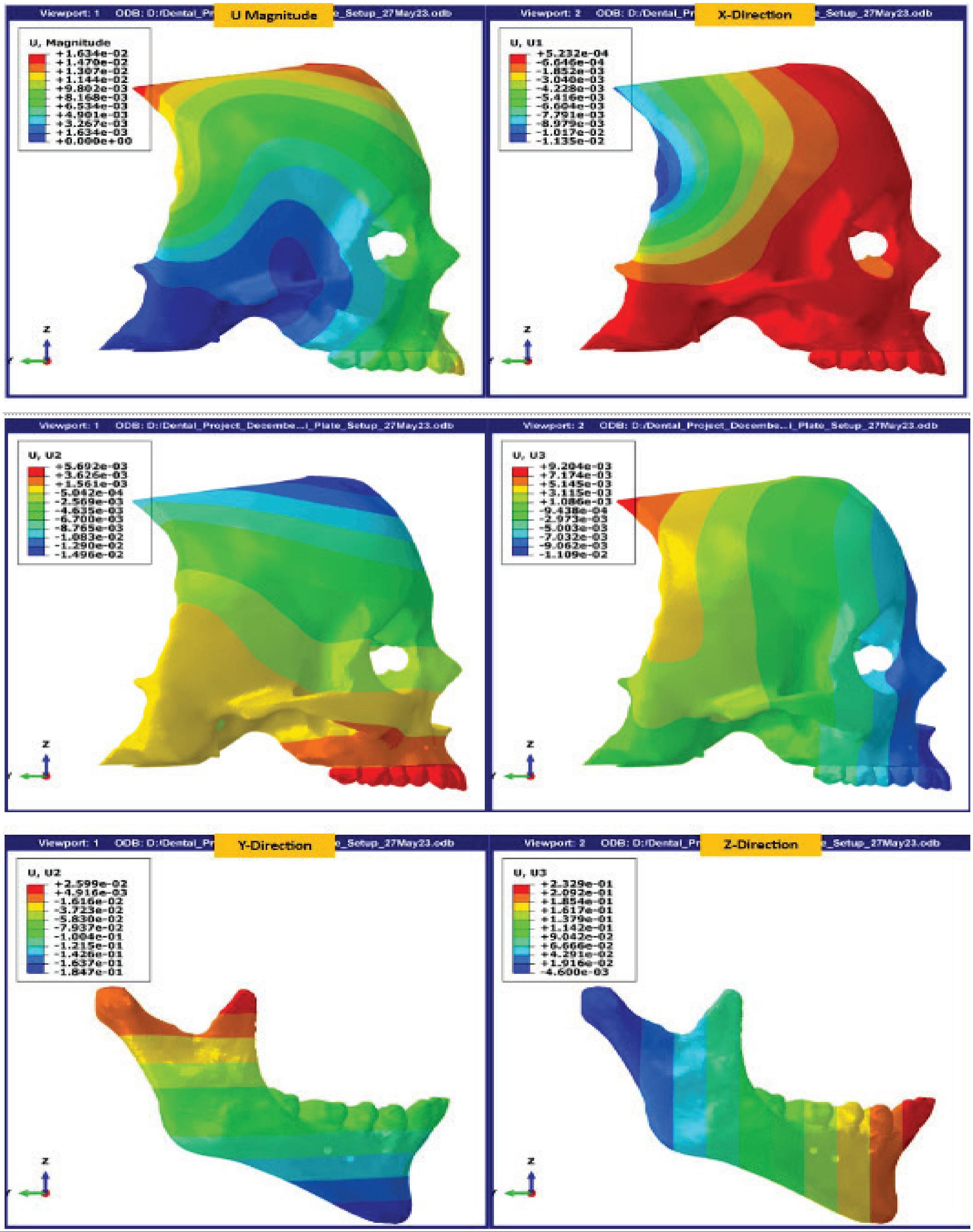

Figure 3. Displacements of the maxilla and mandible

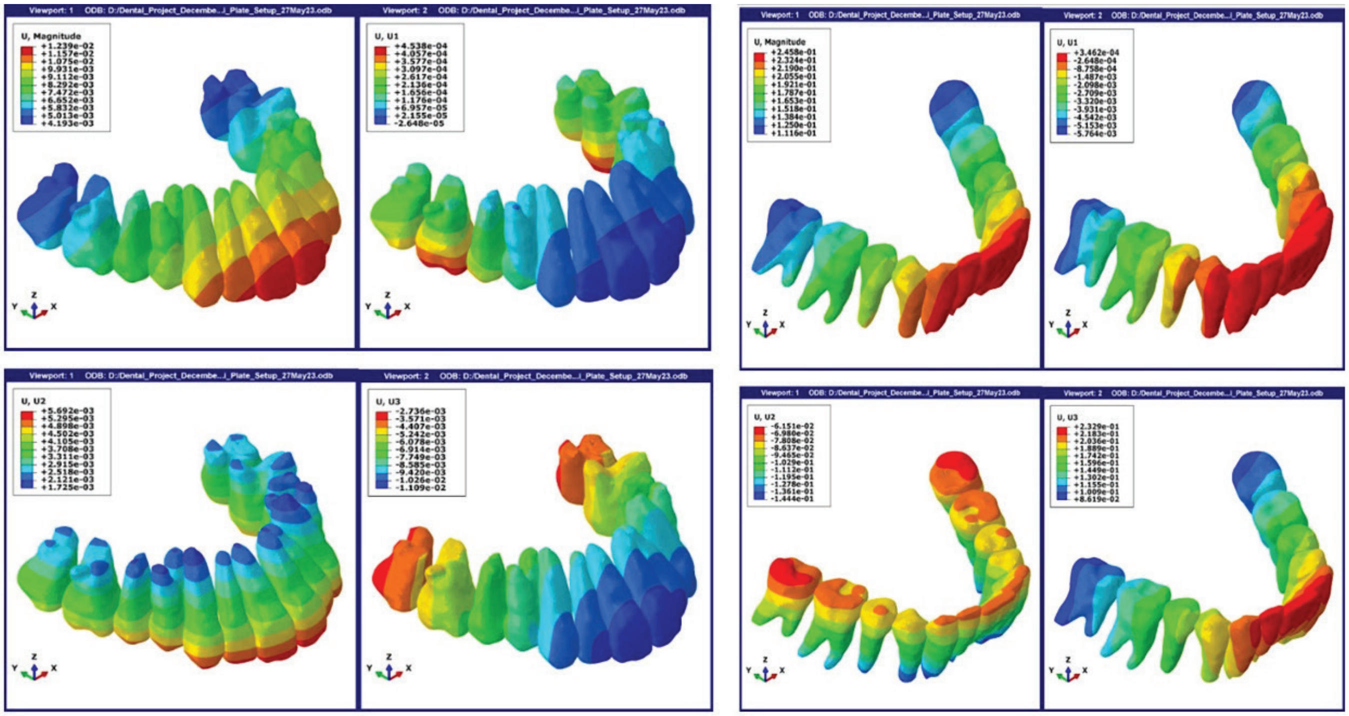

Figure 4. Maxillary and mandibular dentition displacement

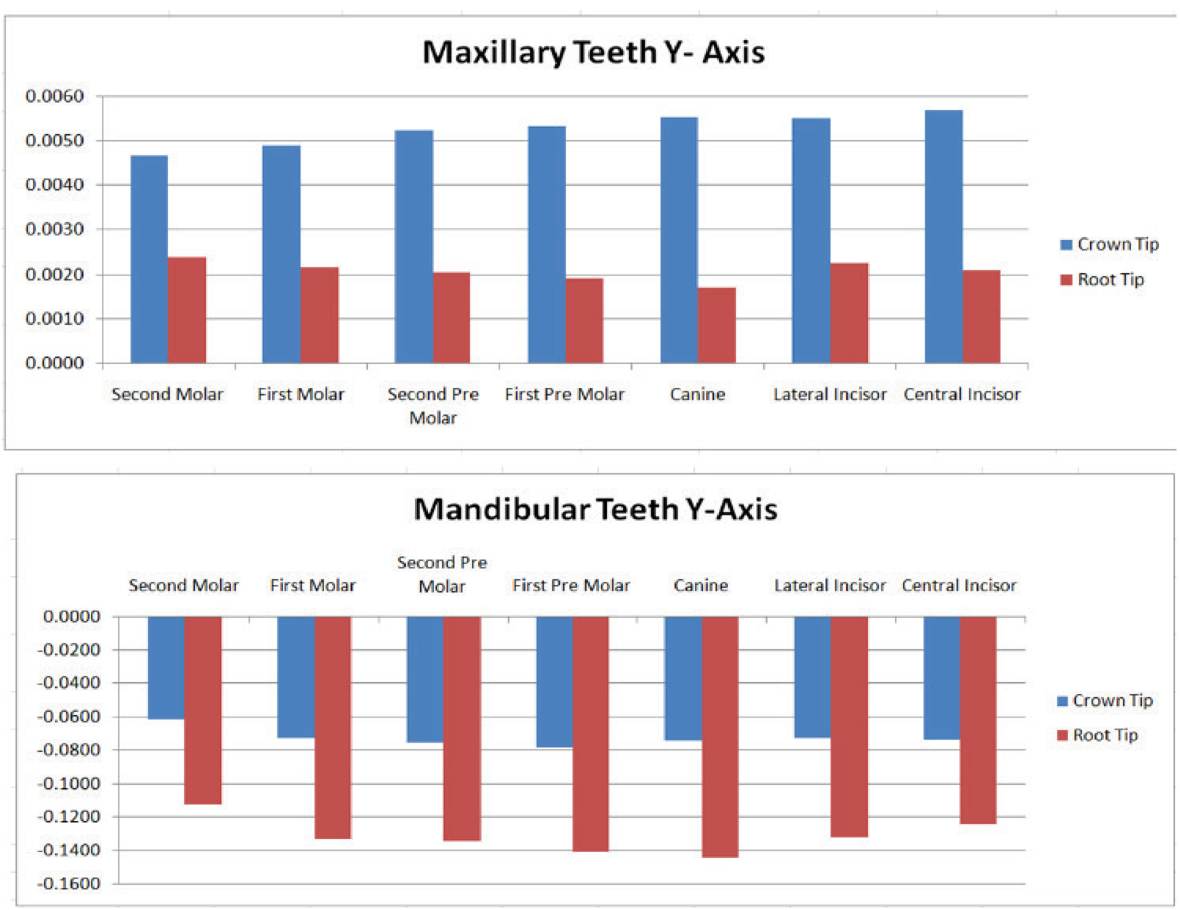

Figure 5. Distalization of the maxillary dentition and mesialisation of the mandibular dentition as seen in the sagittal plane

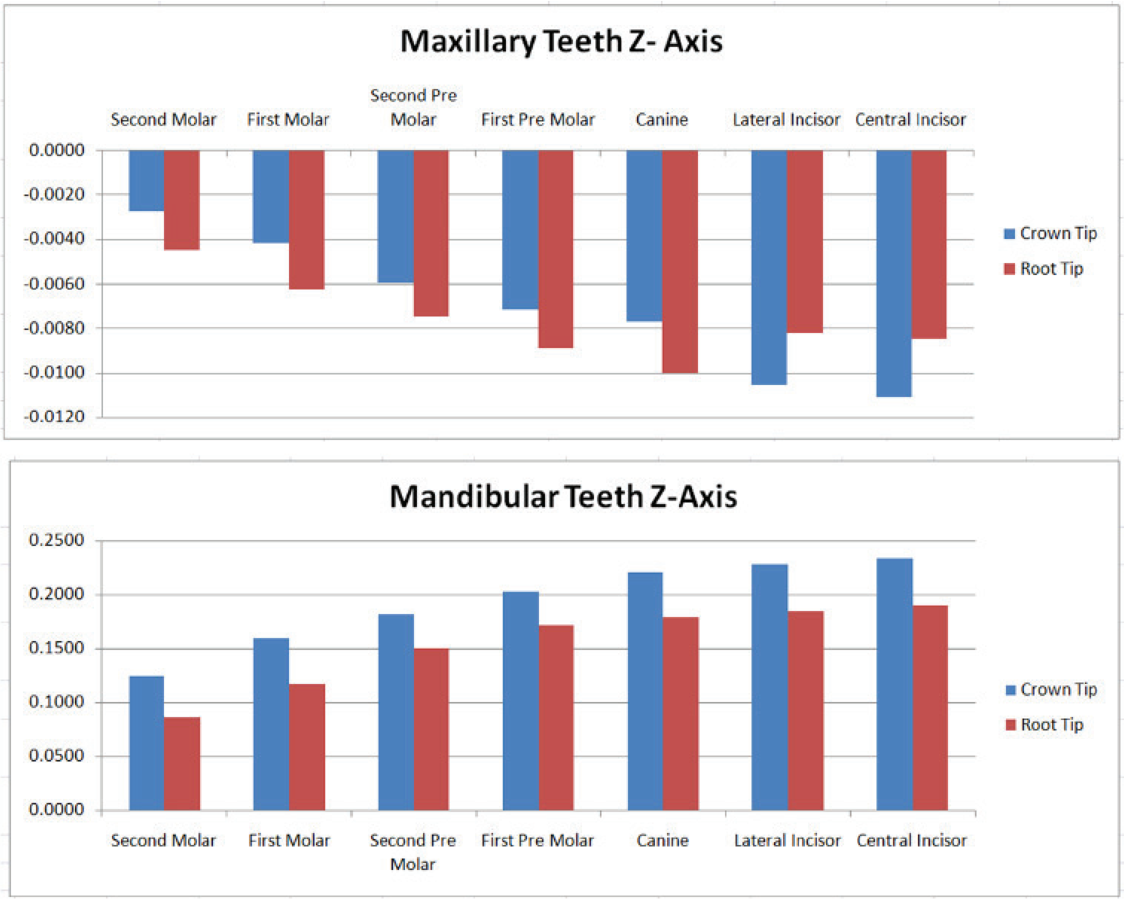

Figure 6. Extrusion of the maxillary crown and Intrusion of the mandibular of the crown and roots as seen in the vertical plane

the anterior dentition. Anterior displacement was observed in both the molars and incisors, with the greatest extrusive displacement occurring in the incisors. These displacements are illustrated in Figure 4.

Figures 5 and 6 provide a graphical representation of crown and root displacements along the Y-axis and Z-axis, respectively. In the Y-axis, displacement values are greater for the crown than the root in the maxillary dentition, while the opposite is observed in the mandibular dentition. This suggests that the retroclination (posterior displacement) of the maxillary teeth is primarily due to tipping, whereas in the mandible, the teeth exhibit anteriorly directed bodily displacement.

Similarly, extrusion of the maxillary posterior teeth is primarily caused by bodily movement, whereas in the anterior segment it is due to tipping. In the lower arch, extrusion of the mandibular teeth appears to result from tipping movements rather than translational displacement.

The finite element analysis investigating the effects of Class II elastics used in conjunction with conjoined implants yielded several significant findings. Notably, in the mandible, the maximum principal and von Mises stresses were concentrated in the cortical bone region of the posterior ramus, whereas the mandibular dentition experienced comparatively lower stress levels. In the maxilla, the highest stresses were observed in the region lateral to the nasal aperture. Additionally, mild expansion was noted in the maxillary dental segments.

Moreover, the condylar process and sigmoid notch exhibited the highest concentrations of principal and von Mises stresses. The analysis also indicated a distalizing effect on the maxilla and a protractive effect on the mandible. Interestingly, dental movements along the mandibular arch in the sagittal plane were primarily attributed to bodily displacement.

However, it is important to note that FEA considers only static loading of the maxilla and mandible. Therefore, a clinical study is necessary to assess the dynamic forces exerted by this therapy. Such a study would provide a more comprehensive understanding of the treatment effects and help validate the findings derived from FEA.

DISCUSSION

The finite element method (FEM) is a computational approach used to approximate solutions for boundary-value problems in engineering applications. It facilitates the simulation of biomechanical parameters, including stress, strain, and displacement, which occur within living systems due to the application of external forces. Bone remodeling occurs in response to compressive and tensile stresses induced by functional orthopedic forces. Understanding displacements and stresses can aid in predicting treatment outcomes.[22-35] Applying FEM analysis to TAD-assisted mandibular advancement enables the study of forces and deformations on the mandible and associated soft tissues.

FEM analysis enables the assessment of force and deformation distribution across the mandible and adjacent soft tissues during TAD-assisted mandibular advancement. This analysis provides valuable insights into the biomechanical response of the dentoskeletal system to TAD-assisted mandibular advancement, supporting treatment planning. FEM analysis also allows for the evaluation of mechanical stresses induced by TADs during mandibular advancement and their impact on dental and craniofacial structures. In this study, the finite element model was constructed to evaluate stress and displacement in the dentition and craniofacial skeleton under a 450 g force applied via intraoral elastics to miniplates connecting two miniscrews placed in the upper canine and lower molar regions. The use of a skeletally anchored appliance prevents unnecessary loading of the dentition, particularly since bone bears mechanical loads more effectively and has a higher modulus of elasticity than the periodontal ligament (PDL).

The study findings revealed that the highest stress concentrations occurred around the miniscrew insertion sites. Furthermore, elevated stress concentrations were observed in the vicinity of the nasal aperture and posterior to the glenoid fossa in the maxilla. In the mandible, notable stress concentrations were found both at the miniscrew insertion sites and on the posterior surface of the ramus, inferior to the condylar neck. These findings suggest that TAD-assisted mandibular advancement can induce significant stress in the mandible and adjacent structures.

The net resultant displacement caused by the application of a pulling force between the maxillary and mandibular miniplates was a restraining force, leading to posterior displacement and expansion of the maxilla, and a tipping force that induced retroclination of the maxillary teeth. The maxillary skeletal base exhibited a posterior directional shift, as evidenced by corresponding nodal displacement. This shift can be attributed to the posterosuperior force applied to the maxilla by the appliance. The maxillary anterior teeth demonstrated a distal and intrusive displacement pattern, whereas the maxillary molars exhibited a distal and extrusive displacement.

In the mandible, forward displacement of the coronoid process and condyle was observed, which opened the bite and caused posteriorly directed displacement of the mental region. Anterior displacement of the lower incisors occurred as a result of the forward movement of the mandible en masse, rather than from loss of anchorage and tipping, as typically seen at the end of treatment with FFAs.

Von Mises stress is a theoretical measure used to estimate material strength, whereas principal stress represents a directly observable mechanical load. Principal stress appears to play a pivotal role in the remodeling processes of craniofacial and alveolar bone. These observations suggest more pronounced remodeling activity on the posterior aspect of the mandibular ramus, with relatively limited dental effects, as documented in clinical research.[35]

Previous FEM studies involving FFA applications have reported findings similar to those of the present study, including distal and extrusive displacement of the maxillary anterior teeth, as well as distal and intrusive displacement of the maxillary molars. The highest von Mises stresses were observed in the mandibular cortical bone—spanning from the canine to premolar regions—and in the sigmoid notch, corresponding to the area where the FFRD engaged in the lower arch.[36] The difference between these results and those of the present study is attributed to the direct attachment of the FFA to the mandibular dentition, which resulted in force application to the teeth—an effect that was circumvented in the current study. Prior studies employing treatment protocols analogous to that of the present investigation have reportedly yielded enhanced skeletal outcomes and reduced mandibular incisor protrusion—findings consistent with the results of the current study.

These findings suggest that TAD-assisted mandibular advancement using Class II elastics is a viable alternative to FFAs and potentially to skeletally anchored FFAs. Since FEM accounts only for static loading and records instantaneous stress patterns, the results may not be clinically reproducible. Therefore, a clinical trial applying this treatment model is necessary to confirm its efficacy. In the current model, the hooks were placed apically. This setup can be replicated in clinical scenarios only when there is sufficient sulcus depth. In cases of insufficient sulcus depth, the hook must either be made very short or positioned mesially on the maxillary plate and distally on the mandibular plate. Alternatively, the hooks may also be placed occlusally. In both scenarios, variations from the current model's results would be expected due to changes in force vectors resulting from altered hook positioning.

A limitation of this study is that mesh structure details were not included due to constraints in the scope and focus of the research, which prioritized overall outcomes and comparative analysis over specific meshing parameters. Additionally, mesh generation was conducted using automated algorithms within the FEM software, with default settings employed to ensure efficiency and consistency across simulations.

CONCLUSION

Finite element analysis demonstrated that Class II elastics combined with interconnected implants generate significant stress concentrations in the posterior ramus of the mandible and the lateral nasal aperture region of the maxilla, with minimal stress on the dentition. This treatment approach produced a distalizing effect on the maxilla and a protractive effect on the mandible, primarily through skeletal displacement. These findings suggest that this approach may be more effective in producing skeletal changes than dental movements. Further clinical studies are required to validate these results under dynamic loading conditions.

Ethics

Ethics Committee Approval: Saveetha Dental College the Institution in Chennai, India Ethics Committee approved the study protocol SRB/SDC/ORTHO-2102/23/231.

Informed Consent: Prior to enrollment, informed consent was obtained from the participant.

Footnotes

Author Contributions: Surgical and Medical Practices - N.V.V.; Concept - N.V.V.; Design - N.R., M.C.; Data Collection and/or Processing - S.H.; Analysis and/or Interpretation - N.R., K.R., G.M.; Literature Search - M.D.B., H.U.; Writing - M.D.B., H.U., G.M.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: This study did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

REFERENCES

1. A J, JR M. Components of Class II Malocclusion in children 8-10 years of age. *Angle Orthod.* 1981;51(3):177-202. [CrossRef]
2. Flores-Mir C, Major MP, Major PW. Soft tissue changes with fixed functional appliances in Class II division 1. *Angle Orthod.* 2006;76(4):712-720. [CrossRef]
3. Zymperdikas VF, Koretsi V, Papageorgiou SN, Papadopoulos MA. Treatment effects of fixed functional appliances in patients with Class II malocclusion: a systematic review and meta-analysis. *Eur J Orthod.* 2016;38(2):113-126. [CrossRef]
4. Bori E, Deslypere C, Estaire Muñoz L, Innocenti B. Clinical results of the use of low-cost TKA prosthesis in low budget countries—a narrative review. *Prosthesis.* 2023; 5(3):840-850. [CrossRef]
5. Wellington IJ, Kaufman CR, Antonacci CL, et al. The effects of interbody device design and placement on lumbar lordosis and disc height in transforaminal lumbar interbody fusion. *Prosthesis.* 2023;5(3):752-762. [CrossRef]
6. Vaid N, Doshi V, Vandekar M. What's "Trend"ing in Orthodontic literature? *APOS Trends Orthod* 2016;6:1-4. [CrossRef]
7. Kravitz ND, Dalloul B, Zaid YA, Shah C, Vaid NR. What percentage of patients switch from Invisalign to braces? A retrospective study evaluating the conversion rate, number of refinement scans, and length of treatment. *Am J Orthod Dentofacial Orthop.* 2023;163(4):526-530. [CrossRef]
8. Çoban G, Gül Amuk N, Yağcı A, Akgün G, Abbood Abbood IH. Evaluation of external apical root resorption caused by fixed functional treatment of class II malocclusion: Cast splint Herbst appliance vs. Forsus fatigue resistant device. *J Orofac Orthop.* 2023;84(1):50-59. [CrossRef]
9. Minervini G, Franco R, Marrapodi MM, Di Blasio M, Isola G, Cicciù M. Conservative treatment of temporomandibular joint condylar fractures: A systematic review conducted according to PRISMA guidelines and the Cochrane Handbook for systematic reviews of interventions. *J Oral Rehabil.* 2023;50(9):886-893. [CrossRef]
10. Adel SM, Vaid NR, El-Harouni N, Kassem H, Zaher AR. TIP, TORQUE & ROTATIONS: How accurately do digital superimposition software packages quantify tooth movement? *Prog Orthod.* 2022;23(1):8. [CrossRef]
11. Awad MG, Ellouze S, Ashley S, Vaid N, Makki L, Ferguson DJ. Accuracy of digital predictions with CAD/CAM labial and lingual appliances: A retrospective cohort study. *Semin Orthod.* 2018;24(4):393-406. [CrossRef]
12. Papadopoulos MA, Tarawneh F. The use of miniscrew implants for temporary skeletal anchorage in orthodontics: a comprehensive review. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 2007;103(5):6-15. [CrossRef]
13. Huang Y, Sun W, Xiong X, Zhang Z, Liu J, Wang J. Effects of fixed functional appliances with temporary anchorage devices on Class II malocclusion: A systematic review and meta-analysis. *J World Fed Orthod.* 2021;10(2):59-69. [CrossRef]
14. Gandedkar NH, Shrikantaiah S, Patil AK, et al. Influence of conventional and skeletal anchorage system supported fixed functional appliance on maxillo-mandibular complex and temporomandibular joint: A preliminary comparative cone beam computed tomography study. *Int Orthod.* 2019;17(2):256-268. [CrossRef]
15. Ince-Bingol S, Kaya B, Bayram B, Arman-Ozcirpici A. Treatment efficiency of activator and skeletal anchored forsus fatigue resistant device appliances. *Clin Oral Investig.* 2021;25(3):1505-1512. [CrossRef]
16. Bakdach WMM, Hadad R. Is there any enhanced treatment effect on class II growing patients when Forsus Fatigue Resistant Device is reinforced by either miniplates or miniscrews? A systematic review and meta-analysis. *Int Orthod.* 2021;19(1):15-24. [CrossRef]
17. Al-Dumaini AA, Halboub E, Alhammadi MS, Ishaq RAR, Youssef M. A novel approach for treatment of skeletal Class II malocclusion: Miniplates-based skeletal anchorage. *Am J Orthod Dentofacial Orthop.* 2018;153(2):239-247. [CrossRef]
18. Consolaro A. Mini-implants and miniplates generate sub-absolute and absolute anchorage. *Dental Press J Orthod.* 2014;19(3):20-23. [CrossRef]
19. Leung MT, Rabie AB, Wong RW. Stability of connected mini-implants and miniplates for skeletal anchorage in orthodontics. *Eur J Orthod.* 2008;30(5):483-489. [CrossRef]
20. Cheruvu RNS, Katuri KK, Dhulipalla R, Kolaparthy L, Adurty C, Thota KM. Evaluation of soft tissue and crestal bone changes around non-submerged implants with and without a platelet-rich fibrin membrane: A randomized controlled clinical trial. *Dent Med Probl. 2023*;60(3):437-443. [CrossRef]
21. Yazarloo S, Arab S, Mirhashemi AH, Gholamrezayi E. Systematic review of preventive and treatment measures regarding orthodontically induced white spot lesions. *Dent Med Probl.* 2023;60(3):527-535. [CrossRef]
22. Jagota V, Sethi APS, Kumar K. Finite element method: an overview. *Walailak J Sci & Tech.* 2013;10(1):1-8. [CrossRef]
23. Chaudhry A, Sidhu MS, Chaudhary G, Grover S, Chaudhry N, Kaushik A. Evaluation of stress changes in the mandible with a fixed functional appliance: a finite element study. *Am J Orthod Dentofacial Orthop.* 2015;147(2):226-234. [CrossRef]
24. Kendre B, Kumar A, Shetty KN, Hedge G, Umale V, Kulshrestha R. Evaluation of stress changes in the maxilla with fixed functional appliances-A 3D FEM study. *J Orthod Sci.* 2021;10:10. [CrossRef]
25. Gracco A, Boccaccio A, Cirignaco A, Cozzani M, Pappalettere C, Vitale G. Numerical/experimental analysis of the stress field around miniscrews for the orthodontic anchorage. *Eur J Orthod.* 2009;31:12-20. [CrossRef]
26. Murugesan A, Navaneethan R. Comparing the efficacy of specs loop and T loop for en masse anterior retraction - a finite element study. *Clin Investig Orthod.* 2022;81(2):93-97. [CrossRef]

27. Murugesan A, Navaneethan R. A newly designed loop for en-masse anterior retraction - a finite element study. *Orthod Waves.* 2021;80:143-148. [CrossRef]
28. Kim KY, Bayome M, Park JH, Kim KB, Mo SS, Kook YA. Displacement and stress distribution of the maxillofacial complex during maxillary protraction with buccal versus palatal plates: finite element analysis. *Eur J Orthod.* 2015;37:275-283. [CrossRef]
29. Minervini G, Franco R, Marrapodi MM, Di Blasio M, Ronsivalle V, Cicciù M. Children oral health and parents education status: a cross sectional study. *BMC Oral Health.* 2023;23(1):787. [CrossRef]
30. Minervini G, Franco R, Marrapodi MM, Almeida LE, Ronsivalle V, Cicciù M. Prevalence of temporomandibular disorders (TMD) in obesity patients: A systematic review and meta-analysis. *J Oral Rehabil.* 2023;50(12):1544-1553. [CrossRef]
31. Huiskes R, Chao EYS. A survey of finite element analysis in orthopedic biomechanics: The first decade. *J Biomech.* 1983;16(6):385-409. [CrossRef]
32. Mackerle J. A finite element bibliography for biomechanics (1987-1997) [Internet]. 1998. [CrossRef]
33. Liu P, Tu J, Wang W, et al. Effects of mechanical stress stimulation on function and expression mechanism of osteoblasts. *Front Bioeng Biotechnol.* 2022;10:830722. [CrossRef]
34. Alkahtany M, Beatty MW, Alsalleeh F, et al. Color stability, physical properties and antifungal effects of ZrO_2 additions to experimental maxillofacial silicones: comparisons with TiO_2. *Prosthesis*. 2023;5(3):916-938. [CrossRef]
35. Ungureanu LM, Alionte CG, Grad D, Daragiu DE. Finite element analysis of the influence of mechanical stresses on the mandible. In: Applied Mechanics and Materials. Trans Tech Publications Ltd; 2014. p. 626-633. [CrossRef]
36. Kumar D, Sharma R, Arora V, Bhupali NR, Tuteja N. Evaluation of displacements and stress changes in the maxillo-mandibular complex with fixed functional appliance skeletally anchored on mandible using miniplates: A finite element study. *J Orthod Sci.* 2022;11:42. [CrossRef]

DOI: 10.4274/TurkJOrthod.2025.2025.28

TURKISH JOURNAL OF
ORTHODONTICS

Original Article

Comparative Effects of Maxillary Advancement Alone and in Combination with Mandibular Setback on Airway Anatomy and Function in Class III Malocclusion: A Controlled Prospective Clinical Study

Hatice Başaran Bal[1], Celal Irgın[2]

[1]Private Practice, Kayseri, Türkiye
[2]Erciyes University Faculty of Dentistry, Department of Orthodontics, Kayseri, Türkiye

Cite this article as: Başaran Bal H, Irgın C. Comparative effects of maxillary advancement alone and in combination with mandibular setback on airway anatomy and function in Class III malocclusion: a controlled prospective clinical study. *Turk J Orthod.* 2025; 38(2): 107-115

Main Points

- Maxillary advancement increased the volume of all sections of the pharyngeal airway and minimum cross-sectional area.
- Maxillary advancement had no significant impact on hyoid bone position or head posture.
- Mandibular setback with maxillary advancement led to an overall increase in pharyngeal airway volume but a reduction in hypopharyngeal volume and minimum cross-sectional area.
- Mandibular setback with maxillary advancement does not increase the risk of obstructive sleep apnea in young, healthy individuals.
- Maxillary advancement may help mitigate airway reduction caused by mandibular setback.

ABSTRACT

Objective: The aim of this study is to evaluate the effects of maxillary advancement (MxA) and bimaxillary osteotomy (MdS-MxA) on upper pharyngeal airway volume (PAV), apnea-hypopnea index (AHI), hyoid bone (HB) position, and head posture (HP) in young and healthy individuals with skeletal Class III malocclusion.

Methods: This prospective clinical study included three groups: MxA, MdS-MxA, and Class I control group, with 12 subjects each. In the surgical groups, lateral cephalometric radiographs, cone-beam computed tomography images, and AHI measurements were obtained preoperatively and approximately six months postoperatively. Only pre-treatment records were collected for the control group. Depending on data distribution, parametric (Paired Samples t-test and ANOVA) or non-parametric (Wilcoxon Signed-Rank and Kruskal-Wallis) tests were used for intra- and inter-group statistical comparisons, with a significance level set at $p<0.05$.

Results: The maxillary forward movement for the MxA group was 5.34 mm. It was 5.32 mm in the MdS-MxA group, and the mandibular setback was 4.71 mm. Nearly six months after surgery, significant differences were observed among the groups in the sagittal positions of the jaws, the vertical position of the mandible, the vertical position of the hyoid bone, and PAV sections. No significant differences were found in HP, minimum cross-sectional area or AHI.

Conclusion: PAV increase was observed in both surgical groups. MdS-MxA did not have an effect on obstructive sleep apnea. Postoperative HB displacement was minimal, with a slight inferior shift observed in the MdS-MxA group.

Keywords: Body mass index, cone-beam computed tomography, hyoid bone, malocclusion, orthognathic surgical procedures, polysomnography

Corresponding author: Celal Irgın, **e-mail:** cirgin@hotmail.com
Received: February 20, 2025 **Accepted:** June 10, 2025 **Publication Date:** July 02, 2025

INTRODUCTION

A skeletal Class III anomaly is characterized by dentofacial disharmony and is often associated with various clinical manifestations. Defined in relation to the anterior cranial base in the sagittal plane, this anomaly may result from excessive mandibular growth, insufficient maxillary development, or a combination of both.[1] These skeletal discrepancies often lead to aesthetic, functional, and structural challenges, necessitating orthognathic treatment in skeletally mature individuals.[2] By combining orthodontic treatment with surgical interventions, this approach repositions the jaws and teeth in all spatial planes to enhance dentofacial harmony, optimize anatomical relationships, and improve quality of life.[3] The most commonly performed orthognathic surgical techniques for correcting skeletal Class III anomalies include bilateral sagittal split ramus osteotomy [mandibular setback (MdS); 10%)], LeFort I osteotomy [maxillary advancement (MxA); 50%], or a combination of both procedures [(MdS-MxA); 40%].[4] These surgical techniques affect both hard and soft tissues, often resulting in structural changes that influence surrounding anatomical regions.[5] The pharyngeal airway volume (PAV), hyoid bone (HB) position, and head posture (HP) are particularly important due to their influence on respiratory function.[6] These anatomical alterations can significantly affect respiratory function, leading to enhancements or complications in airway dynamics. Understanding the relationships among these factors is critical to achieving optimal surgical outcomes and improving patients' quality of life following surgery.

The function of the pharyngeal lumen is heavily influenced by the interaction of the mandible, tongue, soft palate, and lateral pharyngeal walls.[7] Orthognathic surgery can potentially modify the dimensions of the nasal and oral cavities and the PAV, depending on the direction and extent of jaw movement. Consequently, these surgeries can positively or negatively affect an individual's breathing capacity.[8,9] Evidence suggests that surgical techniques such as MxA, maxillomandibular advancement, and surgically assisted rapid maxillary expansion typically result in an increase in PAV.[10] In contrast, studies indicate that approaches involving MdS-MxA or MdS alone are associated with a reduction in PAV in Class III patients. Among these, MdS-MxA tends to produce less pronounced reductions in PAV.[11-13] The primary concern regarding such reductions is the potential development of obstructive sleep apnea (OSA), a subtype of sleep-disordered breathing (SDB). Objective sleep assessments, including the home sleep apnea test (HSAT) and full polysomnography (PSG), play a crucial role in identifying significant respiratory events and evaluating SDB. These tests measure various physiological parameters.

The primary metric used in these assessments is the apnea-hypopnea index (AHI), which quantifies the severity of breathing disturbances. An AHI threshold of 5 events per hour is accepted as indicative of OSA.[10] While the impact of orthognathic surgery on AHI in patients with mild or severe OSA has been explored,[14,15] no study has specifically examined how different surgical techniques affect Class III patients with AHI values below the diagnostic threshold.

The HB, a horseshoe-shaped structure, is situated at the level of the third cervical vertebra and is connected to the mouth floor, tongue, larynx, epiglottis, and pharynx through various muscle attachments. It plays a critical role in essential physiological functions such as maintaining airway patency, mastication, phonation, digestion, and supporting head posture.[16] Orthognathic surgical procedures often result in positional changes to the HB position.[17] The literature includes numerous studies that investigate the short- and long-term effects of orthognathic surgery on the HB position, focusing on the type of surgery performed and the extent of jaw movement.[18] However, this remains an area of ongoing research and debate. Since the HB position is closely related to the mandible and the HP,[19] it is critical to understand how these surrounding structures are affected by orthognathic surgery to ensure stable and predictable treatment outcomes.

Therefore, this study aims to compare the postoperative effects of MxA alone and MdS-MxA on PAV, AHI, HB position, and natural HP and to evaluate how these outcomes differ from those observed in the Class I control group. Accordingly, the null hypothesis is that MxA and MdS-MxA do not have different effects on upper airway anatomy and function in Class III malocclusion.

METHODS

This prospective controlled clinical study was conducted following approval from the Erciyes University Clinical Research Ethics Committee (decision no.: 2022/614, date: 14.09.2022). The sample size was determined using G*Power (ver. 3.1.9.7) analysis software. Based on a 1:1 group ratio, a significance level of α=0.05, a power of 1-β=0.80, and an effect size of d=0.8, a minimum of 10 individuals per group was required. The power analysis was based on differences in airway volume changes reported by Karaaslan et al.[14] To enhance the study's reliability and account for potential variability, 12 participants were included in each group. All procedures involving human participants adhered to the ethical principles outlined in the Declaration of Helsinki. Informed consent was obtained from all participants enrolled in this study. The study included 36 adults categorized into three groups: individuals with skeletal Class III anomalies who underwent MxA, those who underwent MdS-MxA, and a skeletal Class I control group (CI-C). The inclusion criteria for participants are provided in Table 1.

The exclusion criteria for all groups included systemic or chronic airway disease, dysmorphism, severe craniofacial anomalies, pathology in the oropharyngeal or nasal region, a history of pharyngeal airway surgery, or a history of allergy or allergic rhinitis. Table 2 presents the gender distribution, age, follow-up period, and BMI averages for each group, along with the mean sagittal jaw movement achieved through orthognathic surgery in the Class III surgical groups. MxA was performed using LeFort I osteotomy, while MdS was conducted using BSSO without genioplasty. Jaw movement was measured using CBCT records analysed with NemoFAB software (Madrid, Spain). Both surgical procedures were performed by the same surgical team at the Erciyes University Faculty of Dentistry Hospital.

Table 1. Inclusion criteria for participants according to groups

MxA Group	MxA-MdS Group	Cl-C Group
Skeletal and dental Class III (ANB°<0°)	Skeletal and dental Class III (ANB°<0°)	Skeletal Class I (0°<ANB°< 4°)
Normal growth pattern (26°<SN-GoGn°<38°)	Normal growth pattern (26°<SN-GoGn°<38°)	Normal growth pattern (26°<SN-GoGn°<38°)
Patients with Class I and Class II according to the Mallampati classification	Patients with Class I and Class II according to the Mallampati classification	Patients with Class I and Class II according to the Mallampati classification
AHI <5	AHI <5	AHI <5
BMI within normal limits (18.5-24.9 kg/m^2)	BMI within normal limits (18.5-24.9 kg/m^2)	BMI within normal limits (18.5-24.9 kg/m^2)
Patients aged between 18 and 25 years	Patients aged between 18 and 25 years	Patients aged between 18 and 25 years
Patients with maxillary retrognathia	Patients with maxillary retrognathia and mandibular prognathia	Orthognathic
The amount of surgical activation for the maxilla ranging between 4 and 7 mm	Total amount of surgical activation not exceeding 12 mm	None

MxA, maxillary advancement; MdS-MxA, mandibular setback with maxillary advancement; Cl-C, control group; BMI, body mass index; AHI, apnoea–hypopnea index.

Table 2. Sample description

	MxA (n=12)	MdS- MxA (n=12)	Cl-C (n=12)
Gender (Female/Male)	2/10	7/5	6/6
Age (Years)	22.7±2.4	23.6±2.6	18.2±3.4
Follow-up period (Month)	7.14±0.79	7.25±0.74	-
Body mass index (BMI) (kg/m^2)	22.6±3.6	22.9±3.1	21.8±3.3
Maxillary advancement (mm)	5.34±1.23	5.32±0.52	-
Mandibular setback (mm)	-	-4.71±0.66	-

MxA, maxillary advancement; MdS-MxA, mandibular setback with maxillary advancement; Cl-C: control group.

Acquisition of Records and Measurements

This study utilized multiple diagnostic tools, including lateral cephalometric radiographs (LCR), cone beam computed tomography (CBCT) images, an HSAT device, and body mass index (BMI) data. In the surgical groups, records were obtained at two time points: before surgery (T1) and at least six months postoperatively (T2). For the Cl-C group, only pre-orthodontic treatment records (T1) were included, serving as a baseline for comparison.

HP for all participants was determined and recorded using an inclinometer device (MPU-6050 Six-Axis MEMS MotionTracking, TDK Invernesses, Tokyo) mounted on glasses with a motion-sensitive receiver attached to the arm. Based on the recorded quantitative values, lateral cephalometric radiographs (LCRs) were obtained using an X-ray machine (OP300; Instrumentarium Dental, Tuusula, Finland) while participants maintained a natural HP in a standing posture, with lips at rest and teeth in centric occlusion (Figure 1). The LCR images were transferred to Dolphin Imaging software (Dolphin Imaging, USA) for angular and linear measurements (Figure 2), including those related to the HB position, HP, and jaw positions. In the surgical groups, LCRs were taken approximately 12 weeks before surgery to assess incisor inclination, position, and surgical activation amount. Postoperatively, LCRs were taken as a control measure before the orthodontic finishing phase.

CBCT images were obtained from the surgical groups approximately one week before surgery for three-dimensional (3D) surgical planning and splint fabrication and approximately after six months postoperatively for control assessments. In the Cl-C group, CBCT images were taken before orthodontic treatment to evaluate impacted teeth, tooth roots, and the temporomandibular joint. All CBCT scans were acquired using a NewTom 5G device (Quantitative Radiology, Verona, Italy) with participants in a supine position parallel to the floor. The vertical guideline was aligned through the glabella and philtrum, centered on the face, while the horizontal guideline passed through the lateral canthus of the eye. CBCT image files were converted to DICOM format and imported into NemoFAB software for airway analysis. Pharyngeal airway volume (PAV, mm^3) and minimal cross-sectional area (mCSA, mm^2) were calculated, with airway volume measurements divided into three sections: the nasopharynx, oropharynx, and hypopharynx (Figure 3).

The AHI of all participants was determined using an HSAT device (Alice NightOne) to conduct a home sleep breathing test. The AHI value was calculated by transferring one night of sleep data from each participant to a computer and analysing it with the device's Sleepware G3 software. The test was performed over three consecutive nights, and the final AHI score was obtained by averaging the data collected across these nights.

Height (m) and weight (kg) measurements were recorded for each participant. Body mass index (BMI) was calculated using the formula BMI=kg/m^2 by dividing each participant's weight (kg) by the square of their height (m) (Table 2).

Figure 1. Recording the patient's dynamic head posture and transferring the natural head posture to the cephalostat

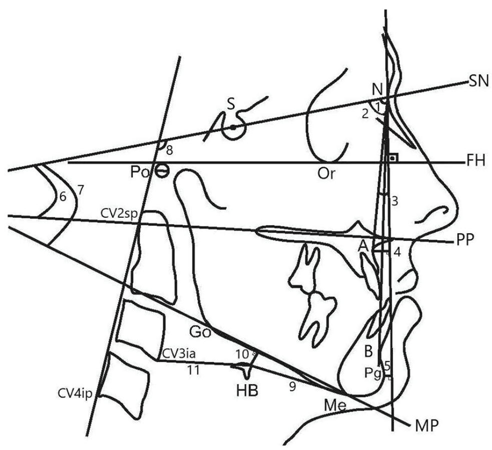

Figure 2. Lateral cephalometric measurements. **l) SNA°:** The angle between the anterior cranial base (SN plane) passing through the Sella (S) and Nasion (N) points and the NA plane passing through the N and A points. **2) SNB°:** The angle between the SN plane passing through the S and N points and the NB plane passing through the N and B points. **3) ANB°:** The angle formed between the NA and NB planes. **4) N⊥ A (mm):** The perpendicular distance from point A to the vertical line drawn from N to FH. The FH plane is the line formed by connecting the Orbitale (Or) and Porion (Po) points. **5) N⊥ Pog (mm):** The perpendicular distance from the Pogonion (Pog) point to the vertical line drawn from N to FH. **6) SN-PP°:** The angle between the SN plane and the palatal plane (PP) [anterior nasal spine (ANS)- posterior nasal spine (PNS)]. **7) SN-MP°:** The angle between the SN plane and the mandibular plane (MP) (Gonion-Menton) **8) CVT-SN°:** The angle between the cervical vertebrae tangent (CVT) [passing through the most superior-posterior point of 2nd cervical vertebra (CV2sp) and the most inferior-posterior point of the 4th cervical vertebra (CV4ip)] and SN plane. **9) HB-Me (mm):** Linear distance from the hyoid bone (HB) to Menton. **10) HB-Cv3 (mm):** Linear distance from the HB to the most inferior-anterior point of 3rd cervical vertebrae (CV3ia). 11) HB-MP (mm): The perpendicular distance of from HB to the MP.

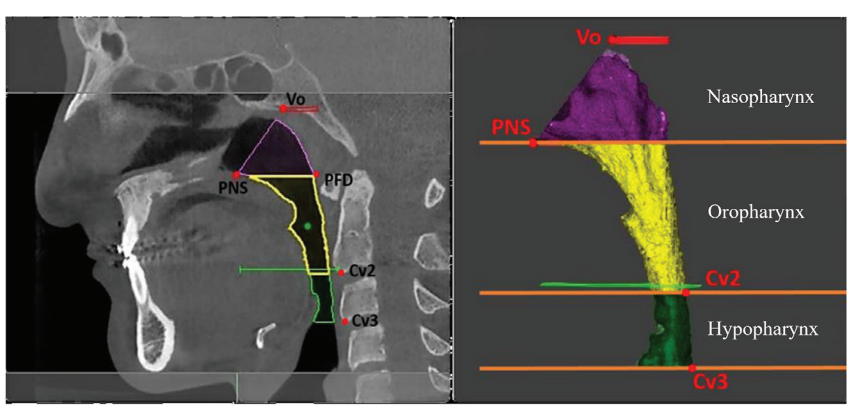

Figure 3. The sections and boundaries of the upper posterior airway with volumetric measurements.

Statistical Analysis

Statistical analyses of the data were performed using IBM Statistical Package for Social Sciences (SPSS, version 21). The normality of data distribution was assessed using the Shapiro-Wilk test. For intra- and inter-group comparisons, parametric tests (Paired Samples t-test and ANOVA) were applied to normally distributed variables. In contrast, non-parametric tests (Wilcoxon Signed-Rank and Kruskal-Wallis) were used for non-normally distributed variables. Results were evaluated with a 95% confidence interval, and p-values below 0.05 were considered statistically significant.

RESULTS

To assess measurement error in the records obtained from the participants, half of the lateral cephalometric radiographs (LCRs) and cone-beam computed tomography (CBCT) images were randomly selected. All measurements were repeated by the same researcher (HBB) after one month. The reliability of the measurements was assessed using Pearson correlation and Cronbach's alpha analysis. The Pearson correlation coefficient ranged from 0.877 to 0.952, while the Cronbach's alpha coefficient ranged from 0.812 to 0.946. No statistically significant difference was found between the initial and repeated measurements.

The means and standard deviations of the measurements at T1 and T2 in the surgical groups and at T1 in the control group, along with intergroup comparisons, are presented in Table 3. Statistically significant differences were observed in preoperative SNA, SNB, ANB, SN-MP angles, N⊥A, N⊥Pog, and HB-MP distances, as well as in PAV sections and mCSA ($p<0.05$). Conversely, no significant differences were found between the groups for SN-PP, CVT-SN angles, HB-CV3, HB-Me distances, and AHI ($p>0.05$). Comparison of T2 data with the control group revealed significant differences in SN-MP angle, N⊥A, N⊥Pog, HB-MP distances, and nasopharyngeal and oropharyngeal volume measurements ($p<0.05$). No significant differences were observed in the remaining parameters ($p>0.05$).

Intragroup comparisons of preoperative and postoperative measurements within the surgical groups are presented in Table 4. In the MxA group, maxillary advancement alone resulted in statistically significant changes in SNA and ANB angles, N⊥A and N⊥Pog distances, all pharyngeal sections, mCSA, and AHI ($p<0.05$). However, no significant changes were observed in the SNB angle, HB position, or CVT-SN angle ($p>0.05$). In the MdS-MxA group, significant changes were observed in all measurements except for SN-PP and SN-MP angles and HB-Me and HB-CV3 distances.

DISCUSSION

The effects of orthognathic surgery on anatomical structures and their impact on patients' quality of life, including chewing, breathing, speech, dentofacial aesthetics, and sleep quality, remain a key research focus. Skeletal Class III anomalies are less common than other sagittal anomalies; however, they are a primary indication for orthognathic treatment due to their adverse effects on facial aesthetics and bite function. The design of the surgical intervention is planned according to the affected jaws from the anomaly, with a strong emphasis on achieving an aesthetic outcome and occlusion. However, excessive focus on facial aesthetics during surgical planning may inadvertently compromise respiratory function, especially when sleeping. To reduce the risk of OSA, combining MdS with MxA is often recommended in cases requiring mandibular repositioning.[11] However, the precise limitations of such combined movements remain unclear. In the present study, a comparative analysis was conducted to evaluate the effects on upper airway anatomy and function. Two surgical approaches were examined: (1) a single-jaw surgery involving 5.34 mm of maxillary advancement in individuals with retrognathic maxilla, and (2) a double-jaw surgery involving 5.32 mm of maxillary advancement combined with 4.71 mm of mandibular setback in individuals with both retrognathic maxilla and prognathic mandible. Except for a few parameters, no statistically significant differences were observed between the groups in the postoperative period. Therefore, the null hypothesis was accepted, indicating that the two surgical approaches produced comparable outcomes in terms of upper airway anatomy and function.

Before orthognathic surgery, all groups had AHI values below the diagnostic threshold; however, significant differences were observed in PAV and mCSA values. The MdS-MxA group demonstrated the largest oropharynx, hypopharynx and mCSA measurements, while the control group had the greatest nasopharyngeal volume. In the MxA group, maxillary advancement resulted in a 19% increase in the nasopharynx, 10% in the oropharynx, 3% in the hypopharynx, and a 24% increase in mCSA. These findings indicate that MxA promotes expansion across all three sections of the PAV, with the degree of expansion gradually decreasing from top to bottom. MdS-MxA surgery led to a 19% increase in the nasopharynx and a 5% increase in the oropharynx while causing a 4% volumetric reduction in the hypopharynx and a 15% decrease in mCSA. A study involving an MdS of at least 9 mm reported a significant postoperative reduction in PAV, oropharyngeal, hypopharyngeal volumes, and retroglossal mCSA, accompanied by an increase in AHI.[11] Our finding suggests that MxA may offer partial protection against the constrictive effects of MdS on the oropharynx, hypopharynx, and mCSA, confirming recent studies.[20-22] Total PAV also increased in both surgical groups (MxA: 11% and MdS-MxA: 6%). Despite the observed reductions in mCSA and hypopharyngeal volume in the MdS-MxA group, these changes did not negatively affect AHI. Both surgical procedures significantly reduced AHI values, and no significant difference was observed between the groups approximately 6 months after surgery. Therefore, in young and healthy individuals, MdS-MxA does not function as a contributing factor to the development of OSA.

Table 3. T1 and T2 comparison across all groups.

	T1					T2				
Measurements	MxA ($\bar{x}$±SD)	MdS-MxA ($\bar{x}$±SD)	CI-C ($\bar{x}$±SD)	Test value	p-value	MxA ($\bar{x}$±SD)	MdS-MxA ($\bar{x}$±SD)	CI-C ($\bar{x}$±SD)	Test value	p-value
SNA°	76.66±4.47^{a}	76.51±4.05^{a}	80.93±3.38^{b}	7.41*	0.025	83.24±2.68	83.57±1.99	80.93±3.37	4.010*	0.135
SNB°	81.43±3.27^{ab}	84.23±3.30^{b}	79.43±3.61^{a}	10.08*	0.006	81.14±1.71	82.00±2.16	79.43±3.61	3.702*	0.157
ANB°	-4.89±2.76^{a}	-7.43±2.67^{a}	1.50±0.47^{b}	25.14*	<0.001	2.05±1.23	1.29±0.85	1.50±0.47	3.548*	0.170
N⊥ A (mm)	-4.74±0.93^{a}	-4.48±0.47^{a}	-0.23±0.62^{b}	157.21†	<0.0001	0.74±0.40^{a}	0.81±0.34^{a}	-0.23±0.62^{b}	16.94*	<0.001
N⊥ Pog (mm)	-2.23±1.01^{a}	0.33±0.79^{b}	-1.41±0.44^{c}	32.99†	<0.0001	-1.90±0.82^{a}	-4.28±0.79^{b}	-1.41±0.44^{a}	24.624*	<0.001
SN-PP°	8.28±4.47	8.42±3.37	7.73±2.39	0.19*	0.911	9.89±2.37	8.13±3.57	7.73±2.39	5.54*	0.063
SN-MP°	31.96±3.05^{a}	36.08±4.03^{b}	34.05±2.52^{ab}	6.15*	0.046	32.83±1.97^{a}	36.63±4.18^{b}	34.05±2.52^{ab}	9.556*	0.008
CVT-SN°	103.10±2.41	103.48±8.78	106.13±5.67	0.268*	0.875	102.12±2.18	107.10±7.70	106.13±5.67	3.776*	0.151
HB-Me (mm)	37.64±5.89	37.38±5.90	34.42±7.65	2.298*	0.317	38.29±2.81	36.60±4.76	34.42±7.65	3.922*	0.141
HB-Cv3 (mm)	35.58±5.76	34.97±4.98	35.30±5.42	0.038†	0.963	36.47±5.44	35.07±4.19	35.30±5.42	0.209*	0.901
HB-ML (mm)	11.58±4.12^{ab}	13.11±4.22^{b}	8.59±2.27^{a}	10.515*	0.005	12.30±5.89^{ab}	14.33±3.98^{a}	8.59±2.27^{b}	10.198*	0.006
Nasopharynx (mm^3)	4359.06±128.7^{a}	3968.31±172.5^{b}	5095.31±230.7^{c}	46.591†	<0.001	5206.27±122.9^{a}	4746.87±236.7^{b}	5095.31±230.7^{a}	15.986*	<0.001
Oropharynx (mm^3)	8753.01±167.7^{a}	9207.23±146,3^{b}	9004.02±197.6^{c}	2793.4†	<0.001	9655.86±229.9^{a}	9562.27±186.5^{a}	9004.02±197.5^{b}	21.536*	<0.001
Hypopharynx (mm^3)	4175.89±160.6^{a}	4865.88±178.2^{b}	4091.89±116.5^{a}	10.183*	0.006	4303.00±179.5^{ab}	4655.95±158.9^{a}	4091.89±116.4^{b}	8.596*	0.01
mCSA (mm^2)	168.39±27.19^{a}	242.99±20.56^{b}	194.74±34.82^{c}	21.683*	<0.001	208.10±22.76	205.71±15.45	194.74±34.82	4.686*	0.096
AHI	2.18±0.95	1.70±0.94	2.23 ± 0.92	1.159†	0.326	1.67±0.63	1.42±0.65	2.23±0.92	4.761*	0.092

^{a,b}, there is a statistically significant difference between groups with different superscript letter; ^{ab}, there is no statistically significant difference between groups with common superscript letter; *, Kruskal-Wallis test; †, ANOVA test; Statistical significance: $p<0.05$.
MxA, maxillary advancement; MdS-MxA, mandibular setback with maxillary advancement; CI-C, control group; $\bar{x}$, mean; SD, standard deviation.

Table 4. Intragroup comparison of surgical groups.

		MxA			MdS-MxA		
		($\bar{x}$±SD)	Test value	p	($\bar{x}$±SD)	Test value	p value
SNA°	T2	83.24±2.68	6.008[a]	<0.001	83.57±1.99	6.991[a]	**<0.001**
	T1	76.66±4.47			76.51±4.05		
SNB°	T2	81.14±1.71	-0.455[a]	0.658	82.00±2.16	-3.059[b]	**0.002**
	T1	81.43±3.27			84.23±3.30		
ANB°	T2	2.05±1.23	9.05[a]	<0.001	1.29±0.85	10.254[a]	**<0.001**
	T1	-4.89±2.76			-7.43±2.67		
N⊥ A (mm)	T2	0.74±0.40	29.38[a]	<0.001	0.81±0.34[a]	36.667[a]	**<0.001**
	T1	-4.74±0.93			-4.48±0.47		
N⊥ Pog (mm)	T2	-1.90±0.82	3.241[a]	0.008	-4.28±0.79	-24.969[a]	**<0.001**
	T1	-2.23±1.01			0.33±0.79		
SN-PP°	T2	9.89±2.37	1.273[a]	0.229	8.13±3.57	-0.458[a]	0.656
	T1	8.28±4.47			8.42±3.37		
SN-MP°	T2	32.83±1.97	1.27[a]	0.23	36.63±4.18	0.754[a]	0.467
	T1	31.96±3.05			36.08±4.03		
CVT-SN°	T2	102.12±2.18	-1.258[a]	0.234	107.10±7.70	2.366[a]	**0.037**
	T1	103.10±2.41			103.48±8.78		
HB-Me (mm)	T2	38.29±2.81	0.364[a]	0.723	36.60±4.76	-0.586[a]	0.467
	T1	37.64±5.89			37.38±5.90		
HB-Cv3 (mm)	T2	36.47±5.44	0.685[a]	0.508	35.07±4.19	0.099[a]	0.467
	T1	35.58±5.76			34.97±4.98		
HB-ML (mm)	T2	12.30±5.89	0.556[a]	0.590	14.33±3.98	2.425[a]	**0.034**
	T1	11.58±4.12			13.11±4.22		
Nasopharynx (mm^3)	T2	5206.27±122.9	14.743[a]	<0.001	4746.87±236.8	5.958[a]	**<0.001**
	T1	4359.06±128.7			3968.31±172.5		
Oropharynx (mm^3)	T2	9655.86±229.9	9.046[a]	<0.001	9562.27±186.6	66.148[a]	**<0.001**
	T1	8753.01±167.7			9207.23±146.3		
Hypopharynx (mm^3)	T2	4303.00±179.5	7.336[a]	<0.001	4655.95±158.9	-10.181[a]	**<0.001**
	T1	4175.89±160.6			4865.88±178.2		
mCSA (mm^2)	T2	208.10±22.76	10.534[a]	<0.001	205.71±15.45	-3.059[b]	**0.002**
	T1	168.39±27.19			242.99±20.56		
AHI	T2	1.67±0.63	-3.485[a]	0.005	1.42±0.65	-2.228[b]	**0.026**
	T1	2.18±0.95			1.70±0.94		

[a]Paired Samples t-test; [b]Wilcoxon signed-rank test, Statistical significance: $p<0.05$.
MxA, maxillary advancement; MdS-MxA, mandibular setback with maxillary advancement; $\bar{x}$, mean; SD, standard deviation.

Reports on the movement of HB following MdS surgery have shown considerable variability. While some studies have documented posterior and superior displacement, others have reported inferior movement or positional stability.[18] Moreover, it has been reported that HB may return to its original position following MdS to preserve airway resistance.[6] In the present study, no significant difference was observed in the anteroposterior position of HB among the groups either before or after orthognathic surgery. However, a significant difference in vertical position was found between the MdS-MxA group and the control group. Postoperatively, HB remained stable in the MxA group, whereas a slight inferior displacement of approximately 1.2 mm was observed in the MdS-MxA group. This result may be attributed to the compression of soft tissues in the submandibular region due to the posterior movement of the mandible without any rotation after surgery, consequently causing HB to shift inferiorly. In essence, this displacement was not associated with any significant reduction in total upper airway volume or worsening of AHI scores. Therefore, the observed positional change represents a compensatory adaptation rather than a functionally significant impairment.

The CVT-SN angle is a reliable and reproducible indicator of HP in relation to craniofacial morphology.[23] In this study, MxA did not affect the CVT-SN angle; however, the MdS-MxA group exhibited a statistically significant yet clinically insignificant

3.6° increase in HP. CVT-SN increase following MdS has been suggested as a compensatory mechanism to maintain PAV. Head extension in this study was primarily attributed to a reduction in hypopharyngeal volume and mCSA rather than total PAV.[12] However, no significant difference in HP was observed between the pre- and post-operative groups.

A recent systematic review emphasized the need for further studies to assess the effects of orthognathic surgery in specific patient groups based on gender, age, and the extent of mandibular setback.[24] Additionally, comparing different orthognathic surgical procedures under standardized conditions is crucial.[6] Thus, this study gathered data from multiple sources while maintaining standardized conditions to enhance the reliability of findings by carefully matching participants in terms of age, BMI, AHI, and Mallampati classification, ensuring greater homogeneity within the study groups and meticulously analysing factors influencing PAV. HP was assessed using an inclinometer, and LCR images were obtained accordingly. While LCRs were historically used to evaluate the airway dimension and mCSA, CBCT imaging may be the preferred method even though it has certain limitations like other methods. CBCT offers advantages over conventional radiography by providing 3D visualization of craniofacial structures and better differentiating soft tissues and PAV.[20] This study used CBCT to precisely measure PAV and mCSA, with images acquired in the supine position. However, due to the unreliability of the supine position in determining natural HP, LCRs taken with the patient standing were also used. Diagnostic tests utilizing the HSAT device have been documented as adequate for the preliminary screening of patients at risk of OSA.[25] We used this device to assess changes in AHI as it allows remote evaluation. To our knowledge, this study is the first to compare Class III surgical groups with a control group in the extant literature.

Study Limitations

This study has several limitations. First, the findings reflect early-stage postoperative results and may not capture long-term outcomes. Second, there was an unequal gender distribution among the groups, which may have influenced the generalizability of the results.

CONCLUSION

The following conclusions may be drawn from the results of this study:

- Maxillary advancement (MxA) increased pharyngeal airway volume (PAV) across all sections, whereas combined mandibular setback and maxillary advancement (MdS-MxA) led to a reduction in hypopharyngeal volume and minimum cross-sectional area (mCSA) despite an overall increase in total PAV.

- Postoperative displacement of the hyoid bone (HB) was minimal. A slight inferior shift observed in the MdS-MxA group, likely due to soft tissue adaptation.

- Neither surgical approach significantly impacted apnea-hypopnea index (AHI), suggesting that MdS-MxA does not contribute to the development of obstructive sleep apnea (OSA) in young and healthy individuals.

Ethics

Ethics Committee Approval: This prospective controlled clinical study was conducted following approval from the Erciyes University Clinical Research Ethics Committee (decision no. 2022/614, date: 14.09.2022).

Informed Consent: Informed consent was obtained from all participants enrolled in this study.

Acknowledgments

This study was produced under the supervision of Assistant Professor Celal Irgın from Hatice Başaranlar Bal's Thesis for Specialization in Dentistry. The authors would like to express their sincere gratitude to Assoc. Prof. Ahmet Emin Demirbaş and his team for performing the orthognathic surgery procedures on the subjects included in this study.

Footnotes

Author Contributions: Concept - C.I.; Design - C.I.; Data Collection and/or Processing - H.Ç.B.; Analysis and/or Interpretation - H.Ç.B., C.I.; Literature Search - H.Ç.B., C.I.; Writing - C.I.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: This study did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

REFERENCES

1. Ngan P, Moon W. Evolution of Class III treatment in orthodontics. *Am J Orthod Dentofacial Orthop.* 2015;148(1):22-36. [CrossRef]
2. Proffit WR, Fields H, Larson B, Sarver DM. Contemporary orthodontics. 6th ed. Mosby; 2018. [CrossRef]
3. Meger MN, Fatturi AL, Gerber JT, et al. Impact of orthognathic surgery on quality of life of patients with dentofacial deformity: a systematic review and meta-analysis. *Br J Oral Maxillofac Surg.* 2021;59(3):265-271. [CrossRef]
4. Busby BR, Bailey L, Proffit WR, Phillips C, White Jr RP. Long-term stability of surgical Class III treatment: a study of 5-year postsurgical results. *Int J Adult Orthod Orthognath Surg*. 2002;17(3):159-170. [CrossRef]
5. Lee S-T, Park J-H, Kwon T-G. Influence of mandibular setback surgery on three-dimensional pharyngeal airway changes. *Int J Oral Maxillofac Surg.* 2019;48(8):1057-1065. [CrossRef]
6. Aydemir H, Memikoğlu U, Karasu H. Pharyngeal airway space, hyoid bone position and head posture after orthognathic surgery in Class III patients. *Angle Orthod.* 2012;82(6):993-1000. [CrossRef]
7. Faria AC, da Silva-Junior SN, Garcia LV, Dos Santos AC, Fernandes MRF, de Mello-Filho FV. Volumetric analysis of the pharynx in patients with obstructive sleep apnea (OSA) treated with maxillomandibular advancement (MMA). *Sleep Breath.* 2013;17(1):395-401. [CrossRef]
8. Saitoh K. Long-term changes in pharyngeal airway morphology after mandibular setback surgery. *Am J Orthod Dentofacial Orthop.* 2004;125(5):556-561. [CrossRef]

9. Hatab N, Konstantinović V, Mudrak J. Pharyngeal airway changes after mono-and bimaxillary surgery in skeletal class III patients: Cone-beam computed tomography evaluation. *J Craniomaxillofac Surg.* 2015;43(4):491-496. [CrossRef]
10. Chang JL, Goldberg AN, Alt JA, et al. International consensus statement on obstructive sleep apnea. *Int Forum Allergy Rhinol.* 2023;13(7):1061-1482. [CrossRef]
11. Yang H, Jung Y-E, Kwon I, Lee J-Y, Hwang S. Airway changes and prevalence of obstructive sleep apnoea after bimaxillary orthognathic surgery with large mandibular setback. *J Oral Maxillofac Surg.* 2020;49(3):342-349. [CrossRef]
12. Kim M-A, Kim B-R, Youn J-K, Kim Y-JR, Park Y-H. Head posture and pharyngeal airway volume changes after bimaxillary surgery for mandibular prognathism. *J Craniomaxillofac Surg.* 2014;42(5):531-535. [CrossRef]
13. He J, Wang Y, Hu H, et al. Impact on the upper airway space of different types of orthognathic surgery for the correction of skeletal Class III malocclusion: A systematic review and meta-analysis. *Int J Surg.* 2017;38:31-40. [CrossRef]
14. Karaaslan S, Tüz HH, El H, Süslü AE, Göktürk T. Three-dimensional evaluation of upper airway changes after bimaxillary surgery of skeletal Class 3 patients. *J Craniofac Surg.* 2023;34(3):996-1000. [CrossRef]
15. Valls-Ontañón A, Giralt-Hernando M, Zamora-Almeida G, Anitua E, Mazarro-Campos A, Hernández-Alfaro F. Does orthognathic surgery have an incidentally beneficial effect on mild or asymptomatic sleep apnoea? *Int J Oral Maxillofac Surg.* 2023;52(12):1255-1261. [CrossRef]
16. Kurbanova A, Aksoy S, Nalça Andrieu M, Öz U, Orhan K. Evaluation of the influence of hyoid bone position, volume, and types on pharyngeal airway volume and cephalometric measurements. *Oral Radiol.* 2023;39(4):731-742. [CrossRef]
17. Auvenshine Dds PRC, Pettit Dmd MSDNJ. The hyoid bone: an overview. *Cranio.* 2020;38(1):6-14. [CrossRef]
18. Chen SM, Cai HY, Yan XZ, et al. CBCT analysis of the hyoid and pharyngeal airway changes in Class III patients with orthognathic surgery. *Orthod Craniofac Res.* 2024. [CrossRef]
19. Tallgren A, Solow B. Hyoid bone position, facial morphology and head posture in adults. *Eur J Orthod.* 1987;9(1):1-8. [CrossRef]
20. Canellas JdS, Barros H, Medeiros P, Ritto F. Effects of surgical correction of Class III malocclusion on the pharyngeal airway and its influence on sleep apnoea. *Int J Oral Maxillofac Surg.* 2016;45(12):1508-1512. [CrossRef]
21. Pereira-Filho VA, Castro-Silva LM, de Moraes M, Gabrielli MFR, Campos JADB, Juergens P. Cephalometric evaluation of pharyngeal airway space changes in Class III patients undergoing orthognathic surgery. *J Oral Maxillofac Surg.* 2011;69(11): e409-e415. [CrossRef]
22. Abbasi S, Rahpeyma A, Shooshtari Z, Rezaeetalab F, Vaezi T, Samieirad S. Bimaxillary orthognathic surgery does not induce obstructive sleep apnea in skeletal Class III patients. *J Oral Maxillofac Surg.* 2022;80(8):1340-1353. [CrossRef]
23. Solow B, Sandham A. Cranio-cervical posture: a factor in the development and function of the dentofacial structures. *Eur J Orthod.* 2002;24(5):447-456. [CrossRef]
24. Honglertnapakul Y, Peanchitlertkajorn S, Likitkulthanaporn A, Saengfai NN, Chaweewannakorn C, Boonpratham S. Impacts of mandibular setback with or without maxillary advancement for class III skeletal correction on sleep-related respiratory parameters: A systematic review and meta-analysis. *Orthod Craniofac Res.* 2024;27(6):839-852. [CrossRef]
25. Khor YH, Khung S-W, Ruehland WR, et al. Portable evaluation of obstructive sleep apnea in adults: A systematic review. *Sleep Med Rev.* 2023; 68:101743. [CrossRef]

TURKISH JOURNAL OF ORTHODONTICS

DOI: 10.4274/TurkJOrthod.2025.2024.153

Original Article

Impact of Camouflage Treatment with Class III Elastics on Temporomandibular Joint and Dentoskeletal Relationships: A Pilot CBCT and MRI-Based Clinical Trial

Panjaree Panpitakkul[1], Teekayu Plangkoon Jorns[2], Warinthorn Phuttharak[3], Rajda Chaichit[4], Pipop Sutthiprapaporn[1]

[1]Khon Kaen University Faculty of Dentistry, Department of Preventive Dentistry, Division of Orthodontics, Khon Kaen, Thailand
[2]Khon Kaen University Faculty of Dentistry, Department of Oral Biomedical Science, Division of Oral Biology, Khon Kaen, Thailand
[3]Khon Kaen University Faculty of Medicine, Department of Radiology, Khon Kaen, Thailand
[4]Khon Kaen University Faculty of Dentistry, Department of Preventive Dentistry, Division of Dental Public Health, Khon Kaen, Thailand

Cite this article as: Panpitakkul P, Jorns TP, Phuttharak W, Chaichit R, Sutthiprapaporn P. Impact of camouflage treatment with Class III elastics on temporomandibular joint and dentoskeletal relationships: a pilot CBCT and MRI-based clinical trial. *Turk J Orthod.* 2025; 38(2): 116-127

Main Points

- Camouflage treatment with conventional Class III elastics significantly improves the dentoskeletal relationship and soft tissue profile.
- Camouflage treatment with conventional Class III elastics did not induce significant adverse changes in the condyles or articular discs, nor cause temporomandibular disorders.

ABSTRACT

Objective: Orthodontic camouflage effectively addresses mild to moderate skeletal Class III malocclusion by repositioning the mandible and anterior teeth. However, recent findings suggest potential temporomandibular joint (TMJ) impact of the intermaxillary elastics frequently used in this treatment. This study aims to comprehensively assess changes in the TMJ and dentoskeletal relationship following Class III camouflage treatment, using a combination of CBCT and MRI.

Methods: This clinical trial enrolled skeletal Class III malocclusion patients meeting eligibility criteria. Non-extraction camouflage treatment was administered, employing the straight wire technique with conventional Class III intermaxillary elastics. CBCT and MRI were conducted at baseline (T0) and after achieving normal occlusion (T1). Condylar position in three dimensions and dentoskeletal relationship were assessed from CBCT images using Dolphin® imaging software, while TMJ disc position and length were measured from MR images using MicroDicom software. Statistical analyses were performed with IBM® SPSS® software.

Results: The dataset comprised nine subjects, with a mean age of 24.3±7.0 years. CBCT analyses indicated significant changes in dentoskeletal relationship, especially those of the mandible (increased ANB 2.32±0.51°, increased SN-MP 2.61±1.05°, decreased profile angle 5.40±1.07°), but nonsignificant changes in condylar position post-treatment (0.11±0.15 mm). Similarly, MRI measurements demonstrated non-significant changes in both position (0.91±1.61°) and length (0.07±0.37 mm) of the articular disc post-treatment.

Conclusion: Class III camouflage treatment using conventional intermaxillary elastics significantly improves the dentoskeletal relationship without significant adverse effects on the condyle and articular disc of the TMJ.

Keywords: Class III malocclusion, camouflage treatment, intermaxillary elastics, condyle, articular disc

Corresponding author: Pipop Sutthiprapaporn, **e-mail:** spipop@kku.ac.th
Received: October 14, 2024 **Accepted:** May 28, 2025 **Publication Date:** July 02, 2025

INTRODUCTION

Skeletal Class III malocclusion is recognized as a prevalent concern prompting patients to seek orthodontic care, especially within Asian populations.[1] It is typically characterized by concave profile with anterior crossbite or minimal overjet, attributed to mandibular prognathism, maxillary deficiency, or a combination of both.[2] Addressing this type of malocclusion in adults is particularly challenging for orthodontists due to the limited treatment options.

Camouflage orthodontic treatment provides a viable alternative for addressing mild-to-moderate skeletal Class III malocclusion, aiming to enhance both function and facial aesthetics. This approach is especially beneficial for patients who want to avoid the risks of orthognathic surgery or have financial constraints. Various approaches can be implemented to correct anterior crossbite and obtain normal occlusion in Class III camouflage treatment, including extracting two lower premolars, extracting one lower incisor, extracting four premolars, distalizing whole lower teeth (with and without temporary anchorage devices, TADs), tipping lower teeth posteriorly by multiloop edgewise archwire (MEAW) technique, and utilizing Class III intermaxillary elastics.[3-8] Among numerous methods, the straight-wire technique combined with conventional Class III intermaxillary elastics stand out as one of the most widely adopted approaches for correcting Class III malocclusion owing to its effectiveness and ease of use. They compensate for skeletal Class III malocclusion mainly through proclination of the upper anterior teeth, retroclination of the lower anterior teeth, and extrusion of the upper molars, resulting in a favorable clockwise rotation of the mandible and reversion of the occlusal plane.[3]

Although the treatment alternative using intermaxillary elastics has long been described with the understanding that correction will be achieved solely at the dentoalveolar level without altering the underlying skeletal components,[9,10] recent studies employing finite element analysis (FEA) have reported the potential impact of intermaxillary elastics on the mandibular position and thus the temporomandibular joints (TMJs).[11-14] Those studies demonstrated that the mechanical stress generated by the Class III intermaxillary elastics could project toward the TMJs and likely initiate a posterior-superior displacement of the condyles. Furthermore, this excessive mechanical stress has been regarded as a crucial factor, given its potential to induce degenerative changes in the TMJs.[12,15]

However, the lack of clinical evidence leaves an important gap in understanding whether camouflage treatment with Class III intermaxillary elastics displaces the condyles and could cause degenerative changes in the TMJ disc-condyle complex. This study aimed to answer this important question in a clinical setting, highlighting the significant impact of elastics on real patients. Consequently, the purpose of this study was to assess changes in the condyles and TMJ articular discs following camouflage treatment with Class III intermaxillary elastics, using a combination of the cone-beam computed tomography (CBCT) and the magnetic resonance imaging (MRI) analyses.

The primary objective of this study was to compare the positions of the condyles and articular discs of the TMJs at baseline (T0) and after achieving normal occlusion (T1) through conventional Class III camouflage treatment. The null hypothesis for this objective postulated that there are no differences in the positions of the condyles and articular discs of the TMJs between baseline (T0) and after achieving normal occlusion (T1).

Whereas, the secondary objective was to investigate the dentoskeletal effects of conventional Class III camouflage treatment by comparing the lateral cephalometric measurements (skeletal, dental, and soft tissues components) at baseline (T0) and after achieving normal occlusion (T1). The null hypothesis for this objective was that there would be no significant difference in the lateral cephalometric measurements between baseline (T0) and after achieving normal occlusion (T1).

METHODS

Trial Design and Important Changes after Trial Commencement

This study is a single-arm clinical trial, specifically a pre-post intervention study. No changes in the method were made after the trial commencement. This clinical trial was registered under the number TCTR20220316003 at the Thai Clinical Trials Registry (www.thaiclinicaltrials.org).

Participants, Eligibility Criteria, and Settings

The study population consists of non-growing patients with mild to moderate skeletal Class III malocclusion who met the eligibility criteria. Subjects were recruited using the consecutive sampling method at the Orthodontic Clinic of the Dental Hospital, Faculty of Dentistry, Khon Kaen University, Thailand, from January to December 2022.

The inclusion criteria included: (1) complete mandibular growth (determined by cervical vertebral maturation stage 6);[16] (2) mild to moderate skeletal Class III malocclusion [skeletal Class III with ANB angle <0.5°, anterior crossbite or edge-to-edge bite, concave profile tendency with profile angle (G'-Sn-Pog') >171°];[17,18] (3) symmetric face (absence of significant chin deviation, ≥3 mm); (4) refusal of orthognathic surgery. Conversely, the exclusion criteria included: (1) pre-existing signs and symptoms of the temporomandibular disorders (TMDs); (2) pre-existing TMJ pathology and asymmetry; (3) presence of the malocclusion traits which indicate extraction (e.g., severe crowding); (4) history of craniofacial or TMJ trauma; (5) presence of contraindications for MRI (e.g., fixed/implanted non-precious metal prostheses, claustrophobia). Furthermore, a few withdrawal criteria were listed: (1) lack of compliance with elastic use and (2) patient request to withdraw.

This study obtained ethical approval from the Khon Kaen University Ethics Committee for Human Research, in accordance with the Declaration of Helsinki and the ICH Good Clinical Practice Guidelines (reference number HE641561). All subjects endorsed the written informed consent prior to participating in the study.

Interventions

All subjects underwent non-extraction camouflage treatment using the pre-adjusted edgewise fixed orthodontic appliances, by using straight-wire technique combined with conventional Class III intermaxillary elastics. Twin polycrystalline ceramic brackets with MBT prescription and 0.022 × 0.028-inch slot (3M™ Clarity™ Advanced Ceramic Brackets, 3M Unitek™, Monrovia, CA) were employed in this study, aiming to reduce metal artifacts and prevent any interaction between the non-precious metal brackets and the magnetic field of MRI system.

Sequence of round and rectangular nickel-titanium (NiTi) archwires (0.014, 0.016, 0.016 × 0.022, 0.017 × 0.025, 0.019 × 0.025-inch NiTi) were used for leveling and aligning. Posterior bite ramps (Ultra band-lok®, Reliance Orthodontic Products, Itasca, IL) were bonded on the occlusal surface of either maxillary or mandibular molars during the initial stage of leveling and aligning, to open the bite while correcting anterior crossbite, as shown in Figure 1. Moreover, archwire expansion, incisor protrusion, interproximal reduction (IPR), or a combination of these approaches were carried out to unravel crowding in cases with mild to moderate crowding.

After leveling and aligning, the sagittal relationship of molars and canines was corrected mainly by applying bilateral Class III intermaxillary elastics (Bear, 1/4", 4.5 oz., Ormco®, Ormco Corporation, Brea, CA) between the maxillary second molars and the mandibular canines, on rectangular stainless-steel archwires (0.017 × 0.025 or 0.019 × 0.025-inch SS), as shown in Figure 2. Subjects were instructed to wear the elastics full time and change them every morning and night. In late stage of Class III correction, unilateral application of these elastics was employed in a few cases due to varying severity of Class III relationship and uneven rate of tooth movement between the left and right sides.

Skull-CBCT and TMJ-MRI were performed to investigate the positions of the condyles and articular discs of the TMJs before treatment (T0) as a baseline and after achieving normal occlusion (T1)-defined as the point at which negative overjet was corrected and Class I molar and canine relationships were established through the use of Class III intermaxillary elastics, using the same machine and imaging settings for all subjects. CBCT images were acquired using the WhiteFox® 3D CBCT system (WhiteFox®, Acteon group, Merignac, France) with the imaging protocol set at 100 kVp, 8 mA, a 0.3 mm^3 isotropic voxel size, and a cylindrical-shaped field of view (FOV) measuring 20 cm in diameter × 17 cm in height. The scan time was 30 seconds, with an effective radiation dose of 30.45 μSv. Based on the manufacturer's specifications, this configuration provides a spatial resolution of approximately 0.3 mm, which corresponds to the selected voxel size and is consistent across the specified FOV. The chosen FOV allows for full coverage of the region of interest while maintaining adequate spatial resolution for diagnostic purposes. During imaging process, subjects were stabilized in the natural head position, with the mouth closed while biting in the maximum intercuspal position (MIP) and lips being relaxed. For MR images, the proton density (PD)-weighted images were obtained from Achieva dStream 3.0T MR Systems (Philips®, Koninklijke Philips N.V., Amsterdam,

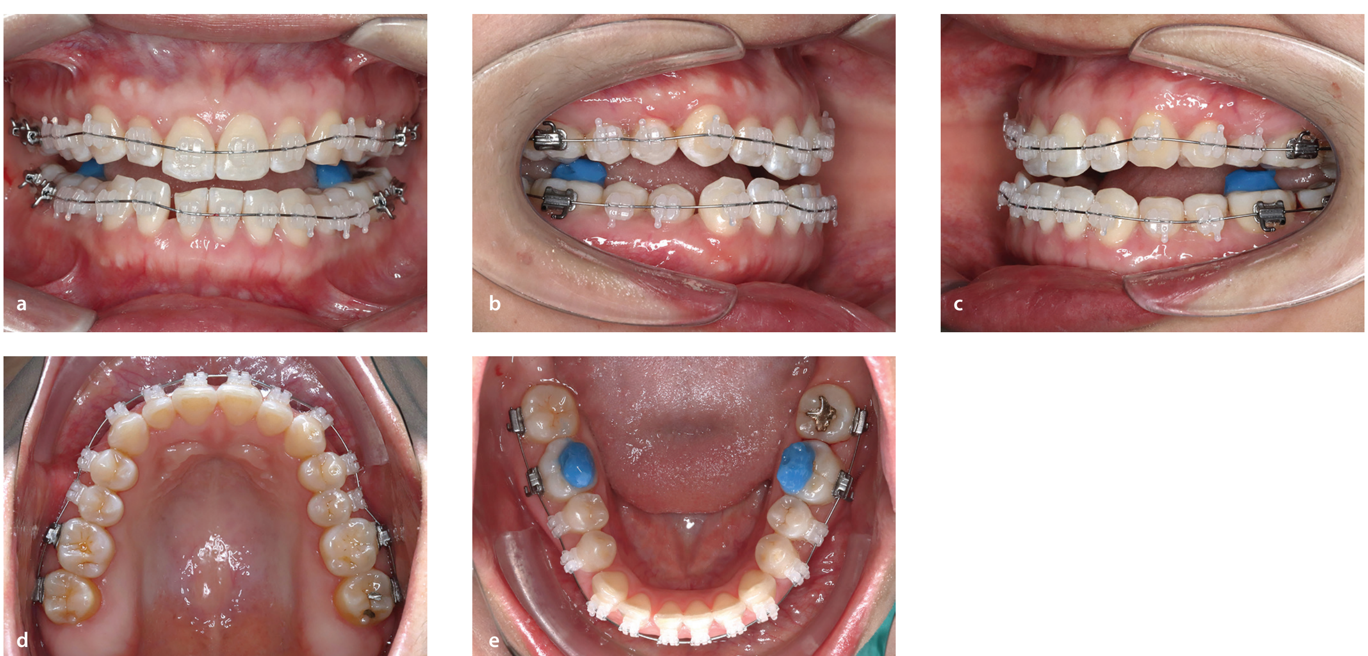

Figure 1. If possible, please explain the stages from a to e in the figures below the figures.

Netherlands) under the protocol of the PD-weighted spin-echo (SE) sequence, 2D acquisition (oblique-sagittal and coronal sections), TR 2200 ms, TE 30 ms, 2 excitations, 332 × 313 matrix size, 2.0 mm slice thickness with 0.2 mm inter-slice gap, 20 × 20 cm FOV, 90° flip angle, and 6 min. scan time. The MR images were taken in supine position while subjects biting in the maximum intercuspal position (MIP). All CBCT and MR images were exported and stored as Digital Imaging and Communications in Medicine format (DICOM) files.

Additionally, lateral cephalograms for each subject were generated from the CBCT volume using Dolphin® 3D imaging software (version 11; Dolphin Imaging and Management Solutions, Chatsworth, CA, USA), ensuring consistent resolution and image quality across all synthesized images. In addition to pre-treatment radiographic evaluation, overbite and overjet were measured intraorally using a calibrated periodontal probe with the patient in centric occlusion while centric occlusion–centric relation (CO-CR) discrepancy was assessed using the bimanual manipulation technique, followed by measurement of mandibular shift in the sagittal plane, to evaluate baseline characteristics of malocclusion.

Furthermore, history taking and clinical examination based on the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) examination form checklists were conducted every

Figure 2. Class III correction phase using class III intermaxillary elastics

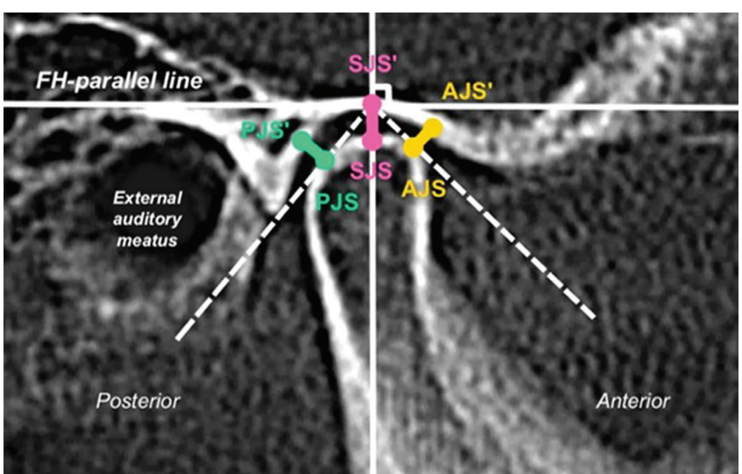

Figure 3. Joint space measurement on sagittal slices. Measurement method was as follows: 1) a vertical line perpendicular to the Frankfort horizontal (FH) plane was drawn through the most superior point of mandibular fossa, and the distance between the most superior point of mandibular fossa (SJS′) and condyle (SJS) was measured along this vertical line as superior joint space width (SJS-SJS′); 2) the anterior tangent line was drawn from the SJS′ point to the most anterior point (AJS) of condyle, and the distance between the most anterior point of mandibular fossa (AJS′) and condyle (AJS) was measured perpendicular to the anterior tangent line as anterior joint space width (AJS-AJS′); 3) the posterior tangent line was drawn from the SJS′ point to the most posterior point (PJS) of condyle, and the distance between the most posterior point of mandibular fossa (PJS′) and condyle (PJS) was measured perpendicular to the posterior tangent line as posterior joint space width (PJS-PJS′).

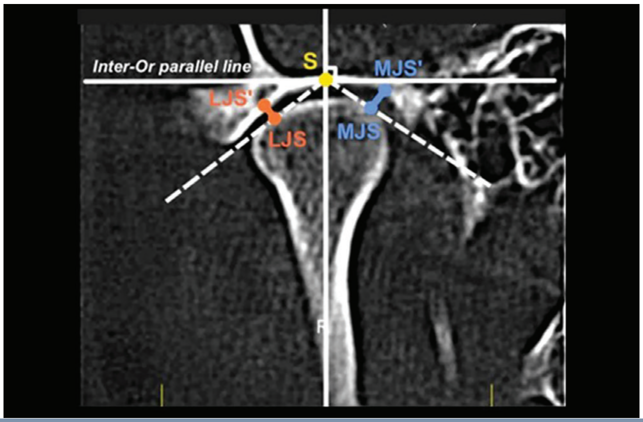

Figure 4. Joint space measurement on coronal slices. Measurement method was as follows: 1) a horizontal line parallel to the inter-orbitale (Or) line was drawn through the most superior point of mandibular fossa (S); 2) the medial tangent line was drawn from the S point to the most medial point (MJS) of condyle, and the distance between the most medial point of mandibular fossa (MJS') and condyle (MJS) was measured perpendicular to the medial tangent line as medial joint space width (MJS-MJS'); 3) the lateral tangent line was drawn from the S point to the most lateral point (LJS) of condyle, and the distance between the most lateral point of mandibular fossa (LJS') and condyle (LJS) was measured perpendicular to the lateral tangent line as lateral joint space width (LJS-LJS').

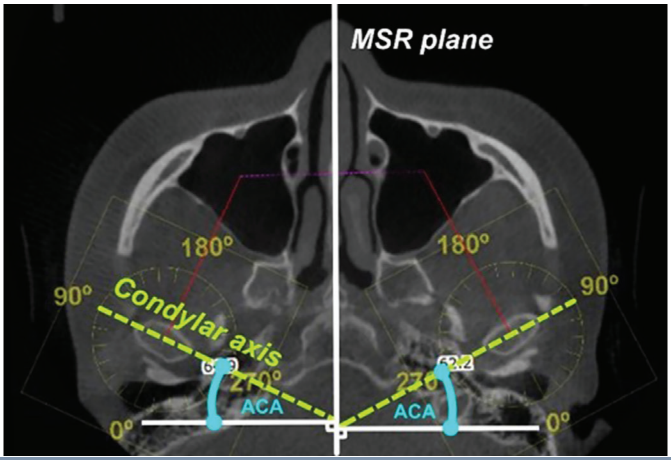

Figure 5. Axial condylar angle measurement on axial slices. Measurement method was as follows: 1) a horizontal line was drawn perpendicular to the mid-sagittal reference (MSR) plane, 2) the condylar axis line passing through lateral and medial poles of condyle was drawn, and 3) the angle formed between these two lines represents axial condylar angle (ACA).

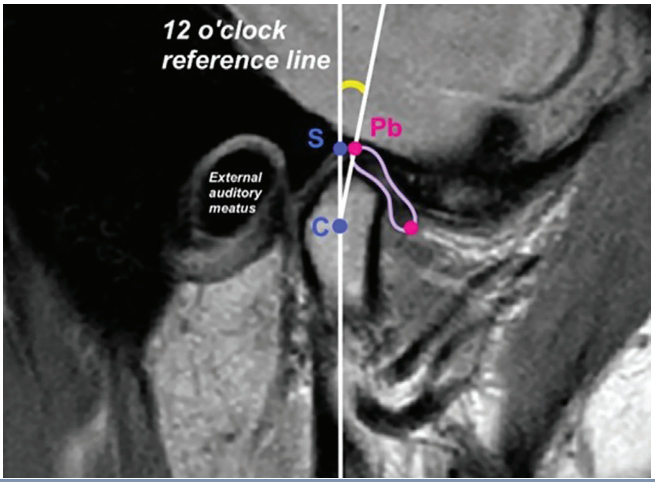

Figure 6. Measurement method for antero-posterior position of the articular disc was as follows: 1) a vertical line perpendicular to the Frankfort horizontal (FH) plane was drawn through center of the condylar head as the 12 o'clock reference line; 2) the tangent line was drawn from center of the condylar head, touching posterior border of the articular disc (Pb); 3) the angle formed between these two lines represents the antero-posterior position of the articular disc relative to the 12 o'clock reference line (SCPb).

three months throughout the period from T0 to T1, aiming to investigate signs and symptoms of TMDs during and after correcting Class III dental relationship with intermaxillary elastics.

Outcomes (Primary and Secondary Outcome Measures)

The primary outcomes were changes in the condyles and articular discs of the TMJs following camouflage treatment. These changes were comprehensively assessed from CBCT and MR images by using Dolphin® 3D imaging software (version 11; Dolphin Imaging and Management Solutions, Chatsworth, CA) and MicroDicom DICOM viewer software (version 2022.1; MicroDicom Ltd, Sofia, Bulgaria), respectively.

Position and rotation of the condyles were investigated from sagittal, coronal, and axial TMJ slices that were generated from CBCT images at T0 and T1. Measurements included anterior, posterior, superior, medial, and lateral joint space width (mm), as well as the axial condylar angle (deg), whose measuring methods were illustrated in Figures 3-5. Additionally, the joint space index (JSI) was calculated using anterior and posterior joint space width: JSI (%) = [(post - ant)/(post + ant)]*100. This calculation determined the condylar position relative to the mandibular fossa; positive JSI indicates an anterior-positioned condyle, while negative JSI indicates a posterior-positioned condyle.

For the articular discs, their position and length were measured from oblique-sagittal and coronal slices of the PD-weighted MR images at T0 and T1. The antero-posterior position of articular discs relative to the 12 o'clock reference line (deg) and their length (mm) were measured from oblique-sagittal slice, while their medio-lateral position was measured from coronal slices. The measuring methods for these measurements were illustrated in Figures 6-8. In addition, the presence or absence of signs and symptoms of TMDs throughout a period from T0 to T1 was reported as the descriptive data.

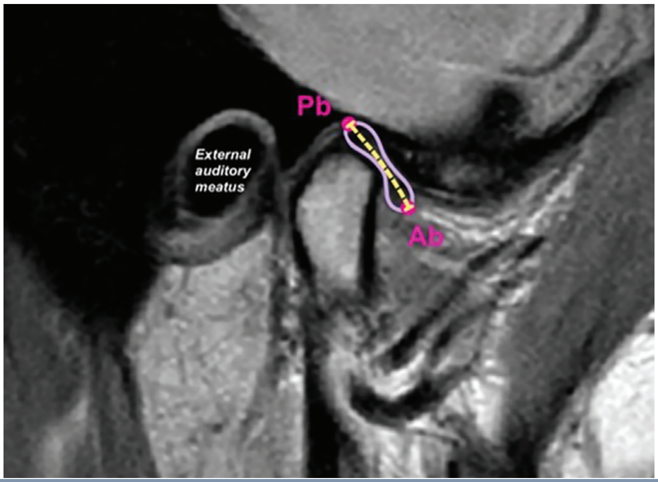

Figure 7. Measurement method for length of the articular disc. Articular disc length (Ab-Pb) was measured by a distance between anterior (Ab) and posterior (Pb) borders of the articular disc.

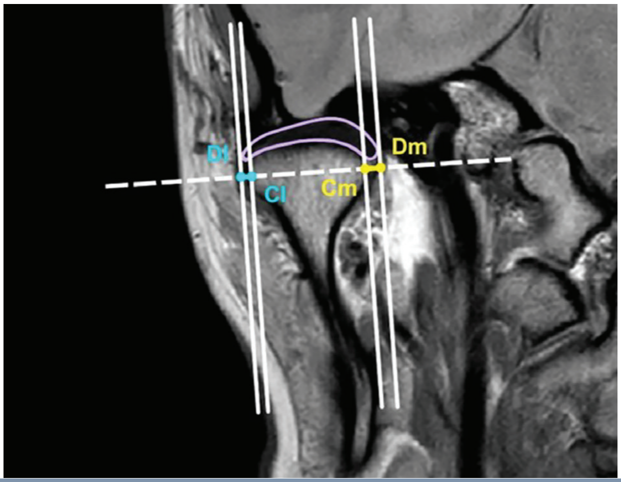

Figure 8. Measurement method for medio-lateral position of articular disc was as follows: 1) a horizontal line was drawn through medial (Cm) and lateral (Cl) poles of condyle; 2) four vertical lines perpendicular to this horizontal line were drawn through medial (Cm) and lateral (Cl) poles of condyle, as well as medial (Dm) and lateral (Dl) poles of the disc; 3) the distances between Dm-Cm and Dl-Cl were measured along this horizontal line, as medial (Dm-Cm) and lateral (Dl-Cl) extents of the articular disc.

The secondary outcomes encompassed dentoskeletal effects resulting from conventional Class III camouflage treatment, assessed from the lateral cephalogram which was generated from the skull-CBCT at T0 and T1. This aspect was measured as the lateral cephalometric measurements, including skeletal, dental, and soft tissue components. Skeletal measurements comprised SN-FH (deg), SNA (deg), CoA (mm), SNB (deg), CoGn (mm), SNPog (deg), ANB (deg), SN-MP (deg), and PP-MP (deg). Dental measurements contained U1-NA (deg), U1-NA (mm), L1-MP (deg), L1-NB (deg), L1-NB (mm), and SN-OP (deg). Soft tissue measurements included profile angle (G'-Sn-Pog') (deg), nasolabial angle (deg), upper lip to E-line (mm), and lower lip to E-line (mm).

All outcome variables in this study were assessed and analyzed by a single examiner. The examiner underwent training and standardization with both an oral and maxillofacial radiologist and a medical radiologist until achieving an intraclass correlation coefficient (ICC) greater than 0.8 for all variables, at which point the measurement process commenced.

Sample Size

The sample size was calculated based on joint space width changes, using data from a previous study by Guo (2020), which reported a mean difference of 0.67 mm and a pooled variance of 0.76 mm. To achieve 80% power at a 5% significance level, 7 patients (14 TMJs) were needed. Accounting for a 30% expected dropout rate, 10 patients were recruited.

Statistical Analysis

CBCT and MR images were anonymized before assessment, and the data analyst remained blinded during statistical analysis. The images of 30% of all subjects were randomly selected and measured repeatedly by the examiner three times with 14-day interval. The intra-examiner reliability was assessed using the ICC and the average values from the three measurements were used for statistical analysis.

Statistical analysis was conducted using IBM SPSS software (version 28.0; IBM Corp., Armonk, NY). Normal distribution was determined using the Shapiro-Wilk test. Comparisons between T0 and T1 data, regarding condylar position and rotation (i.e., joint space width, axial condylar angle), articular disc position and length, as well as lateral cephalometric measurements, were performed using either paired t-test or Wilcoxon signed-rank test, based on the normality. The significant level was set at p-value < 0.05.

RESULTS

Participant Flow (Including Exclusions after Randomization, and Recruitment and Follow-up Periods)

Subject recruitment took a full year in 2022 (January to December 2022). A total of 36 patients with skeletal Class III malocclusion were assessed for eligibility; 24 did not meet the inclusion criteria, and 2 declined to participate. Consequently, 10 patients (representing 20 TMJs) were successfully recruited at the beginning of the trial. Length of follow-up period varies for each subject, depending on the severity of the initial malocclusion and rate of tooth movement. However, one of the 10 subjects was excluded during treatment due to poor compliance with the use of Class III intermaxillary elastics, leaving a total of 9 patients (18 TMJs) for analysis.

Baseline Data

Demographic data for the entire subject group (n=9), including sex, age, elastics-application duration, and total treatment duration (T0 to T1), were presented in Table 1. An overview of the baseline characteristics of malocclusion was described in Table 2.

Numbers Analyzed (Including Number of Participants, Reliability, Each Primary and Secondary Outcome, and Power of Test)

One out of 10 patients (10%) was excluded during the treatment period because of poor compliance with Class III intermaxillary elastics use. The primary analyses were carried out on a per-protocol basis, involving all remaining subjects (n=9). Furthermore, excellent intra-examiner reliability was verified by ICC values ranging from 0.94 to 0.99. As primary outcomes, the differences of condylar position, condylar rotation, articular disc position, and articular disc length between T0 and T1 were individually analyzed.

Regarding condylar changes, displacement of the condyle was demonstrated by alterations in joint space width on both sagittal and coronal planes, while outward rotation of condyle was indicated by decreased axial condylar angle (Δ T0-T1 = R 0.32 ± 1.73°, L 0.32 ± 1.73°) on the axial planes. Condylar displacement occurred in posterior, superior, and lateral

Table 1. Demographic data

Variables	Mean	SD	Range
Sex, n=9			
Male, 1	11.11%		
Female, 8	88.89%		
Age (year)	24	6.59	18-36
Elastics application duration (month)	4.57	1.64	2-7
Total treatment duration, T0 to T1 (month)	12.44	1.74	10-15

SD: Standard deviation

Table 2. Baseline characteristics of malocclusion

Variables	Mean	SD	Range
Overjet (mm)	(-) 2.28	0.57	(-) 1.5 - (-) 3
Overbite (mm)	3.5	1.87	1 - 5.5
CO-CR discrepancy (mm)	1.72	0.78	0 - 2.5
ANB (°)	(-) 2.96	1.55	(-) 1.5 - (-) 6.6
Profile angle (°)	180.08	2.48	176.8 - 183.2

SD: Standard deviation

directions, as evidenced by decreased posterior joint space width (Δ T0-T1 = R 0.08 ± 0.31 mm, L 0.10 ± 0.24 mm), increased anterior joint space width (Δ T0-T1 = R (-) 0.06 ± 0.16 mm, L (-) 0.02 ± 0.24 mm), decreased superior joint space width (Δ T0-T1 = R 0.03 ± 0.20 mm, L 0.04 ± 0.27 mm), decreased lateral joint space width (Δ T0-T1 = R 0.08 ± 0.21 mm, L 0.11 ± 0.15 mm), and increased medial joint space width (Δ T0-T1 = R (-) 0.06 ± 0.45 mm, L (-) 0.03 ± 0.24 mm). Moreover, the decrease in JSI reinforces the posterior displacement of the condyle. This JSI value was also observed to decrease towards zero, reflecting that the condyle moved towards the center of the mandibular fossa. The same direction of displacement and rotation of the condyle was noted in both left and right condyles, with similar magnitude. Nonetheless, the amount of condylar displacement in all three planes was considered statistically insignificant, as shown in Table 3.

In addition to the condylar changes, there were also minor alterations in both position and length of the TMJ articular disc. On the oblique-sagittal plane, anterior displacement of the articular disc was indicated by an increase of S-Pb (Δ T0-T1 = R (-) 0.91 ± 1.61°, L (-) 0.81 ± 1.78°), while a slight decrease of the articular disc length was also observed (Δ T0-T1 = R 0.07 ± 0.37 mm, L 0.06 ± 0.16 mm). On the coronal plane, minimal medial displacement of the articular disc was demonstrated through increased Dm-Cm (Δ T0-T1 = R 0.15 ± 0.39 mm, L 0.04 ± 0.52 mm) and decreased Dl-Cl (Δ T0-T1 = R 0.11 ± 0.34 mm, L 0.05 ± 0.19 mm). Similarly to the condylar changes, none of the articular disc changes were statistically significant, as shown in Table 4.

Since the main results (condylar and articular disc changes) did not show significant findings in our group of subjects, a post-hoc power analysis was conducted to evaluate the adequacy of the sample size and statistical power for the measurements. The analysis revealed acceptable power levels for condylar measurements (ranging from 0.84 to 0.98) and articular disc measurements (ranging from 0.78 to 0.93).

For secondary outcomes, the dentoskeletal changes resulting from this camouflage treatment were individually analyzed as three main parts: skeletal, dental, and soft tissue. The significant changes were indicated in all three parts, as described by the lateral cephalometric measurements at T0 and T1 in Table 5.

Skeletal measurements demonstrated no significant changes in the anterior cranial base and maxilla (as indicated by stable SN-FH and SNA). However, significant changes in mandibular position resulting from clockwise rotation were observed (as indicated by decreased SNB and SNPog, as well as increased

Table 3. Changes in condylar position and rotation (Mean ± SD)

Variables	Pre-treatment (T0)		Post-treatment (T1)		Differences (ΔT0-T1)[b]		p-value	
	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.
Sagittal dimension								
AJS-AJS' (mm)	1.54±0.45	1.40±0.41	1.61±0.48	1.42±0.47	(-) 0.06±0.16	(-) 0.02±0.24	0.282	0.820
SJS-SJS' (mm)	2.29±0.79	2.35±0.59	2.25±0.79	2.31±0.76	0.03±0.20	0.04±0.27	0.637	0.691
PJS-PJS' (mm)	1.67±0.27	1.70±0.30	1.59±0.25	1.61±0.37	0.08±0.31	0.10±0.24	0.467	0.255
JSI[a]	4.97%	10.60%	0.61%	7.11%	4.37%	3.49%	-	-
Coronal dimension								
MJS-MJS' (mm)	2.46±1.01	2.49±0.74	2.52±0.81	2.52±0.79	(-) 0.06±0.45	(-) 0.03±0.24	0.684	0.996
LJS-LJS' (mm)	1.76±0.33	1.80±0.38	1.67±0.35	1.68±0.46	0.08±0.21	0.11±0.15	0.287	0.275
Axial dimension								
ACA (°)	17.17±7.78	17.01±6.65	16.86±7.19	15.70±6.04	0.32±1.73	1.31±2.61	0.600	0.172

[a]JSI percentage was reported as the average values (mean)
[b]Value indicating increase, + value indicating decrease
SD: Standard deviation

Table 4. Changes in articular disc position and length (Mean ± SD)

Variables	Pre-treatment (T0)		Post-treatment (T1)		Differences (ΔT0-T1)[b]		p-value	
	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.
Sagittal dimension								
SCPb (°)	11.09±4.17	11.82±8.19	12.01±4.33	12.63±8.37	(-) 0.91±1.61	(-) 0.81±1.77	0.128	0.210
Ab-Pb (mm)	10.78±1.37	10.27±1.37	10.71±1.41	10.21±1.45	0.07±0.37	0.06±0.16	0.579	0.281
Coronal dimension								
Dm-Cm (mm)	3.26±1.15	2.86±0.78	3.40±1.34	2.91±0.82	(-) 0.15±0.38	(-) 0.04±0.52	0.288	0.804
Dl-Cl (mm)	2.13±0.59	1.93±0.44	2.02±0.40	1.88±0.43	0.11±0.34	0.05±0.18	0.352	0.428

[b]Value indicating increase, + value indicating decrease
SD: Standard deviation

Table 5. Comparison of lateral cephalometric measurements between T0 and T1 (Mean ± SD)

Variables	Pre-treatment (T0)	Post-treatment (T1)	Differences (ΔT0-T1)	p-value
Skeletal measurements				
SN-FH (°)	6.80±1.62	6.80±1.62	0.00	N/A[a]
SNA (°)	83.38±2.69	83.42±2.65	(-) 0.04±0.15	0.403
SNB (°)	86.33±2.79	84.06±2.69	2.28±0.53	<0.001*
SNPog (mm)	86.13±2.21	83.82±2.09	2.31±0.55	<0.001*
ANB (°)	(-) 2.96±1.55	(-) 0.63±1.41	(-) 2.32±0.51	<0.001*
SN-PP (°)	6.39±3.33	6.42±3.25	(-) 0.03±0.13	0.471
SN-MP (°)	26.20±4.95	28.81±5.24	(-) 2.61±1.05	<0.001*
PP-MP (°)	20.20±4.88	22.74±4.89	(-) 2.54±1.24	<0.001*
Dental measurements				
U1-NA (°)	25.74±5.42	29.42±2.63	(-) 3.68±4.96	0.057
U1-NA (mm)	6.46±1.94	7.29±1.44	(-) 0.83±0.87	0.021*
L1-MP (°)	84.90±5.67	82.01±5.32	2.89±1.88	0.002*
L1-NB (°)	21.50±4.38	19.14±4.70	2.36±2.88	0.04*
L1-NB (mm)	5.47±1.26	4.29±1.64	1.18±0.92	0.005*
SN-OP (°)	11.61±4.95	13.19±5.71	(-) 1.58±1.83	0.033*
Soft tissue measurements				
Profile angle (°)	180.08±2.48	174.68±2.87	5.40±1.07	<0.001*
Nasolabial angle (°)	91.84±11.19	95.86±9.96	(-) 4.02±2.44	0.001*
U lip to E-line (mm)	(-) 2.73±2.09	(-) 2.13±1.68	(-) 0.60±0.73	0.039*
L lip to E-line (mm)	2.53±2.06	1.80±1.63	0.73±0.58	0.005*

[a]The correlation and T cannot be computed because the standard error of the difference is 0.
*Statistically significant (p-value <0.05)
SD: Standard deviation

SN-MP), leading to significant alterations in the maxillo-mandibular relationship in both antero-posterior and vertical dimensions (as indicated by increased ANB and PP-MP).

Dental measurements demonstrated significant forward movement of the upper incisor (as indicated by increased U1-NA) along with significant backward movement of the lower incisor as indicated by decreased L1-MP and L1-NB), leading to the attainment of a normal overjet (OJ) following treatment. Also, significant clockwise rotation of the occlusal plane was noticed.

In the soft tissue aspect, the measurements demonstrated significantly enhanced facial profile concavity (as indicated by decreased profile angle), improved upper lip retrusion (as indicated by increased upper lip to E-line distance), and reduced lower lip protrusion (as indicated by decreased lower lip to E-line distance).

The follow-up period for the nine patients ranged from 10 to 15 months, corresponding to the duration of treatment needed to achieve normal occlusion using Class III intermaxillary elastics. The results from the DC/TMD examination, conducted at 3-month intervals during and after correcting Class III with intermaxillary elastics (from T0 to T1), revealed that no signs or symptoms of TMDs were reported by any subjects, except for one individual (a 20-year-old female) reported painless unilateral TMJ clicking that began approximately two months after discontinuing elastic use and resolved spontaneously within about 14 days. This presentation was consistent with asymptomatic TMJ clicking commonly observed in the general population. Therefore, no active intervention or modifications to her treatment protocol were made.

No significant adverse events were observed apart from the general adverse effects commonly associated with full-fixed orthodontic appliances. These include pain, difficulty in eating, mucosal irritation from the appliances, and gingivitis associated with plaque accumulation.

DISCUSSION

As mentioned in the introduction, recent FEA studies have revealed potential stress transmission from the intermaxillary elastics to the condyle and articular disc of TMJs, challenging the long-held understanding that these elastics only induce changes at the dentoalveolar level in non-growing patients.[11–13] Nonetheless, studies investigating TMJ changes following these elastics use in clinical settings remain limited. To the best of our knowledge, only one study by Guo Y et al.[19] (2020) has previously evaluated the condylar changes after Class III camouflage treatment, using the multiloop edgewise archwire

(MEAW) technique with short Class III intermaxillary elastics. However, this technique has not been generally adopted due to its time-consuming nature for the operator and higher discomfort for the patient.[20] This clinical trial is the first study to comprehensively investigate TMJ changes in non-growing patients undergoing conventional Class III camouflage treatment using the widely-used straight-wire technique with Class III intermaxillary elastics. A combination of CBCT and MRI were utilized to evaluate changes in both the condyle and articular disc. Regarding the MRI sequence used in this study, proton density-weighted imaging (PDWI) was selected due to its superior signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR), and signal intensity ratio (SIR), all of which are critical for the clear visualization of the temporomandibular joint (TMJ) disc. These image quality parameters are especially important when assessing subtle changes in disc morphology and position.[21]

According to the results of this study, condylar displacement occurred in the posterior, superior, and lateral directions following treatment, as evidenced by changes in joint spaces. These findings coincide with those of Guo et al.[19] regarding the direction of condylar displacement after treatment, although our study observed a smaller magnitude of displacement. Furthermore, a recent FEA study by Gurbanov et al.[11] also demonstrated greater tensile stress on the anterior and anterosuperior regions, with greater compressive stress on the posterosuperior and posterior regions of the condyle due to the application of Class III intermaxillary elastics. This corresponds with the posterior and superior displacement observed in our study. Another FEA study by Zhang et al.[12] also indicated greater compressive stress on the posterosuperior surface of the condyle produced by both Class III and short Class III intermaxillary elastics. As demonstrated by our findings and those of previous studies, the direction of condylar displacement and the stress distribution pattern on the condyle clearly correlate with the force vectors of Class III intermaxillary elastics. These elastics, drawn from the mandibular canines to the maxillary second molars, generate both upward and backward traction forces at the mandibular canines, thus affecting the mandible and condyle. This posterior displacement of the condyle is advantageous in skeletal Class III patients since their condyles are likely to be positioned anteriorly in the glenoid fossa.[22] Consistent with the change of the JSI noticed in this study, which decreased towards zero after treatment, it re-emphasizes both posterior displacement and concentric movement of the condyle.

Several studies regarding the orthopedic treatment in growing patients and animal studies conducted in growing samples have indicated that changes in mandibular position following the application of external force are primarily associated with the remodeling of the condyle and mandible.[23-26] Despite the cessation of skeletal growth in non-growing patients, the remodeling of the condyle should not be overlooked as the forces transmitted to the TMJs could affect their inner structures, potentially leading to adaptive remodeling that may accrue in the condylar position.

With respect to the articular disc, only the negligible changes were observed regardless of FEA studies of Gurbanov et al.[11] and Zhang et al.[12] indicating the potentially transmitted compressive stress from Class III intermaxillary elastics toward the articular disc. Moreover, findings from Zhang's study which demonstrated greater compressive stress on the intermediate zone during elastics application are seemingly consistent with the superior displacement of the condyle shown in our study. However, a small anterior displacement of the articular disc may be related to the posterior displacement of the condyle, which could either induce actual anterior displacement of the disc or alter the position of the reference point for measurement located on the condyle. Likewise, medial displacement of the articular disc is possibly associated with lateral displacement of the condyle. Despite the small sample size, the post-hoc power analysis demonstrated acceptable power levels for the measurements, suggesting that the study's methodology was sufficient to evaluate the measurements.

Regarding the effects of intermaxillary elastics treatment on TMDs, the stress transmitted to the TMJs in this study does not appear to have any effect that predispose to any TMD sign or symptom, in spite of the presence of small changes in the TMJ disc-condyle complex and a recent three-dimensional finite element study observed that the elastic forces increase the stress on the TMJ, especially for Class III patients.[11] A potential rationale for this observation may be that these changes have not yet exceeded the individual adaptability and physiological tolerance threshold, as described by Michelotte et al.[27]

In terms of dentoskeletal changes, clockwise rotation of the mandible and dental compensation, specifically upper incisor proclination accompanied by lower incisor retroclination, play a crucial role in enhancing skeletal and soft tissue relationships as well as achieving normal occlusion following camouflage treatment. Additionally, clockwise rotation of the mandible is influenced by the extrusive force by intermaxillary elastics applied to the upper molars, as described in a study by Tseng, Chang, and Roberts[28] (2016). This study detailed the side effects of Class III intermaxillary elastics, including labial tipping of the upper incisors, distal tipping of the lower teeth, and extrusion of the upper molars, all of which are advantageous for patients with Class III malocclusion and deep overbite, as they could correct sagittal relationship and deep overbite simultaneously. Consequently, Class III intermaxillary elastics are particularly suitable for our samples. These data indicate that both skeletal and dental changes primarily stem from the dentoalveolar effect of Class III intermaxillary elastics. As a result of these changes, the soft tissue profile improvement was achieved as anticipated.

Study Limitations

A significant limitation of this study was the lack of an untreated sample of non-growing individuals with mild-to-moderate Class III malocclusion to serve as a control group. However, exposing an untreated group to unnecessary CBCT radiation and withholding needed treatment for a year would have raised ethical concerns. Additionally, since the intervention required patient compliance with elastics, unpredictable compliance may have introduced bias.

The generalizability of this study is supported by using specific inclusion criteria for young adults with skeletal Class III malocclusion, ensuring that the findings are applicable to non-growing patients within this group.

CONCLUSION

Conventional Class III camouflage treatment with intermaxillary elastics significantly improves the dentoskeletal relationship and shows no significant adverse effects on the condyles and articular discs of the TMJs.

Ethics

Ethics Committee Approval: This study obtained ethical approval from the Khon Kaen University Ethics Committee for Human Research, in accordance with the Declaration of Helsinki and the ICH Good Clinical Practice Guidelines (reference number: HE641561, date: 23.01.2022).

Informed Consent: All subjects endorsed the written informed consent prior to participating in the study.

Footnotes

Author Contributions: Surgical and Medical Practices - P.P., T.P.J., W.P., R.C., P.S.; Concept - P.P., T.P.J., P.S.; Design - P.P., T.P.J., W.P., R.C., P.S.; Data Collection and/or Processing - P.P., P.S.; Analysis and/or Interpretation - P.P., W.P., R.C., P.S.; Literature Search - P.P., P.S.; Writing - P.P., T.P.J., W.P., R.C., P.S.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: This study was funded by Khon Kaen University, Thailand, through internal research grants. There are no financial conflicts of interest to declare, and no commercial entities were involved in the funding or conduct of this research.

REFERENCES

1. Hardy DK, Cubas YP, Orellana MF. Prevalence of angle class III malocclusion: a systematic review and meta-analysis. *Open J Epidemiol*. 2012;2(4):75-82. [CrossRef]
2. Kolokitha O-E, Georgiadis T. Differential diagnosis of skeletal Class III. *Balk J Dent Med*. 2019;23(3):55-62. [CrossRef]
3. Sakoda KL, Pinzan A, Cury SEN, Bellini-Pereira S, Castillo AA-D, Janson G. Class III malocclusion camouflage treatment in adults: a systematic review. *J Dent Open Access*. 2019;1(1):1-12. [CrossRef]
4. He S, Gao J, Wamalwa P, Wang Y, Zou S, Chen S. Camouflage treatment of skeletal Class III malocclusion with multiloop edgewise arch wire and modified Class III elastics by maxillary mini-implant anchorage. *Angle Orthod*. 2013;83(4):630-640. [CrossRef]
5. Færøvig E, Zachrisson BU. Effects of mandibular incisor extraction on anterior occlusion in adults with Class III malocclusion and reduced overbite. *Am J Orthod Dentofac Orthop*. 1999;115(2):113-124. [CrossRef]
6. Ning F, Duan Y. Camouflage treatment in adult skeletal Class III cases by extraction of two lower premolars. *Korean J Orthod*. 2010;40(5):349-357. [CrossRef]
7. Nakamura M, Kawanabe N, Kataoka T, Murakami T, Yamashiro T, Kamioka H. Comparative evaluation of treatment outcomes between temporary anchorage devices and Class III elastics in Class III malocclusions. *Am J Orthod Dentofac Orthop*. 2017;151(6):1116-1124. [CrossRef]
8. Yu J, Park JH, Bayome M, et al. Treatment effects of mandibular total arch distalization using a ramal plate. *Korean J Orthod*. 2016;46(4):212. [CrossRef]
9. Jayachandran S, Wiltshire WA, Hayasaki SM, Pinheiro FHSL. Comparison of AdvanSync and intermaxillary elastics in the correction of Class II malocclusions: A retrospective clinical study. *Am J Orthod Dentofac Orthop*. 2016;150(6):979-988. [CrossRef]
10. Mazzini WU, Torres FM. Orthodontic camouflage: a treatment option - a clinical case report. *Contemp Clin Dent*. 2017;8(4):658-661. [CrossRef]
11. Gurbanov V, Bas B, Öz AA. Evaluation of stresses on temporomandibular joint in the use of Class II and III orthodontic elastics: a three-dimensional finite element study. *J Oral Maxillofac Surg*. 2020;78(5):705-716. [CrossRef]
12. Zhang Y, Keilig L, Dörsam I, Bourauel C. Numerical investigation of the biomechanical effects of orthodontic intermaxillary elastics on the temporomandibular joint. *J Mech Behav Biomed Mater*. 2023;141(December 2022). [CrossRef]
13. Uzunçıbuk H, Marrapodi MM, Meto A, Ronsivalle V, Cicciù M, Minervini G. Prevalence of temporomandibular disorders in clear aligner patients using orthodontic intermaxillary elastics assessed with diagnostic criteria for temporomandibular disorders (DC/TMD) axis II evaluation: A cross-sectional study. *J Oral Rehabil*. 2024;51(3):500-509. [CrossRef]
14. Sambataro S, Bocchieri S, Bafumi L, Fiorillo L, Cervino G, Cicciù M. Elastics selector gauge as orthodontics device applied to inter-maxillary traction during malocclusion correction. *J Funct Morphol Kinesiol*. 2019;4(3). [CrossRef]
15. Tanaka E, Detamore MS, Mercuri LG. Degenerative disorders of the temporomandibular joint: etiology, diagnosis, and treatment. *J Dent Res*. 2008;87(4):296-307. [CrossRef]
16. Baccetti T, Franchi L, McNamara Jr JA. The cervical vertebral maturation (CVM) method for the assessment of optimal treatment timing in dentofacial orthopedics. In: *Seminars in Orthodontics*. Vol 11. Elsevier; 2005:119-129. [CrossRef]
17. Suchato W CJ. Cephalometric evaluation of the dentofacial complex of Thai adults. *J Dent Assoc Thai*. 1984;34(5):233-243. [CrossRef]
18. Sutthiprapaporn P Manosudprasit A, Manosudprasit M, Pisek P, Phaoseree N, Manosudprasit A. Establishing esthetic lateral cephalometric values for Thai adults after orthodontic treatment. *Khon Kaen Dent J*. 2020;23(2):31-41. [CrossRef]
19. Guo Y, Qiao X, Yao S, Li T, Jiang N, Peng C. CBCT analysis of changes in dental occlusion and temporomandibular joints before and after MEAW orthotherapy in patients with nonlow angle of skeletal Class III. *Biomed Res Int*. 2020;2020. [CrossRef]
20. Hisano M, Chung C ryung J, Soma K. Nonsurgical correction of skeletal Class III malocclusion with lateral shift in an adult. *Am J Orthod Dentofac Orthop*. 2007;131(6):797-804. [CrossRef]
21. Dong M, Sun Q, Yu Q, Tao X, Yang C, Qiu W. Determining the optimal magnetic resonance imaging sequences for the efficient diagnosis of temporomandibular joint disorders. *Quant Imaging Med Surg*. 2021;11(4):1343. [CrossRef]

22. Seren E, Akan H, Toller MO, Akyar S. An evaluation of the condylar position of the temporomandibular joint by computerized tomography in Class III malocclusions: A preliminary study. *Am J Orthod Dentofac Orthop*. 1994;105(5):483-488. [CrossRef]
23. De Clerck H, Nguyen T, De Paula LK, Cevidanes L. Three-dimensional assessment of mandibular and glenoid fossa changes after bone-anchored Class III intermaxillary traction. *Am J Orthod Dentofac Orthop*. 2012;142(1):25-31. [CrossRef]
24. Gökalp H, Kurt G. Magnetic resonance imaging of the condylar growth pattern and disk position after chin cup therapy: A preliminary study. *Angle Orthod*. 2005;75(4):568-575. [CrossRef]
25. Kurt H, Alioğlu C, Karayazgan B, Tuncer N, Kılıçoğlu H. The effects of two methods of Class III malocclusion treatment on temporomandibular disorders. *Eur J Orthod*. 2011;33(6):636-641. [CrossRef]
26. Xu Y, Wu T, Chen Y, Zhang Z. Regulation of the response of the adult rat condyle to intermaxillary asymmetric force by the rankl-opg system. *Angle Orthod*. 2009;79(4):646-651. [CrossRef]
27. Michelotti A, Rongo R, D'Antò V, Bucci R. Occlusion, orthodontics, and temporomandibular disorders: Cutting edge of the current evidence. *J World Fed Orthod*. 2020;9(3):S15-S18. [CrossRef]
28. Tseng LLY, Chang CH, Roberts WE. Diagnosis and conservative treatment of skeletal Class III malocclusion with anterior crossbite and asymmetric maxillary crowding. *Am J Orthod Dentofac Orthop*. 2016;149(4):555-566. [CrossRef]

TURKISH JOURNAL OF
ORTHODONTICS

DOI: 10.4274/TurkJOrthod.2025.2025.33

Review

The Effect of Diabetes Mellitus on Mandibular Growth

Nearchos Panayi[1], Apostolos Tsolakis[2], Dimitrios Konstantonis[2], Ioannis Tsolakis[3], Maria Kouri[2], Georgia Kotantoula[2], Ismene A. Dontas[4]

[1]European University Cyprus Faculty of Dentistry, Department of Orthodontics, Nicosia, Cyprus
[2]National and Kapodistrian University of Athens Faculty of Dentistry, Department of Orthodontics, Athens, Greece
[3]Aristotle University of Thessaloniki, Faculty of Health Sciences, Department of Dentistry, Thessaloniki, Greece
[4]National and Kapodistrian University of Athens Faculty of Medicine, Laboratory for Research of the Musculoskeletal System, Attica, Greece

Cite this article as: Panayi N, Tsolakis A, Konstantonis D, et al. The Effect of diabetes mellitus on mandibular growth. *Turk J Orthod.* 2025; 38(2): 128-132

Main Points

- Diabetes affects growth and development of the mandible.
- Impaired bone healing and formation affects orthodontic treatment in diabetic patients.
- More effective clinical strategies will help optimize patient orthodontic treatment outcomes.

ABSTRACT

Diabetes mellitus is a chronic condition characterized by insufficient insulin production or utilization. Affecting approximately 8.5% of adults globally, diabetes is categorized primarily into Type 1, Type 2, and gestational diabetes. Diabetes markedly impacts bone health, particularly affecting the growth and development of the mandible. Key alterations include impaired bone metabolism leading to diminished bone density and strength. Additionally, diabetes impairs bone healing processes, often exacerbated by deficiencies in vitamin D, thus increasing fracture risks. Understanding the interplay between diabetes and mandibular growth is essential for effective dental treatment planning and patient management. Importantly, the condition also alters essential growth factors and local blood supply to the mandibular region, compromising overall growth. Impaired bone healing and formation also affects orthodontic treatment in diabetic patients. Future research should prioritize longitudinal studies examining diabetes's long-term impact on mandibular development, exploring genetic predispositions and biomechanical properties. Understanding these mechanisms will facilitate more effective clinical strategies to mitigate the adverse effects of diabetes on bone health and optimize patient outcomes.

Keywords: Diabetes mellitus, bone metabolism, bone density, bone strength, healing, mandibular growth, genetic predisposition, clinical strategies

INTRODUCTION

Diabetes is a chronic condition that occurs when the pancreas does not produce enough insulin or when the body is unable to effectively utilize the insulin it produces. Insulin is a hormone crucial for regulating blood glucose levels.[1] The condition is characterized by hyperglycemia, which is persistently elevated blood glucose levels. There are several types of diabetes, including Type 1, Type 2, and gestational diabetes.[2] According to a study in 2017, around 8.5% of adults aged 18 and older were affected by diabetes, highlighting its prevalence and impact.[2] Diabetes can lead to serious health problems if not controlled, such as heart disease, nerve damage, eye issues, kidney failure, and amputations.[1] The mortality rates due to diabetes have shown an increase between 2000 and 2019, especially in lower-middle-income countries.[2] Symptoms of diabetes can vary and may include increased thirst, frequent urination, fatigue, blurred vision, unintentional weight loss, and more.[2] Diabetes

Corresponding author: Nearchos Panayi, **e-mail:** dr.panayi@cytanet.com.cy
Received: March 11, 2025 **Accepted:** June 16, 2025 **Publication Date:** July 02, 2025

management encompasses blood sugar monitoring, taking oral medications or insulin, following a healthy diet, engaging in physical activity, and maintaining a healthy lifestyle.[3] Managing blood sugar levels is crucial to prevent complications and improve overall well-being.[3] The prognosis for diabetes varies based on various factors like the type of diabetes, how well it is managed, age at diagnosis, presence of other health conditions, and the development of complications.[3] This review article will assess the effects of diabetes mellitus (DM) on bone metabolism and consequently the orthodontic tooth movement and mandibular growth, thereby elucidating the relationship between DM and orthodontic treatment.

Effect of Diabetes on Bone

According to scientific studies diabetes exerts significant effects on bone growth and development, impacting various aspects of bone health as follows:[4-6]

Altered bone metabolism: Diabetes, particularly type 2 DM disrupts bone metabolism by compromising bone cell function and matrix structure. This imbalance includes diminished osteoblast differentiation, increased osteoblast apoptosis, and enhanced osteoclast-mediated bone resorption, leading to impaired bone formation and turnover.[7]

Reduced trabecular bone mass: Diabetes affects trabecular bone mass negatively, contributing to decreased bone density and strength.[8]

Increased cortical bone mass: Interestingly, while trabecular bone mass is decreased, individuals with diabetes may experience an increase in cortical bone mass.[8]

Impaired bone healing: Diabetic status, as characterized by elevated blood glucose and HbA1c levels, can adversely impact bone healing processes.[9]

Vitamin D deficiency: Individuals with diabetes often have decreased serum levels of vitamin D, which plays a crucial role in calcium and phosphate homeostasis, essential for proper bone growth and mineralization.[5,6]

Increased fracture risk: The alterations in bone metabolism and structure induced by diabetes can contribute to an increased risk of fractures, particularly in individuals with longstanding diabetes.[10]

Factors Influencing Mandibular Growth

Apart from diabetes, several factors influence the growth and development of the mandible, shaping its structure and function over time.[11-13] Biological factors, such as genetics, hormonal regulation, and metabolic processes, have a significant impact on mandibular growth. Genetic predispositions can influence the size and shape of the mandible, while hormonal imbalances can disrupt growth patterns.[14] Adequate nutrition is essential for proper mandibular development. Nutrients like calcium, vitamin D, and protein are crucial for bone growth and mineralization in the mandible. Malnutrition or deficiencies in key nutrients can hinder optimal mandibular growth.[15] Functional factors, including masticatory forces and muscle activity, play a role in guiding mandibular growth.[16] The mechanical stress generated during chewing and jaw movement contributes to the remodeling and adaptation of the mandible over time.[15] In addition, environmental influences, such as oral habits (like thumb sucking), breathing patterns, and posture, can impact mandibular growth.[17,18] Abnormal habits or posture can exert asymmetric forces on the mandible, leading to malocclusions and structural deviations.[16,19] Mandibular growth patterns vary at different developmental stages. Growth spurts during childhood and adolescence can significantly impact the length, width, and shape of the mandible.[17]

Proper development of the mandible ensures harmonious facial proportions, which can impact self-esteem, confidence, and overall psychological well-being.[20,21] Proper mandibular development enables efficient mastication, aiding in digestion and nutrient absorption. In addition, along with the maxilla, forms the foundation for speech production. The mandible also plays a role in airway patency and breathing. Proper mandibular growth ensures sufficient space for the tongue, prevents airway obstruction, and supports healthy breathing patterns. The proper alignment and development of the mandible are essential for the health and function of the temporomandibular joint (TMJ).[22] Unbalanced mandibular growth can lead to TMJ disorders, pain, and dysfunction. Additionally, the muscles associated with the mandible play a role in facial expression, chewing, and head posture. Balanced mandibular growth ensures optimal muscle function and alignment, reducing the risk of muscle strain or discomfort.

The Effect of DM in Mandibular Growth

The impact of diabetes on bone growth has been extensively documented in the literature.[4-10] The mandible, as a critical component of the skeletal system, is likely not exempt from the effects of diabetes on bone metabolism and development. Diabetes has a significant impact on mandibular growth, primarily affecting the quality and structure of the mandibular bone. Research indicates that diabetes, particularly Type 1 diabetes can lead to a decrease in bone formation in the mandible. This causes a delay in the growth and development of bones, potentially resulting in a slower rate of skeletal maturation.[19] Studies have shown that in diabetic conditions there is a deterioration in the quality of mandibular bone. This includes a significant decrease in bone volume, bone surface, and alterations in trabecular properties, indicating compromised bone integrity and structure.[19] Abbassy et al.[23] assessed the effect of type 1 DM on the structure of mandibular bone and changes in alveolar/jaw bone formation. Experimental Diabetes induction resulted in a decrease in mineral apposition and bone turnover, significant deterioration of bone quality, and reduced bone turnover around the alveolar wall in rats with diabetes compared to controls.[23] Experimental induction of diabetes in rats resulted in decreased mandibular growth, deformities in mandibular structure, and alterations in various mandibular dimensions. Reductions in growth rates of different mandibular regions were observed following diabetes induction; emphasizing the detrimental effects of diabetes on mandibular growth.[23] Another study highlighted the therapeutic potential of calcitonin and vitamin D3 in improving diabetic mandibular growth. The intermittent combination of calcitonin and vitamin D3 showed promise in enhancing mandibular growth in a diabetic context, suggesting a potential avenue for managing diabetes-related effects on mandibular development.[24] Diabetes can induce biomechanical alterations in the mandible, affecting its strength and overall mechanical properties.[25] These changes can impact the functional aspects of the mandible, including chewing and speech, due to the altered bone composition and quality. The pathophysiological mechanisms underlying the impact of diabetes on mandibular growth involve complex cellular and molecular processes. These include oxidative stress, impaired angiogenesis, altered gene expression, and disturbances in bone remodeling, all contributing to the impaired growth of the mandible.[26]

Understanding how diabetes affects mandibular growth is evidently essential in orthodontic practice. It influences treatment planning, the choice of orthodontic interventions, and the prediction of treatment outcomes in diabetic patients, considering the altered bone dynamics in the mandible. The effects of diabetes on mandibular growth can have long-term implications for dental health and overall well-being. Slowed or impaired mandibular growth may lead to functional problems, malocclusions, and increased susceptibility to dental issues in diabetic individuals. A recent demographic study projects a rising prevalence of diabetes in the coming years.[2] Concurrently, there is an anticipated increase in the number of patients seeking orthodontic treatment. Given this trend, it is imperative for orthodontic practitioners to be cognizant of the potential implications of diabetes on the oral tissues that may be influenced by orthodontic interventions.

Diabetes and Orthodontics

DM both type 1 and type 2, is known to significantly affect various physiological processes, including bone remodeling and healing, which are critical during orthodontic tooth movement. Bone remodeling during tooth movement, treatment timing considerations, alterations in force applications, and healing processes must be taken into account when an orthodontic treatment will be undertaken.

In diabetic patients, the response to orthodontic forces may be altered due to impaired osteoblast and osteoclast activity. Studies have shown that hyperglycemia can lead to changes in bone turnover, resulting in reduced osteogenesis and an increased risk of osteopenia. For instance, a study by Uehara et al.[27] demonstrated that diabetes affects the differentiation and function of osteoblasts, which are vital for bone formation during orthodontic tooth movement. Additionally, An et al.[28] found that diabetic rats exhibited a delayed response to mechanical forces applied to teeth, suggesting that the rate of orthodontic tooth movement may be compromised. Due to potential complications related to delayed healing and altered bone remodeling, practitioners may need to adjust the timing of orthodontic interventions. For instance, Bailey et al.[29] emphasized that optimal glycemic control should be achieved before initiating orthodontic treatment to minimize risks and complications. They found that uncontrolled diabetes not only delayed tooth movement but also increased the likelihood of periodontal complications. Regarding force application a study by Pang et al.[30] indicated that reduced bone density and impaired bone remodeling in diabetic individuals could necessitate the use of lighter forces to achieve tooth movement without the risk of root resorption or periodontal damage. The slower rate of tissue repair and remodeling in diabetic patients can lead to prolonged treatment durations and increased risk of complications. Takahashi et al.[31] reported that diabetic individuals often experience delayed healing due to impaired cytokine and growth factor expression, which affects periodontal tissue response. Consequently, this delayed healing may necessitate longer intervals between adjustments and a more conservative approach to force application.

Mechanisms Underlying the Effects of Diabetes on the Mandible

The mechanisms underlying the effects of diabetes on the mandible encompass a complex interplay of biological processes that impact the growth, structure, and function of the mandible. Diabetes is associated with increased oxidative stress in various tissues, including the mandible. Elevated levels of reactive oxygen species lead to oxidative damage, affecting mandibular bone cells and tissues. Oxidative stress contributes to bone loss, compromises bone regeneration, and impairs the healing capacity of the mandible.[32,33] Chronic inflammation is a hallmark of diabetes and plays a significant role in the pathogenesis of diabetic complications, including those affecting the mandible. Inflammatory mediators released in response to diabetes can contribute to bone resorption, inhibit bone formation, and disrupt the normal bone remodeling process in the mandible.[33] The formation of Advanced Glycation End-Products (AGEs), a consequence of hyperglycemia in diabetes, can impact the structure and function of mandibular bone. AGEs accumulate in bone collagen and impair its mechanical properties, potentially leading to decreased bone strength and increased susceptibility to fractures in the mandible.[34] Diabetes-related vascular complications, including microvascular damage, can affect blood supply to the mandible. Poor vascular health in diabetic individuals can compromise the delivery of nutrients and oxygen to mandibular tissues, leading to impaired bone growth and regeneration.[35] Diabetes-induced neuropathy can also influence the innervation of the mandible, affecting sensory perception, muscle function, and bone remodeling processes. Neuropathic changes in the mandible may contribute to alterations in chewing function, TMJ disorders, and overall craniofacial development.[36] Understanding these underlying mechanisms is crucial for comprehensively addressing the effects of diabetes on the mandible. By elucidating these pathways, researchers and healthcare professionals can develop targeted interventions to mitigate the negative impact of diabetes on mandibular health and function. The relationship between mandibular growth and diabetes presents critical implications for clinical practice and treatment strategies. For this reason research should be directed to uncover the cause and effect relation between diabetes and mandibular growth.

Future Research Directions for Diabetes and Mandibular Growth

Further investigation into the effect of diabetes on mandibular growth is essential to deepen our understanding of this complex relationship and improve patient care. Longitudinal studies examining the long-term impact of diabetes on mandibular growth are mandatory. Investigating how diabetes influences mandibular development over extended periods can provide insights into progressive changes, potential complications, and the stability of treatment outcomes. Exploring the genetic predisposition to diabetes-related effects on mandibular growth is important. Genetic studies could help identify specific markers or pathways that contribute to variations in mandibular development in diabetic individuals, potentially offering personalized treatment approaches.[23] Research focusing on the biomechanical properties of mandibular bone in diabetes is also needed. Understanding how diabetes alters the mechanical behavior, strength, and resilience of mandibular bone can enhance treatment planning in orthodontics and maxillofacial surgery. Investigating the broader impact of diabetes on craniofacial growth, beyond just the mandible, is valuable. Assessing how diabetes influences overall craniofacial development, including facial bone structure and dental arch morphology, can provide a comprehensive picture of the systemic effects of diabetes on oral health.[37] Advanced studies on the cellular and molecular mechanisms linking diabetes to mandibular growth alterations are necessary. Delving deeper into the specific cellular pathways, gene expressions, and signaling cascades involved in diabetes-induced changes in mandibular bone can unveil therapeutic targets and intervention strategies.[32] Clinical trials evaluating the efficacy of therapeutic interventions on mandibular growth in diabetic patients are warranted. Investigating the outcomes of innovative treatments, such as growth factors, bone grafting techniques, or pharmacological agents, can provide evidence-based recommendations for managing diabetes-related mandibular growth issues. Large-scale epidemiological studies focusing on diverse populations are also important, thus more have to be conducted. Understanding how different ethnicities, age groups, and socioeconomic backgrounds respond to the impact of diabetes on mandibular growth can lead to tailored approaches that account for variations in risk factors and treatment outcomes. Artificial intelligence (AI) is definitely a tool that can help uncover previously unknown factors contributing to diabetes while, it can predict in a subclinical level the possibility of an individual to express diabetes. On the other hand, a customized, personalized treatment could be designed for higher treatment efficiency something that AI can play a significant role.[38-40] The existing body of research regarding the effect of diabetes on bone and particularly mandibular bone derives from animal studies. However, it is essential to acknowledge the translational gap that exists between findings derived from animal research and their application on humans and more specifically in clinical orthodontic practice. Additionally, human dental and skeletal development is influenced by complex genetic, environmental, and behavioral factors that may not be fully replicated in animal models.

CONCLUSION

Reduced bone formation, low quality of bone, biomechanical alterations in the bone are the main effects of diabetes on bone growth. This is particularly evident in the mandible, where diabetes can hinder mandibular growth and development, creating challenges for both oral health and overall quality of life mandible as a craniofacial bone is equally affected by diabetes altering the quality and structure of the basal mandibular bone, changing the trabecular bone, while a reduction of bone volume and growth rate is also observed. The mechanical properties of the mandible are also affected decreasing its mandible's strength. The detrimental effects of diabetes on mandibular bone have an impact on several aspects of the mandible itself and the surrounding tissues. As a result, the implementation of effective clinical strategies is crucial for managing bone health in diabetic patients. By understanding the complex interplay between diabetes and bone physiology, healthcare professionals can better address the specific needs of these patients and promote optimal bone healing and strength. Diabetes has a direct impact in orthodontic treatment mainly on bone healing and formation. Special considerations should be taken to adjust the orthodontic treatment in diabetic patients. Future research should be directed towards early subclinical detection of diabetes, while the genetic predisposition is another big chapter that has to be investigated. AI is a tool that has to be used to overcome problems like the inability of early diagnosis, while it will help in creating personalized treatments based on the individual patient special characteristics combined with the characteristics of diabetes, which are expressed in the specific patient.

Footnotes

Author Contributions: Concept - N.P., A.T., D.K., I.T., M.K., G.K., I.A.D.; Design - N.P., A.T., D.K., I.T., M.K., G.K., I.A.D.; Data Collection and/or Processing - N.P., A.T., D.K., I.T., M.K., G.K., I.A.D.; Analysis and/or Interpretation - N.P., A.T., D.K., I.T., M.K., G.K., I.A.D.; Literature Search - N.P., A.T., D.K., I.T., M.K., G.K., I.A.D.; Writing - N.P., A.T., D.K., I.T., M.K., G.K., I.A.D.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: This study did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

1. Gupta S, Sharma N, Arora S, Verma S. Diabetes: A review of its pathophysiology, and advanced methods of mitigation. *Curr Med Res Opin.* 2024;40(5):773-780. [CrossRef]
2. Al-Lawati JA. Diabetes mellitus: a local and global public health emergency! *Oman Med J.* 2017;32(3):177-179. [CrossRef]
3. Ahmad F, Joshi SH. Self-care practices and their role in the control of diabetes: A narrative review. *Cureus.* 2023;15(7):e41409. [CrossRef]
4. Murray CE, Coleman CM. Impact of diabetes mellitus on bone health. *Int J Mol Sci.* 2019;20(19):4873. [CrossRef]
5. Sundararaghavan V, Mazur MM, Evans B, Liu J, Ebraheim NA. Diabetes and bone health: latest evidence and clinical implications. *Adv Musculoskelet Dis.* 2017;9(3):67-74. [CrossRef]
6. Al Ghadeer HA, AlRamadan MS, Al Amer MM, et al. Vitamin D serum levels in type 2 diabetic patients: a cross-sectional study. *Cureus.* 2022;14(2):e22558. [CrossRef]
7. Sanches CP, Vianna AG, Barreto F de. The impact of type 2 diabetes on Bone metabolism. *Diabetol Metab Syndr.* 2017;9(1). [CrossRef]
8. Picke AK, Campbell G, Napoli N, Hofbauer LC, Rauner M. Update on the impact of type 2 diabetes mellitus on bone metabolism and material properties. *Endocr Connect.* 2019;8(3):R55-R70. [CrossRef]
9. Bhamb N, Kanim LEA, Maldonado RC, et al. The impact of type 2 diabetes on bone metabolism and growth after spinal fusion. *Spine J.* 2019;19(6):1085-1093. [CrossRef]
10. Valderrábano RJ, Linares MI. Diabetes mellitus and bone health: Epidemiology, etiology and implications for fracture risk stratification. *Clin Diabetes Endocrinol.* 2018;4(1). [CrossRef]
11. Smartt JM, Low DW, Bartlett SP. The pediatric mandible: I. A primer on growth and development. *Plast Reconstr Surg.* 2005;116:14e-23e. [CrossRef]
12. Subramaniam P, Naidu P. Mandibular dimensional changes and skeletal maturity. *Contemp Clin Dent.* 2010;1:218. [CrossRef]
13. Lee SK, Kim YS, Oh HS, Yang KH, Kim EC, Chi JG. Prenatal development of the human mandible. *Anat Rec.* 2001;263:314-25. [CrossRef]
14. Ahmed M, Ye X, Taub P. Review of the genetic basis of jaw malformations. *J Pediatr Genet.* 2016;05:209-219. [CrossRef]
15. Karadede B, Karadede B, Karadede Mİ. Growth, development, and ossification of mandible and temporomandibular joint. Springer eBooks, 2018, p. 43-57. [CrossRef]
16. Tsolakis IA, Verikokos C, Papaioannou W, et al. Long-term effect of diet consistency on mandibular growth within three generations: a longitudinal cephalometric study in rats. *Biology*. 2023;12(4):568. [CrossRef]
17. Tsolakis IA, Verikokos C, Perrea D, et al. Effects of diet consistency on rat maxillary and mandibular growth within three generations-a longitudinal CBCT study. *Biology (Basel).* 2023;12(9):1260. [CrossRef]
18. Yamaguchi H, Sueishi K. Malloclusion associated with abnormal posture. *Bull Tokyo Dent Coll.* 2003;44:43-54. [CrossRef]
19. Spyropoulos MN, Tsolakis AI. Altered mandibular function and prevention of skeletal asymmetries after unilateral condylectomy in rats. *Eur J Orthod.* 1997;19:211-218. [CrossRef]
20. Liu YP, Behrents RG, Buschang PH. Mandibular growth, remodeling, and maturation during infancy and early childhood. Angle Orthod. 2010;80(1):97-105. [CrossRef]
21. Wright, T. D., & Laskin, D. M. Facial Aesthetics: Understanding the Influence on Psychological Well-being. Angle Orthod , 2021:91(3), 419-425. [CrossRef]
22. Johal A, Alyaqoobi I, Patel R, Cox S. The impact of orthodontic treatment on quality of life and self-esteem in adult patients. *Eur J Orthod.* 2015;37(3):233-237. [CrossRef]
23. Garstka AA, Brzózka M, Bitenc-Jasiejko A, Ardan R, Gronwald H, Skomro P, Lietz-Kijak D. Cause-effect relationships between painful TMD and postural and functional changes in the musculoskeletal system: a preliminary report. *Pain Res Manag.* 2022 Feb 28;2022:1429932. [CrossRef]
24. Abbassy MA, Watari I, Soma K. The effect of diabetes mellitus on rat mandibular bone formation and microarchitecture. *Eur J Oral Sci.* 2010;118:364-369. [CrossRef]
25. Abbassy MA, Watari I, Bakry AS, Ono T, Hassan AH. Calcitonin and vitamin D3 have high therapeutic potential for improving diabetic mandibular growth. *Int J Oral Sci.* 2015;8:39-44. [CrossRef]
26. Cai F, Liu Y, Liu K, et al. Diabetes mellitus impairs bone regeneration and biomechanics. *J Orthop Surg Res.* 2023;18(1)169. [CrossRef]
27. Yaribeygi H, Sathyapalan T, Atkin SL, Sahebkar A. Molecular mechanisms linking oxidative stress and diabetes mellitus. *Oxid Med Cell Longev*. 2020;2020:1-13. [CrossRef]
28. Uehara, J., et al. The effect of diabetes on the differentiation and function of osteoblasts. *J Dent Res.* 2012;91(5):453-458. [CrossRef]
29. An, J. H., et al. (2020). Delayed orthodontic tooth movement in diabetic rats. J. Dent. Res., 99(1), 22-30. [CrossRef]
30. Bailey, D. A., et al. (2018). Orthodontic treatment and periodontal status in patients with diabetes: A review. Am. J. Orthod. 154(2), 185-190. [CrossRef]
31. Pang, N. S., et al. The effect of biomechanical factors on orthodontic tooth movement in patients with diabetes. Eur J Orthod. 36(4), 387-392. [CrossRef]
32. Takahashi, I., et al. (2015). The influence of diabetes on healing post orthodontic tooth movement. J. Periodontol, 86(3), 345-352. [CrossRef]
33. Lima JEBF, Moreira NCS, Sakamoto-Hojo ET. Mechanisms underlying the pathophysiology of type 2 diabetes: from risk factors to oxidative stress, metabolic dysfunction, and hyperglycemia. *Mutat Res Genet Toxicol Environ Mutagen.* 2022;874-875:503437. [CrossRef]
34. Giacco F, Brownlee M. Mechanisms of hyperglycemic damage in diabetes. In: Skyler, J. (eds) Atlas of Diabetes. Springer, Boston, MA, 2012. [CrossRef]
35. Eid S, Sas KM, Abcouwer SF, et al. New insights into the mechanisms of diabetic complications: role of lipids and lipid metabolism. *Diabetologia.* 2019;62(9):1539-1549. [CrossRef]
36. Lu Y, Wang W, Liu J, Xie M, Liu Q, Li S. Vascular complications of diabetes: A narrative review. *Medicine (Baltimore).* 2023;102(40):e35285. [CrossRef]
37. Forbes JM, Cooper ME. Mechanisms of diabetic complications. *Physiol Rev.* 2013;93:137-188. [CrossRef]
38. Chałas R, Rudzka O, Wójcik-Chęcińska I, Vodanović M. The impact of type 1 diabetes on the development of the craniofacial mineralised tissues (bones and teeth): literature review. *Folia Morphol.* 2016;75:275-280. [CrossRef]
39. Guan Z, Li H, Liu R, et al. Artificial intelligence in diabetes management: Advancements, opportunities, and challenges. *Cell Rep Med.* 2023;4(10):101213. [CrossRef]
40. Sarma AD, Devi M. Artificial intelligence in diabetes management: transformative potential, challenges, and opportunities in healthcare. *Hormones (Athens).* 2025 Mar 21. [CrossRef]

DOI: 10.4274/TurkJOrthod.2025.2024.38

TURKISH JOURNAL OF
ORTHODONTICS

Systematic Review

Clinical Outcomes of Skeletal Anchorage Versus Conventional Anchorage in the Class III Orthopaedic Treatment in Growing Patients: A Systematic Review and Meta-Analysis

Rachele Podda, Francesca Imondi, Adriana Assunta De Stefano, Martina Horodynski, Roberto Antonio Vernucci, Gabriella Galluccio

Sapienza University of Rome, Department of Odontostomatological and Maxillofacial Sciences, Rome, Italy

Cite this article as: Podda R, Imondi F, De Stefano AA, Horodynski M, Vernucci RA, Galluccio G. Clinical outcomes of skeletal anchorage versus conventional anchorage in the class III orthopaedic treatment in growing patients: a systematic review and meta-analysis. *Turk J Orthod.* 2025;38(2):133-141

Main Points

In the orthopaedic treatment of Class III malocclusion in growing patients:

- Skeletal anchorage showed greater improvements in ANB and Wits.
- Fewer dental side effects with skeletal anchorage (less incisive protrusion).
- Better vertical control with skeletal anchorage
- BAMP protocol was the most effective for maxillary advancement with minimal side effects.

ABSTRACT

The aim of this systematic review was to evaluate the clinical outcomes of skeletal anchorage, compared to conventional anchorage, in the treatment of skeletal Class III malocclusion in growing patients. A systematic review was conducted following PRISMA guidelines. A specific search strategy was developed for PubMed, Web of Science, Embase, and Cochrane searching for randomized controlled trials and non-randomized clinical trials. Eleven interventions were assessed, three employing conventional anchorage (group A) and eight skeletal anchorage (group B). Nine pre-treatment (T0) and post-treatment (T1) mean cephalometric outcomes were statistically polled (SNA, SNB, ANB, Wits, Overjet, Overbite, SNMP, IMPA, U1PP). In total, 196 studies were identified, 17 studies were included in the qualitative and quantitative analysis. In the skeletal anchorage group, a greater increase in both ANB (+2.511°) and Wits (+4.691 mm) were observed and the increase in SNMP resulted well-controlled (+0.758°). The conventional anchorage group showed higher dentoalveolar side effects: increase in U1PP (+5.624°), decrease in IMPA (-0.866°) and increase in overjet (+5.255 mm). Treatments exploiting skeletal anchorage determined a better correction of skeletal Class III, thanks to a combination of greater advancement of the maxilla and more enhanced retrusion of the mandible. In all treatment protocols exploiting dental anchorage, the increase in the inclination of the central incisor resulted significantly greater. Further longitudinal studies are required to evaluate the long-term effects of skeletal anchorage in growing patients.

Keywords: Class III malocclusion, orthodontic anchorage procedures, orthodontic appliances, interceptive treatment, bone anchored maxillary protraction (BAMP)

Corresponding author: Adriana Assunta De Stefano, **e-mail:** adriana.destefano@uniroma1.it
Received: March 09, 2024 **Accepted:** April 16, 2025 **Publication Date:** July 02, 2025

INTRODUCTION

Skeletal Class III malocclusion is a complex dentofacial deformity caused by a discrepancy in the three-dimensional growth of the upper and lower jaws.[1] It is regarded by many as the most arduous malocclusion to treat, representing a true challenge for clinicians. Etiologically, skeletal Class III may derive from a retrognathic maxilla, a prognathic mandible or a combination of both.[2] According to literature, its prevalence varies amongst different ethnical groups, affecting 1-4% of Caucasians,[3] 5-8% of Afro-Americans,[4] and 4-14% of Asians.[5] The clinical manifestation of skeletal Class III may be very heterogenous, comprising several different dental and skeletal morphological variants. The patient's age and individual growth pattern represent two decisive factors to consider in the establishment of the optimal treatment strategy.[6,7] In growing patients, interceptive treatment is aimed at preventing irreversible changes in the skeletal structures and associated soft tissues, thus restoring a more favourable growth environment and facial aesthetics.[8,9] A variety of treatment strategies are accurately reported in literature and may be distinguished in two main subtypes: treatment plans that employ dental or conventional anchorage and ones that make use of skeletal anchorage. The latter has the objective of maximizing orthopaedic effects in growing patients whilst minimizing undesired dentoalveolar changes.[10-12] To date, not many studies have analysed the comparative effectiveness of maxillary protraction with or without the use of skeletal anchorage systems. Furthermore, according to the recent reviews published in literature,[13-18] there is still insufficient evidence to support the advantages and beneficial clinical outcomes of maxillary protraction using skeletal anchorage compared to traditional treatments, such as facemask therapy. Nevertheless, the implementation of skeletal anchorage continues to spread and new scientific evidence is being produced. These reviews have examined the clinical effectiveness of different anchoring protocols in the treatment of skeletal Class III, but without a detailed evaluation of the different types of interventions and with a reduced range of cephalometric results.[13-18]

Therefore, the aim of this systematic review was to evaluate the clinical outcomes of skeletal anchorage, compared to conventional anchorage, in the treatment of skeletal Class III malocclusion in growing patients.

METHODS

Search Strategy

The systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines[19] to ensure exhaustiveness and transparency. A specific search strategy was developed for PubMed, Web of Science, Embase, and Cochrane. English literature was searched with no time limit. A rigorous electronic search was carried out for randomized controlled trials (RCTs) and non-randomized clinical trials (CCTs) on patients affected by skeletal Class III, treated with protocols employing dental anchorage [rapid maxillary expansion (RME) combined with face mask (FM); Alternate RME and Constriction (Alt-RAMEC) combined with FM] and skeletal anchorage (mini-implants and/or mini-plates). All previous systematic reviews were carefully screened until July 2023 to identify potentially useful articles.

Eligibility Criteria

In order to be included in the systematic review, articles had to meet the following inclusion criteria: (a) population: patients affected by skeletal Class III malocclusion; (b) intervention: patients submitted to orthodontic treatment through the use of skeletal or dental anchorage appliances; (c) comparisons: availability of pre-treatment (T0) and post-treatment (T1) lateral cephalograms to compare cephalometric outcomes; (d) outcomes: availability of angular and millimetric cephalometric outcomes, pre and post-treatment, to evaluate treatment effectiveness; (e) study design: RCTs and CCTs in the English language, with full-text availability. The following exclusion criteria were implemented: (a) studies conducted on patients affected by syndromes or craniofacial deformities; (b) studies conducted on patients who received a previous orthodontic or surgical treatment; (c) studies in which patients were treated using a combination of skeletal and dental anchorage systems, without a clear distinction between data related to the two different types of anchorage; (d) case reports, systematic reviews, meta-analysis and finite element analysis were excluded.

Selection Process

Two independent authors (RP and FI) screened the titles and abstracts of articles identified through the electronic search. When the articles fulfilled the inclusion criteria, the full text was achieved; when the abstract did not contain sufficient information to allow the article's selection, the full text was visioned. The authors read and assessed the full-text articles to verify the attainment of all inclusion criteria; the identification of exclusion criteria led to the rejection of the article. In case of disagreement between the two authors (RP and FI) a third and fourth reviewer (ADS and MH) were appointed to reach the final decision.

Data Items

Data extraction from the articles was performed by the same two authors (RP and FI). The following data were recorded for each article: author/s, year of publication, study type, inclusion and exclusion criteria, treatment strategy, sample size, number of drop-outs, patients' mean age, clinical and cephalometric out-comes reported in the study, direction and intensity of the applied force, mean force application time, mean treatment duration, mean follow-up time, radiographic examinations. Specifically, pre-treatment and post-treatment cephalometric out-comes were classified as follows: (a) sagittal measurements: SNA (°), SNB (°), ANB (°), Wits (mm), overjet (mm); (b) vertical measurements: SNMP (°), overbite (mm); dental relationships: IMPA (°), U1PP (°).

Methodological Quality Assessment

A quality assessment of the articles included in this review was performed. Ten distinct characteristics were evaluated for each article and were assigned an individual score. The overall score, deriving from the sum of the ten individual ones, represented the quality of the article. Quality was expressed as low (total score ≤7), medium (total score >7 e ≤10), medium-high (total score >10 e ≤14) and high (total score >14).

Risk of Bias Assessment

Following the Cochrane risk of bias assessment tool,[20] the risk of bias was individually evaluated for each article by taking into consideration six distinct domains: selection bias, attrition bias, performance bias, reporting bias, detection bias and other bias.

RESULTS

Characteristics of Eligible Studies

A specific search strategy, reported in Table 1, was developed for PubMed, Web of Science, Embase, and Cochrane. In total, 196 studies were identified through the electronic search and submitted to screening, after which 109 studies were immediately excluded (98 duplicates, 11 not written in English). The 87 remaining studies were attentively assessed by the same two reviewers (RP and FM) who determined the exclusion of 70 studies for the following reasons: 47 were case reports, 4 were systematic reviews or meta-analysis, 10 included patients affected by craniofacial deformities or syndromes, 2 included patients previously treated orthodontically and finally, 4 were excluded for other reasons. Hence, the selection process, summarized in the PRISMA flow diagram in Figure 1, led to the inclusion of 17 studies in the qualitative and quantitative analysis, 5 were RCTs and 12 were CCTs.

Ten studies compared the effects of a conventional anchorage therapeutic protocol, represented by RME associated with FM, to a skeletal anchorage therapeutic protocol, represented by the following options: bone anchored maxillary protraction (BAMP) (2 studies),[21,22] zygomatic mini-plates associated with FM (2 studies),[23,25] zygomatic mini-screws associated with FM (1 study),[25] mini-plates inserted laterally to the pyriform aperture associated with FM (3 studies),[26-28], hybrid-hyrax expansion associated with face (2 studies).[29,30] One study compared treatment with a conventional palatal arch associated with FM to treatment with a skeletally anchored palatal arch using 2 miniscrews associated with FM.[31] The remaining 6 studies evaluated the effectiveness of specific treatment protocols in the absence of a reference control group. In particular, two studies assessed the effects of Hybrid-hyrax expansion associated with FM;[32,33] one study evaluated the effects of the BAMP protocol,[12] one study assessed the Alt-RAMEC expansion associated with facemask,[36] one study analysed zygomatic mini-plates associated with FM[28] and, lastly, one study assessed

Table 1. Search strategy

Database	Research Concept	Research Strategy
Pubmed	Concept 1: Patients with class III malocclusion	Class III malocclusion OR Angle class III OR skeletal class III OR retrognathia OR maxillary hypoplasia OR maxillary retrusion OR mandibular hyperplasia OR mandibular protrusion OR Hapsburg jaw
	Concept 2: Orthopedic treatment	Removable orthodontic appliance OR functional orthodontic appliance OR activator device OR reverse-pull headgear OR extra-oral traction appliance OR orthodontic chincup OR facemask
	Concept 3: Skeletal anchorage	Orthodontic anchorage OR skeletal anchorage OR temporary anchorage devices OR miniscrew OR miniplate OR bone anchors OR bone anchored maxillary protraction
Cochrane database	Concept 1: Patients with class III malocclusion	Class III malocclusion OR Angle class III OR skeletal class III OR retrognathia OR maxillary hypoplasia OR maxillary retrusion OR mandibular protrusion
	Concept 2: Orthopedic treatment	Removable orthodontic appliance OR functional orthodontic appliance OR activator device OR reverse-pull headgear OR extra-oral traction appliance OR orthodontic chincup OR facemask
	Concept 3: Skeletal anchorage	Orthodontic anchorage OR skeletal anchorage OR temporary anchorage devices OR miniscrew OR miniplate OR bone anchors OR skeletal maxillofacial protraction
Embase	Concept 1: Patients with class III malocclusion	Class III malocclusion OR Angle class III OR skeletal class III OR retrognathia OR maxillary hypoplasia OR mandibular hyperplasia OR jaw occlusion disorder
	Concept 2: Orthopedic treatment	Removable orthodontic appliance OR functional orthodontic appliance OR activator device OR reverse-pull headgear OR extra-oral traction appliance OR orthodontic chincup OR facemask
	Concept 3: Skeletal anchorage	Orthodontic anchorage OR skeletal anchorage OR temporary anchorage devices OR miniscrew OR miniplate OR bone anchors OR skeletal maxillofacial protraction
Web of Science	Concept 1: Patients with class III malocclusion	Class III malocclusion OR Angle class III OR skeletal class III OR retrognathia OR maxillary hypoplasia OR maxillary retrusion OR mandibular hyperplasia OR mandibular protrusion
	Concept 2: Orthopedic treatment	Removable orthodontic appliance OR functional orthodontic appliance OR activator device OR reverse-pull headgear OR extra-oral traction appliance OR orthodontic chincup OR facemask
	Concept 3: Skeletal anchorage	Orthodontic anchorage OR skeletal anchorage OR temporary anchorage devices OR miniscrew OR miniplate OR bone anchors OR bone anchored maxillary protraction

the effectiveness of the Alt-RAMEC expansion associated with miniplates inserted in the pyriform aperture and FM.[35]

Overall, out of the 17 studies assessed, the authors extrapolated 11 distinct treatment protocols of which 3 made use of conventional anchorage (RME associated with FM, Alt-RAMEC maxillary expansion associated with FM, palatal arch associated with FM) and 8 made use of skeletal anchorage treatment protocols (Hybrid-hyrax associated with FM, BAMP protocol, zygomatic miniplates associated with FM, zygomatic miniscrews associated with FM, skeletally anchored palatal arch associated with FM, miniplates inserted in the pyriform aperture associated with FM, Alt-RAMEC Hybrid-hyrax associated with FM, Alt-RAMEC expansion associated with miniplates inserted in the pyriform aperture and FM). The number of treated case groups and the associated treatment protocols were attentively recorded for each article and are summarized in Table 2. Specifically, a total of 29 case groups were identified, of which 12 were treated with conventional anchorage (group A) and 17 were treated with skeletal anchorage (group B). The detailed description of all the assessed therapeutic protocols is reported and data extracted from the selected articles were displayed in Appendix A to allow synthesis and clarity.

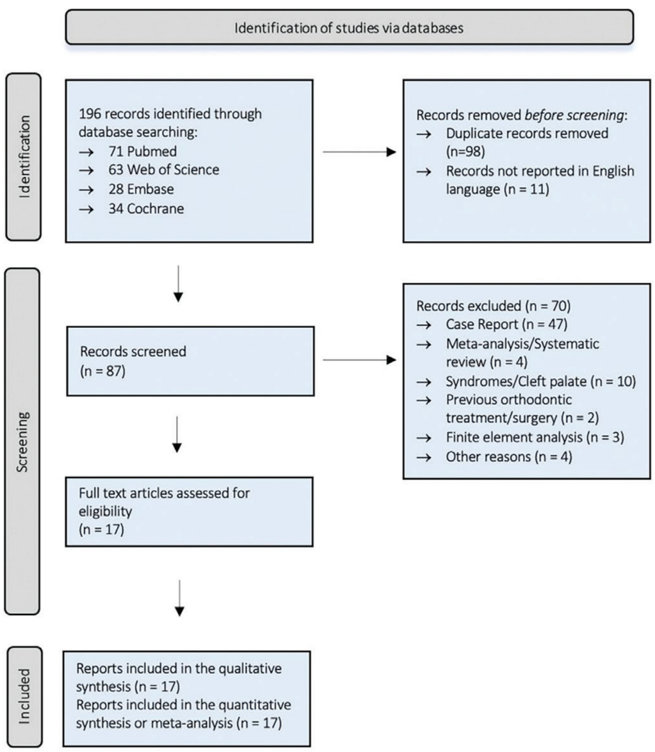

Figure 1. Prisma flow diagram

Methodological Quality Assessment

A quality assessment of the articles included in this review was performed. Ten distinct characteristics, reported in Table 3, were evaluated for each article, and were assigned an individual score. The overall score, deriving from the sum of the ten individual ones, represented the quality of the article, with a maximum score of 16. Overall, six studies resulted of medium quality, ten studies of medium-high quality and no study attained a high-quality score. The summary of the scores established in the quality assessment is reported in Table 4.

Risk of Bias Assessment

Following the Cochrane risk of bias assessment tool, the risk of bias was individually evaluated for each article by taking into consideration six distinct domains. The attribution of the scores corresponding to each domain is reported in Table 5. Overall, the greatest bias was attributed to performance and detection, since no blinding was performed in the process of patient selection and outcome analysis respectively. On the other hand, attrition bias and reporting bias were both regarded as low since all articles attentively reported all data related to the outcomes assessed in the studies.

Statistical Analysis

All statistical analyses were performed using a computer software (The Jamovi Project, 2023, edition 2.3) and all tables were displayed using Excel database (Microsoft Corporation, Washington, 2018). According to the statistical analysis, mean

Table 2. Summary of treatment protocols and number of case groups

Type of anchorage	Levels	N° Case groups	% of total
Conventional	RME + Facemask	10	34.5%
	Palatal Arch + Facemask	1	3.4%
	RME Alt-RAMEC + Facemask	1	3.4%
Skeletal	Hybrid Hyrax + Facemask	4	13.8%
	BAMP Protocol	3	10.3%
	Zygomatic Miniscrews + Facemask	1	3.4%
	Zygomatic Miniplates + Facemask	3	10.3%
	Miniplates Pyriform Apertura + Facemask	3	10.3%
	Palatal Arch + Miniscrew + Facemask	1	3.4%
	Alt-RAMEC + H-Hyrax + Mandibular Miniscrews	1	3.4%
	RME Alt-RAMEC + Miniplates + Facemask	1	3.4%
	Total	**29**	**100.0%**

treatment time was greater in the conventional anchorage treatment protocols when compared to the skeletal anchorage ones, with an average duration of 11.15 months and 9.59 months respectively. In both anchorage groups, the maximum treatment duration resulted in 21 months, whereas the minimum treatment duration was reported as 6.24 months for conventional anchorage protocols and 5.8 months for skeletal anchorage protocols.

Particular attention was paid to the patient's mean age in the conventional and skeletal anchorage treatment protocols. The mean patient age was 9.99 years in the first group and 10.68 years in the second group; the mean patient age refers to the age of the patients at the start of the treatment protocol. The minimum age was recorded as 6.5 years and 8.74 years in the conventional and skeletal treatment protocols respectively. The maximum age, instead, was registered as 11.7 years in the conventional anchorage group and 12.5 years in the skeletal anchorage group.

Pre-treatment (T0) and post-treatment (T1) mean cephalometric outcomes in the conventional and skeletal anchorage treatment protocols were compared. On the sagittal plane, the ANB showed a greater increase in the skeletal anchorage group (+2.511°) with respect to the conventional anchorage group (+2.094°): this increase was the result of both a larger increase in the angle SNA (2.511° compared to 2.094°) and a larger decrease

Table 3. Parameters assessed in the qualitative analysis and method of score attribution

Pre-established characteristics	Code	Score
Adequacy of sample selection description based on age and sex across the groups	A	Full: 2 points; partial: 1 point
Study design for the inclusion of the treated group	B	Prospective: 1 point; retrospective or not declared: 0 points
Description of the Class III (full, skeletal, and/or dental parameters; partial, only dental parameters)	C	Full: 2 points; partial: 1 point
Distribution of the different maturational stages among the investigated subjects	D	Full: 2 points; partial: 1 point
Adequacy of treatment description based on: (a) orthodontic appliance; (b) description of TADs and their placement (miniscrews, miniplates); (c) treatment duration	E	Full: 2 points; partial: 1 point
Withdrawals declared or derivable	F	No/Yes: 1 point; not declared: 0 points
Description of the method error analysis	G	Yes: 2 points; no: 0 points
Blinding for measurements	H	Yes: 1 point; no: 0 points
Adequacy of statistics based on the comparisons of the intragroup changes over time among/between group	I	Yes: 2 points, no: 1 point
Prior estimation of sample size or a posteriori power analysis	J	Yes: 1 point, no: 0 points

Table 4. Summary of scores attributed in the qualitative analysis of the articles

Author	A	B	C	D	E	F	G	H	I	J	Total score	Article quality
de Souza et al.[22]	2	1	2	1	2	0	2	1	2	1	14	Medium/High
Lee et al.[36]	2	0	2	1	2	0	2	0	2	0	11	Medium/High
Willmann et al.[29]	2	0	2	1	2	0	0	0	2	0	9	Medium
Seiryu et al.[31]	2	1	2	1	2	0	2	1	2	1	14	Medium/High
Bozkaya et al.[23]	2	0	2	1	2	0	0	0	2	0	9	Medium
Ngan et al.[30]	2	0	2	1	2	0	2	0	2	0	11	Medium/High
NienKemper et al.[32]	2	0	2	1	2	0	2	0	2	0	11	Medium/High
Ge et al.[25]	2	0	2	1	2	0	2	0	2	0	11	Medium/High
Nienkemper et al.[33]	2	0	2	1	2	0	2	0	2	1	12	Medium/High
Papadopoulou et al.[34]	2	1	2	1	2	0	2	0	2	0	11	Medium/High
Kaya et al.[35]	2	1	2	1	2	0	0	0	2	0	10	Medium
De Clerck et al.[12]	1	0	2	1	1	0	0	0	1	0	6	Low
Buyukcavus et al.[26]	2	0	2	1	2	0	2	0	2	1	12	Medium/High
Ağlarcı et al.[21]	2	1	2	1	2	1	2	0	2	1	14	Medium/High
Koh and Chung[24]	2	0	2	2	2	0	0	0	2	0	10	Medium
Sar et al.[27]	2	1	2	1	2	0	0	0	2	0	10	Medium
Tripathi et al.[28]	2	0	2	1	2	0	0	0	2	0	9	Medium

in the angle SNB (-1.058° compared to -0.914°) in patients treated with skeletal anchorage systems. These data agree with Wits' index, which underwent a more substantial increase in the skeletal anchorage group compared to the traditional anchorage group (+4.691 mm and +3.781 mm respectively). In the vertical plane, the SNMP angle between the Sella-Nasion plane and the mandibular plane was assessed. The increase of this angle resulted less enhanced in patients treated with skeletal anchorage (+0.758°) with respect to patients submitted to conventional treatment protocols (+1.221°). Respectfully to dental parameters, in the dental anchorage group the mean increase in overjet was greater compared to the skeletal anchorage group (+5.255 mm and +4.797 mm respectively), whereas overbite showed a similar mean decrease in both treatment protocols (-0.671 mm and -0.758 mm respectively). The mean decrease in the IMPA angle resulted more enhanced in the conventional anchorage protocols (-2.866°) compared to the skeletal anchorage protocols (-2.518°). However, the more outstanding result was achieved by the angle between the axis of the central upper incisor and the palatal plane, which underwent a substantially higher increase in the conventional anchorage protocols (+5.624°) compared to the skeletal anchorage protocols (+1.193°).

Meta-Analysis

A statistical meta-analysis was conducted to compare the effects of the following treatment protocols:

1. RME + FM
2. BAMP
3. Hybrid-Hyrax + FM
4. Zygomatic miniplates + FM
5. Miniplates in the pyriform aperture + FM

The protocol RME + FM was considered as landmark for conventional anchorage treatment strategies. Pre-treatment and post-treatment mean cephalometric outcomes were statistically compared. The objective of the following meta-analysis was to evaluate the relative effectiveness of each individual skeletal anchorage protocol compared to the conventional anchorage reference protocol (RME + FM). The standardized mean difference (SMD) was used to quantify the effect size. The SMD corresponded to the standardized value of the difference between the mean values of cephalometric outcomes in the conventional and skeletal anchorage treatment protocols. The meta-analysis allowed to identify compelling results, which are reported as follows. In all treatment protocols, exploiting both skeletal and dental anchorage, the increase in the angle SNA resulted as statistically significant and was particularly enhanced in 2 protocols: BAMP and Miniplates in the pyriform aperture + FM. The decrease in angle SNB resulted statistically significant in only 2 protocols: RME + FM and Zygomatic miniplates + FM. With respect to angle ANB, its increase was statistically significant in all protocols and distinctly emphasized in 2 of them: Miniplates in the pyriform aperture + FM and BAMP. The increase in the Wits index was, again, statistically significant in only 2 protocols: BAMP and RME + FM. The increase in the angle SNMB did not result statistically significant. Regarding the dental parameters, the increase in overjet resulted statistically significant only in the treatment protocol employing dental anchorage, RME + FM. The decrease in overbite did not result statistically significant in any of the protocols examined. At last, the increase in the angle

Table 5. Risk of bias evaluation

Author	Selection bias	Attrition bias	Performance bias	Reporting bias	Detection bias	Other bias
de Souza et al.[22]	Low	Low	Low	Low	Low	Low
Lee et al.[36]	High	Low	High	Low	High	Low
Willmann et al.[29]	Low	Low	High	Low	High	Low
Seiryu et al.[31]	High	Low	Low	Low	Low	Low
Bozkaya et al.[23]	Low	Low	High	Low	High	Low
Ngan et al.[30]	Low	Low	High	Low	High	Low
NienKemper et al.[32]	High	Low	High	Low	High	Low
Ge et al.[25]	Low	Low	High	Low	High	Low
Nienkemper et al.[33]	Low	Low	High	Low	High	Low
Papadopoulou et al.[34]	High	Low	High	Low	High	Low
Kaya et al.[35]	High	Low	High	Low	High	Low
De Clerck et al.[12]	Unclear	Low	High	Low	High	Low
Buyukcavus et al.[26]	Low	Low	High	Low	High	Low
Ağlarcı et al.[21]	Low	Low	High	Low	High	Low
Koh and Chung[24]	High	Low	High	Low	High	Low
Sar et al.[27]	High	Low	High	Low	High	Low
Tripathi et al.[28]	High	Low	High	Low	High	Low

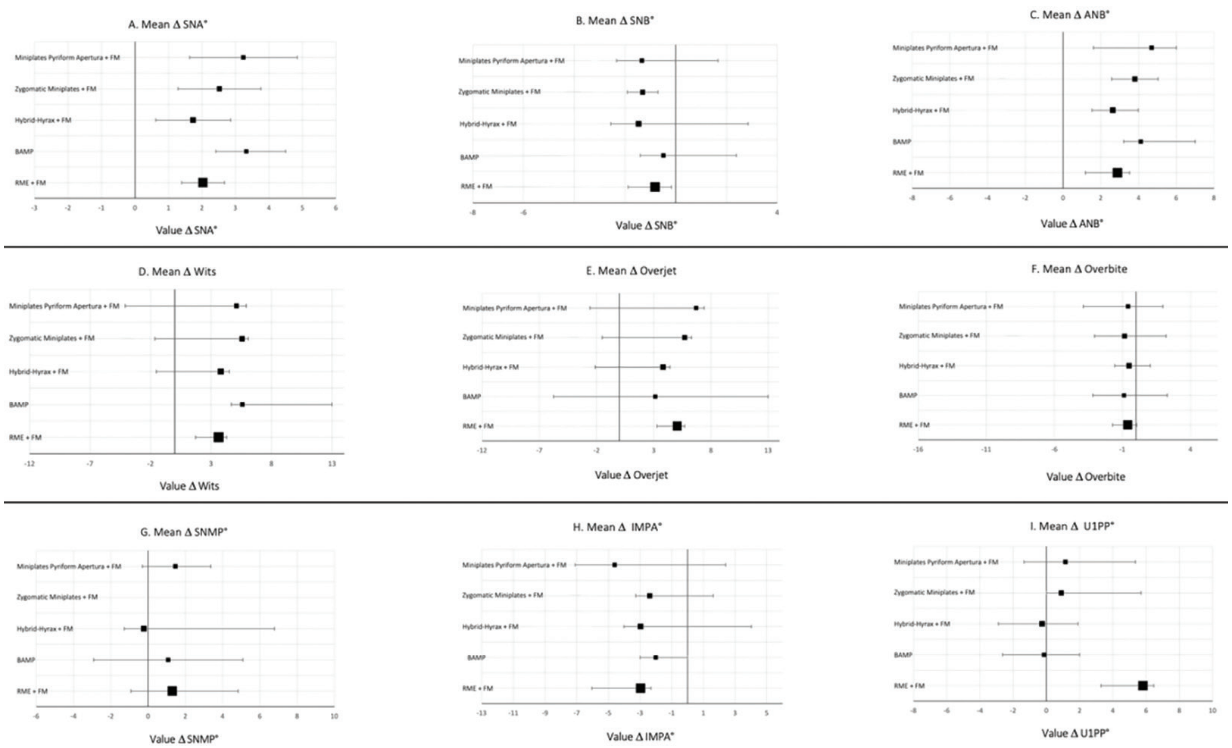

Figure 2. Forest plots of the effects of the treatment protocols. A. Effect in SNA°; B Effect in SNB°; C. Effect in ANB°; D. Effect in Witts; E. Effect in Overjet; F. Effect in overbite; G. Effect in SNMP°; H. Effect in IMPA°; I. Effect in U1PP°

U1PP and the decrease in the angle IMPA resulted statistically significant only in the dental anchorage treatment protocol. The forest plots of interventional treatments included in the meta-analysis are available in Figure 2.

DISCUSSION

A variety of distinct strategies are reported in literature with respect to orthopaedic treatment of skeletal Class III.[36-39] What may be asserted with certainty is that the earlier the orthopaedic approach is employed, the greater the skeletal changes that may be appreciated. With advancing age, skeletal correction may be surmounted by dental adjustments.[6,36] Hence, treatment results and their long-term stability represent a current research topic which orthodontists are scrupulously investigating.

To date, early treatment of skeletal Class III malocclusion is regarded as a valid strategy to improve the patients' aesthetics and to reduce the future need of combined surgical and orthodontic treatments.[40] The clinician's choice of the best timing of intervention should also take into consideration that, amongst the objectives of orthodontic treatment, the improvement of facial aesthetics represents a key component, along with the resolution of dental and skeletal discrepancies.[41,42] According to Alhammadi et al.[43] the age of the patient and the severity of the malocclusion represent the two decisive factors to assess in the decision of the best treatment timing. The results of this research highlight that the mean patient age was higher in treatments exploiting skeletal anchorage protocols compared to conventional ones.

There is a vast amount of existing research supporting the effectiveness of bone-anchored devices in the treatment of Class III malocclusion. The key advantages of skeletal anchorage are represented by the predictability of the biomechanical forces and the stability of the clinical outcomes,[37] allowing the clinician to contrast the adverse effects of facemask therapy, such as the increase in the lower anterior facial height, the proclination of the maxillary incisors and the retroclination of the mandibular incisors.[15,18,38]

The analysis of the results shows that treatments that exploited skeletal anchorage determined on average a better correction of skeletal Class III. This was made possible by of increased maxillary advancement and improved mandibular retrusion. Nevertheless, the results of the meta-analysis show that even in the conventional anchorage protocol, represented by RME + FM, the increase in angles SNA and ANB resulted statistically significant. Thus, the employment of a dental anchorage protocol does allow the correction of class III but not without any drawbacks. In fact, dental movements appeared to be significantly more enhanced in the conventional anchorage treatment protocols, in which the increase in overjet was predominantly achieved by accentuating the buccal inclination of the upper central incisors. As the results of the meta-analysis demonstrate, the increase in the angle U1PP and the decrease in the IMPA angle resulted statistically significant exclusively in the RME + FM protocol, implicating a lower long-term stability of the Class III correction. With respect to vertical changes, overall, the increase in the angle SNMP resulted less enhanced in patients treated with skeletal anchorage but, according to the meta-analysis, the difference in vertical changes between skeletal and dental anchorage treatment protocols may not be considered as statistically significant.

Along with the choice of which anchorage type to implement, the clinician also faces the choice of the most appropriate treatment timing.

Study Limitations

The main limitation of the present study is represented by the restricted sample size examined for each of the distinct treatment protocols employing skeletal anchorage. Hence, the results achieved do not allow the establishment of evidence-based conclusions with respect to the effects of skeletal anchorage in interceptive Class III treatment. Another key limitation is represented by the lack of data regarding the long-term effects of therapies exploiting skeletal anchorage as very few studies included a long-term follow-up of the patients submitted to treatment.

The ultimate goal of this review was to identify which therapeutic approach yields the best results in correcting maxillary deficiency in skeletal Class III children with minimal adverse effects. In the short term, according to the assessment of the results of the present study, it seems that the most promising treatment protocol employing skeletal anchorage is the BAMP. In fact, in patients treated with such protocol, the following were observed: highest increase in the angle SNA, lowest increase in the proclination of the upper incisors, lowest retroclination of the lower incisors and good control of the vertical dimension. Clearly, this study presents insufficient evidence to support the encouraging results observed but it raises awareness on the need of future studies that may assess the auspicious outcomes of the BAMP protocol in the interceptive treatment of skeletal Class III.

CONCLUSION

The conventional treatment protocol, comprising RME associated to facemask, allows the correction of Class III malocclusion through a combination of skeletal and dentoalveolar effects. More specifically, in all treatment protocols exploiting dental anchorage, the increase in the inclination of the central incisor resulted significantly greater compared to bone anchorage protocols. The application of skeletal anchorage, instead, allows to convey the employed forces directly to the skeletal components and circum-maxillary sutures, thus maximizing skeletal changes whilst minimizing undesired dental movements. Furthermore, the employment of skeletal anchorage enhances the sagittal advancement of the maxilla and reduces the unwanted vertical changes. It should be noted that there has been insufficient long-term research, thus conclusions should be drawn cautiously. These conclusions do not ensure any direct therapeutic success; rather, the clinician should exercise caution when using skeletal anchorage invasively in Class III children, as increasing bone conditions and stability are vulnerable to many circumstances.

Ethics

Informed Consent: A systematic review and meta-analysis.

Acknowledgments: The authors would like to thank Dott. Daniele Bellini for his support in the statistical analysis.

Footnotes

Author Contributions: Concept - R.P., G.G.; Design - G.G.; Data Collection and/or Processing - F.I., A.A.D.S. M.H., R.A.V.; Analysis and/or Interpretation - A.A.D.S. M.H.; Literature Search - R.P., F.I., R.A.V.; Writing - R.P., A.A.D.S. M.H.

Conflict of Interest: All the authors declare no conflict of interest in connection with this article.

Financial Disclosure: This study did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

1. Ngan P, Moon W. Evolution of class III treatment in orthodontics. *Am J Orthod Dentofacial Orthop.* 2015;148(1):22-36. [CrossRef]
2. Ellis E 3rd, McNamara JA Jr. Components of adult class III malocclusion. *J Oral Maxillofac Surg.* 1984;42(5):295-305. [CrossRef]
3. Ainsworth NJ. The incidence of dental disease in the children. In Medical Research Council: reports of the committee for the investigation of dental disease, Special Report Series, No 97, 1925. [CrossRef]
4. Altemus LA. Frequency of the incidence of malocclusion in American Negro children aged 12-16. *Angle Orthod.* 1959;29(4):189-200. [CrossRef]
5. Lin M, Xie C, Yang H, Wu C, Ren A. Prevalence of malocclusion in Chinese schoolchildren from 1991 to 2018: A systematic review and meta-analysis. *Int J Paediatr Dent.* 2020;30(2):144-155. Epub 2019 Nov 29. [CrossRef]
6. Ngan P. Early treatment of class III malocclusion: is it worth the burden? *Am J Orthod Dentofacial Orthop.* 2006;129(4 Suppl):S82-85. [CrossRef]
7. Turpin DL. Orthodontic treatment and self-esteem. *Am J Orthod Dentofacial Orthop.* 2007;131(5):571-572. [CrossRef]
8. Woon SC, Thiruvenkatachari B. Early orthodontic treatment for class III malocclusion: a systematic review and meta-analysis. *Am J Orthod Dentofacial Orthop.* 2017;151(1):28-52. [CrossRef]
9. Ngan P. Biomechanics of maxillary expansion and protraction in class III patients. *Am J Orthod Dentofacial Orthop.* 2002;121(6):582-583. [CrossRef]
10. Baccetti T, Tollaro I. A retrospective comparison of functional appliance treatment of class III malocclusions in the deciduous and mixed dentitions. *Eur J Orthod.* 1998;20(3):309-317. [CrossRef]
11. Costello BJ, Ruiz RL, Petrone J, Sohn J. Temporary skeletal anchorage devices for orthodontics. *Oral Maxillofac Surg Clin North Am.* 2010;22(1):91-105. [CrossRef]
12. De Clerck HJ, Cornelis MA, Cevidanes LH, Heymann GC, Tulloch CJ. Orthopedic traction of the maxilla with miniplates: a new perspective for treatment of midface deficiency. *J Oral Maxillofac Surg.* 2009;67(10):2123-2129. [CrossRef]
13. Kamath A, Sudhakar SS, Kannan G, Rai K, Sb A. Bone-anchored maxillary protraction (BAMP): A review. *J Orthod Sci.* 2022;11:8. [CrossRef]
14. Rutili V, Nieri M, Franceschi D, Pierleoni F, Giuntini V, Franchi L. Effects produced by the facemask with and without skeletal anchorage for the orthopaedic treatment of class III malocclusion

in growing patients: a systematic review and meta-analysis of RCTs. *Eur J Orthod.* 2023;45(2):157-168. [CrossRef]

15. Wang J, Yang Y, Wang Y, et al. Clinical effectiveness of different types of bone-anchored maxillary protraction devices for skeletal class III malocclusion: systematic review and network meta-analysis. *Korean J Orthod.* 2022;52(5):313-323. [CrossRef]
16. Rodríguez de Guzmán-Barrera J, Sáez Martínez C, Boronat-Catalá M, et al. Effectiveness of interceptive treatment of class III malocclusions with skeletal anchorage: A systematic review and meta-analysis. *PLoS One.* 2017;12(3):e0173875. [CrossRef]
17. Si M, Hao Z, Fan H, Zhang H, Yuan R, Feng Z. Maxillary protraction: a bibliometric analysis. *Int Dent J.* 2023;73(6):873-880. Epub 2023 Jun 26.
18. Cornelis MA, Tepedino M, Riis NV, Niu X, Cattaneo PM. Treatment effect of bone-anchored maxillary protraction in growing patients compared to controls: a systematic review with meta-analysis. *Eur J Orthod.* 2021;43(1):51-68. [CrossRef]
19. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ.* 2021;372:n71. [CrossRef]
20. Epstein R, Fonnesbeck C, Williamson E, et al. Psychosocial and pharmacologic interventions for disruptive behavior in children and adolescents rockville (MD): agency for healthcare research and quality (US); 2015 Oct. (Comparative Effectiveness Reviews, No. 154.) Appendix C, Risk of Bias Assessment Forms and Summaries. [CrossRef]
21. Ağlarcı C, Esenlik E, Fındık Y. Comparison of short-term effects between face mask and skeletal anchorage therapy with intermaxillary elastics in patients with maxillary retrognathia. *Eur J Orthod.* 2016;38(3):313-323. [CrossRef]
22. de Souza RA, Rino Neto J, de Paiva JB. Maxillary protraction with rapid maxillary expansion and facemask versus skeletal anchorage with mini-implants in class III patients: a non-randomized clinical trial. *Prog Orthod.* 2019;20(1):35. [CrossRef]
23. Bozkaya E, Yüksel AS, Bozkaya S. Zygomatic miniplates for skeletal anchorage in orthopedic correction of class III malocclusion: A controlled clinical trial. *Korean J Orthod.* 2017;47(2):118-129. Epub 2017 Jan 25. [CrossRef]
24. Koh SD, Chung DH. Comparison of skeletal anchored facemask and tooth-borne facemask according to vertical skeletal pattern and growth stage. *Angle Orthod.* 2014;84(4):628-633. Epub 2013 Nov 25. [CrossRef]
25. Ge YS, Liu J, Chen L, Han JL, Guo X. Dentofacial effects of two facemask therapies for maxillary protraction. *Angle Orthod.* 2012;82(6):1083-1091. Epub 2012 May 28. [CrossRef]
26. Buyukcavus MH, Kale B, Aydemir B. Comparison of treatment effects of different maxillary protraction methods in skeletal class III patients. *Orthod Craniofac Res.* 2020;23(4):445-454. Epub 2020 May 25. [CrossRef]
27. Sar C, Arman-Özçırpıcı A, Uçkan S, Yazıcı AC. Comparative evaluation of maxillary protraction with or without skeletal anchorage. *Am J Orthod Dentofacial Orthop.* 2011;139(5):636-649. [CrossRef]
28. Tripathi T, Rai P, Singh N, Kalra S. A comparative evaluation of skeletal, dental, and soft tissue changes with skeletal anchored and conventional facemask protraction therapy. *J Orthod Sci.* 2016;5(3):92-99. [CrossRef]
29. Willmann JH, Nienkemper M, Tarraf NE, Wilmes B, Drescher D. Early class III treatment with hybrid-hyrax - facemask in comparison to Hybrid-Hyrax-Mentoplate - skeletal and dental outcomes. *Prog Orthod.* 2018;19(1):42. [CrossRef]
30. Ngan P, Wilmes B, Drescher D, Martin C, Weaver B, Gunel E. Comparison of two maxillary protraction protocols: tooth-borne versus bone-anchored protraction facemask treatment. *Prog Orthod.* 2015;16:26. Epub 2015 Aug 25. [CrossRef]
31. Seiryu M, Ida H, Mayama A, et al. A comparative assessment of orthodontic treatment outcomes of mild skeletal class III malocclusion between facemask and facemask in combination with a miniscrew for anchorage in growing patients: a single-center, prospective randomized controlled trial. *Angle Orthod.* 2020;90(1):3-12. Epub 2019 Aug 12. [CrossRef]
32. Nienkemper M, Wilmes B, Pauls A, Drescher D. Maxillary protraction using a hybrid hyrax-facemask combination. *Prog Orthod.* 2013;14(1):5. [CrossRef]
33. Nienkemper M, Wilmes B, Franchi L, Drescher D. Effectiveness of maxillary protraction using a hybrid hyrax-facemask combination: a controlled clinical study. *Angle Orthod.* 2015;85(5):764-770. Epub 2014 Nov 13. [CrossRef]
34. Papadopoulou AK, Koletsi D, Masucci C, Giuntini V, Franchi L, Darendeliler MA. A retrospective long-term comparison of early RME-facemask versus late hybrid-hyrax, alt-RAMEC and miniscrew-supported intraoral elastics in growing class III patients. *Int Orthod.* 2022 Mar;20(1):100603. Epub 2021 Dec 28. [CrossRef]
35. Kaya D, Kocadereli I, Kan B, Tasar F. Effects of facemask treatment anchored with miniplates after alternate rapid maxillary expansions and constrictions; a pilot study. *Angle Orthod.* 2011;81(4):639-46. Epub 2011 Feb 7. [CrossRef]
36. Lee HJ , Choi DS, Jang I, Cha BK. Comparison of facemask therapy effects using skeletal and tooth-borne anchorage. Angle Orthod. 2022;92(3):307-314. [CrossRef]
37. Jedliński M, Janiszewska-Olszowska J, Mazur M, Ottolenghi L, Grocholewicz K, Galluccio G. Guided insertion of temporary anchorage device in form of orthodontic titanium miniscrews with customized 3D templates—a systematic review with meta-analysis of clinical studies. *Coatings*. 2021;11(12):1488. [CrossRef]
38. Baccetti Baccetti T, McGill JS, Franchi L, McNamara JA Jr, Tollaro I. Skeletal effects of early treatment of class III malocclusion with maxillary expansion and face-mask therapy. Am J Orthod Dentofacial Orthop. 1998;113(3):333-343. [CrossRef]
39. Wu Z, Zhang X, Li Z, et al. A Bayesian network meta-analysis of orthopaedic treatment in class III malocclusion: maxillary protraction with skeletal anchorage or a rapid maxillary expander. *Orthod Craniofac Res.* 2020;23(1):1-15. Epub 2019 Sep 15. [CrossRef]
40. Stellzig-Eisenhauer A, Lux CJ, Schuster G. Treatment decision in adult patients with class III malocclusion: orthodontic therapy or orthognathic surgery? *Am J Orthod Dentofacial Orthop.* 2002;122(1):27-37; discussion 37-8. [CrossRef]
41. Serritella E, Impellizzeri A, Musone L, De Stefano AA, Gabriella G. Cranio-cervical posture and rapid palatal expansion therapy. *J Orthod Sci.* 2022;11:13. [CrossRef]
42. Serritella E, Migliaccio S, Musone L, Impellizzeri A, De Stefano AA, Galluccio G. Perceived pain during rapid maxillary expansion (RME): trends, anatomical distinctions, and age and gender correlations. *Pain Res Manag.* 2021;2021:7396466. [CrossRef]
43. Alhammadi MS, Almashraqi AA, Khadhi AH, et al. Orthodontic camouflage versus orthodontic-orthognathic surgical treatment in borderline class III malocclusion: a systematic review. *Clin Oral Investig.* 2022;26(11):6443-6455. Epub 2022 Sep 13. [CrossRef]

Appendix: https://d2v96fxpocvxx.cloudfront.net/90a4190a-90d9-41a4-a9c9-d78d3fa8efda/content-images/9ef152b8-dbab-45ea-b88b-cdb4c39dff03.pdf