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TURKISH JOURNAL OF ORTHODONTICS

Original Article

Does Lip Change Following Premolar Extraction Differ in Patients with High and Normal Vertical Growth Patterns?

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Main Points

- Lip changes following premolar extraction differ between patients with high and normal vertical growth patterns.
- Upper lip retraction is more pronounced in patients with a high vertical growth pattern.
- Vertical growth pattern and lip strain should be considered when predicting soft tissue response to extraction therapy.

ABSTRACT

Objective: To evaluate the relationship between incisor retraction and upper and lower lip repositioning in patients with high and normal vertical growth patterns (NVP), and to assess whether vertical growth pattern influences soft tissue changes following extraction treatments.

Methods: Pre- and post-treatment lateral cephalograms of 79 patients who underwent extraction of two or four first premolars were analyzed. Patients were divided into a [high vertical pattern (HVP); Frankfort-mandibular plane angle (FMA) >30°, n=49] and a NVP; 22< FMA ≤30°, n=30) group. Horizontal and vertical changes in the lips, labiomental fold, and lip strain were measured, and correlations between these changes and incisor movements were assessed.

Results: Upper lip retraction was greater in the HVP group (2.86 mm, $p<0.05$) than in the NVP group (1.97 mm, not significant). Upper lip height decreased significantly in both groups, with a slightly greater decrease in the NVP group ($p<0.001$). Upper lip strain decreased in both groups, especially in the HVP group ($p<0.001$). Incisor retraction was strongly correlated with upper-lip changes in both groups, and with lower-lip and labiomental-fold repositioning in the NVP group.

Conclusion: Soft tissue response to incisor retraction varies with vertical growth pattern, with greater upper lip retraction in HVP patients. Vertical growth patterns should be considered for optimal soft tissue outcomes.

Keywords: Orthodontic extraction, soft tissue profile, mandibular growth pattern, lip strain, labiomental fold

INTRODUCTION

People's appreciation of facial attractiveness has increased alongside the growing popularity of uploading photos to social media. Consequently, planning and outcomes of orthodontic treatments that may affect an individual's profile have become increasingly important owing to greater awareness of facial alterations. One of the orthodontic treatment modalities that has the greatest impact on profile is premolar extraction.[1] Premolars are most frequently extracted for orthodontic treatment.[2] Retraction of the anterior teeth is likely required following premolar extraction, resulting in noticeable changes in the anterior soft-tissue profile.

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Patients are often hesitant to undergo extractions, and clinicians try to avoid them; however, in certain cases, extractions are necessary. In patients with vertical growth patterns, the "drawbridge" or "de-wedging" effect of premolar extraction can reduce the vertical skeletal dimension, potentially conferring a clinical benefit.[3-5] However, possible effects of such treatment on the lips must also be considered. Studies examining incisor retraction and soft tissue changes have reported varying outcomes, suggesting that multiple factors influence the lip response.[6-12]

Lip competence also influences soft-tissue positions. It refers to the ability of the lips to maintain a seal at rest and is an important factor that can significantly affect soft-tissue positions.[13] Moreover, some researchers have shown that lip retraction is significantly more pronounced in patients with incompetent lips.[14]

Although studies have evaluated the profile according to vertical growth patterns, none have assessed soft tissue changes in the closed-lip position, which reflects how the lips are affected when maintaining a lip seal after orthodontic treatment involving extractions.

The craniofacial skeletal pattern is another factor influencing the soft tissue profile.[15,16] While differences in soft tissue thickness among various skeletal classifications have been documented,[17-19] the influence of vertical growth pattern on soft tissue changes following incisor retraction is not well established.

Therefore, this study aimed to evaluate the effects of incisor retraction on the closed-lip soft-tissue profile in patients with different vertical growth patterns and assess the role of lip competence in these changes. We hypothesized that the vertical growth pattern and lip competence significantly influence soft tissue changes following incisor retraction.

METHODS

The study protocol received approval from the Marmara University Non-Drug and Non-Medical Device Research Ethics Committee (approval no: 09.2024.673, date: 17.05.2024). A retrospective review of all electronic patient records from the Department of Orthodontics, Marmara University Faculty of Dentistry, was conducted for the period January 2008 to January 2023.

Inclusion criteria were non-growing patients (cervical vertebral maturation index stage 6, age ≥17) with no craniofacial anomalies or history of orthognathic surgery, who had class I or class II molar relationships and completed orthodontic treatment with extraction of two maxillary first premolars or four first premolars (two maxillary and two mandibular). All patients were treated with 0.018-inch slot Roth prescription Gemini brackets (3M Unitek, Monrovia, CA, USA). Initial space closure was performed with t-loops to distalize the canines segmentally. After completion of canine distalization, all posterior teeth were consolidated with a continuous figure-eight ligature. Retraction of the maxillary incisors was then carried out using 0.017×0.025-inch titanium-molybdenum alloy retraction arches. Pre-treatment (T0) and post-treatment (T1) lateral cephalometric radiographs were obtained with the lips closed. Patients with initial crowding ≥8 mm, >2° change in mandibular plane angle (SN-GoMe) during treatment, or any cosmetic procedure during treatment were excluded.

All cephalometric tracings and measurements were performed by a single investigator (E.B.) to ensure consistency. Intra-rater reliability was assessed by re-evaluating 20% of the sample after a two-week interval. Method error was calculated using Dahlberg's formula, and systematic error was evaluated using paired statistical tests. No statistically significant systematic error was detected ($p>0.05$).

The sample was divided into two groups based on the Frankfort-mandibular plane angle (FMA): patients with FMA >30° were classified as having a high vertical pattern (HVP) (n=49, mean age 24.2 years) and those with FMA ≥22° and ≤30° were classified as having a normal vertical growth pattern (NVP) (n=30, mean age 22.4 years). Patients with FMA <22° were not included in the present study.

For cephalometric analysis, a horizontal reference line, SN-7° (7° below the Sella-Nasion line through Sella), and a vertical line through Nasion perpendicular to it were used as the coordinate system.[20-22] Cephalometric landmarks and reference planes are shown in Figure 1, and variables are defined in Table 1. Lip strain was calculated using Holdaway's method[23] as the difference between basic lip thickness and actual lip thickness with the lips closed (Figure 2).

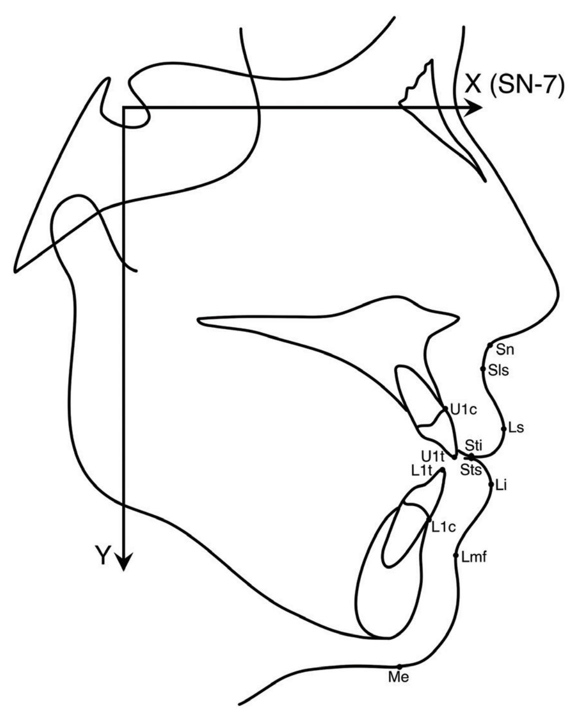

Figure 1. Cephalometric landmarks and reference planes.

Statistical Analysis

The data were analyzed using the statistical software IBM SPSS Statistics 27.0 (IBM Corp., Armonk, New York, USA). Normality of numerical variables was assessed using the Shapiro-Wilk test and Q-Q plots. Categorical variables were presented as frequencies and percentages. Descriptive statistics are given as mean ± standard deviation and median values. A paired-sample t-test was used to compare dependent continuous variables at T0 and T1 when the normality assumption was met; the Wilcoxon signed-rank test was used when it was not. The relationship between dental parameters and the T0-T1 difference in soft tissue parameters for groups NVP, HVP, and total patients was evaluated using Pearson's or Spearman's correlation analysis. A value of $p<0.05$ was considered statistically significant. Linear regression analyses were performed for the NVP and HVP groups to evaluate the associations between the horizontal movement of U1c and L1c and changes in soft-tissue variables, with regression coefficient (B), standard error, standardized beta coefficient, 95% confidence interval, and p-value reported.

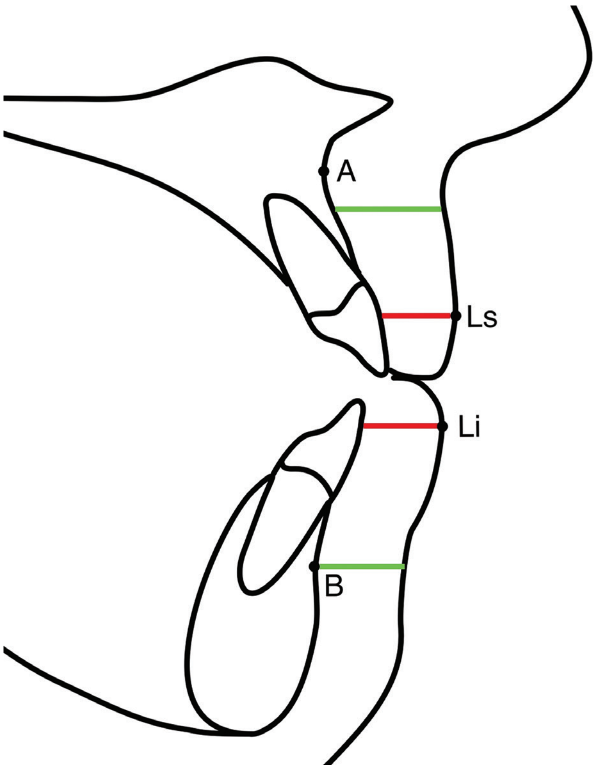

Figure 2. Green lines: Basic lip thickness in the closed lip position; Red lines: Lip thickness in the closed lip position.

RESULTS

There were no statistically significant differences between the HVP and NVP groups in baseline age or sagittal skeletal parameters ($p>0.05$). As expected, vertical skeletal measurements differed between groups due to the predefined classification criteria. The sex distribution across groups did not differ significantly ($p>0.05$).

Table 1. Hard-tissue and soft-tissue variables measured on the lateral cephalometric X-ray

Parameter (mm)	Description
yU1c	Distance from y line to the upper incisor's cervical point
yU1t	Distance from y line to the upper incisor's tip
yL1c	Distance from y line to the lower incisor's cervical point
yL1t	Distance from y line to the lower incisor's tip
ySls	Distance from y line to the deepest point of upper lip
yLs	Distance from y line to the most anterior point of upper lip
xU1c	Distance from x line to the upper incisor's cervical point
xU1t	Distance from x line to the upper incisor's tip
xL1c	Distance from x line to the lower incisor's cervical point
xL1t	Distance from x line to the lower incisor's tip
xSls	Distance from x line to the deepest point of upper lip
xLs	Distance from x line to the most anterior point of upper lip
Ls-U1c	Distance from the most anterior point of upper incisor's cervical point (upper lip thickness)
Sn-Sts	Distance from subnasale to stomion superior (upper lip height)
Upper lip strain	Difference between upper lip thickness and basic upper lip thickness
yLi	Distance from y line to the most anterior point of lower lip
ylmf	Distance from y line to the deepest point of labiomental fold
xLi	Distance from x line to the most anterior point of lower lip
xlmf	Distance from x line to the deepest point of labiomental fold
Li-L1c	Distance from the most anterior point of lower incisor's cervical point (lower lip thickness)
Sti-Me'	Distance from subnasale to stomion superior (lower lip height)
Lower lip strain	Difference between lower lip thickness and basic lower lip thickness

Descriptive statistics of pre- and post-treatment measurements are presented in Table 2. There were no significant changes in the mandibular plane angle during treatment in either the NVP or HVP group (NVP: p=0.184; HVP: p=0.855).

In both groups, the upper incisor cervical points moved significantly posteriorly (~2 mm; p<0.05) and slightly inferiorly. The upper incisor tips also moved posteriorly in both groups, with greater retraction in the HVP group (p<0.001). The cervical points of the lower incisors moved posteriorly in the NVP group (p=0.038). The cervical points of the lower incisors moved slightly downward in the NVP group (p=0.038).

In the HVP group, the upper lip moved 2.86 mm backward (p<0.05) (Table 3). Upper lip thickness increased in both groups after treatment (p<0.05). The labiomental fold moved posteriorly in the NVP group (2.5 mm, p=0.027).

Upper lip height decreased significantly in both groups (HVP: -1.94 mm, NVP: -2.23 mm; p<0.001). The vertical position of the upper lip did not change significantly in either group (HVP: +0.73 mm, p=0.453; NVP: -0.80 mm, p=0.290). Similarly, the vertical position of the lower lip showed no significant change (HVP: +0.47 mm, p=0.509; NVP: -0.31 mm, p=0.757). The vertical position of the labiomental sulcus remained unchanged in both groups.

Upper lip strain decreased significantly in both groups, with a larger reduction in HVP (-3.72 mm) than in NVP (-2.84 mm) (p<0.001 for both). Lower lip strain increased slightly in the HVP group (+0.90 mm, p=0.014).

Correlation coefficients between dental and soft-tissue changes are presented in Table 4. In NVP, horizontal incisor retraction was strongly correlated with the posterior movements of the lower lip and the labiomental fold (correlation coefficients

Table 2. Statistical comparisons by T0-T1 changes in skeletal and dental parameters in NVP and HVP groups

	NVP (n=30)				HVP (n=49)			
	T0	T1	T0- T1 difference	p-value	T0	T1	T0- T1 difference	p-value
Skeletal parameters								
GoMe-SN (°)	37.00 (5.00)	38.00 (5.25)	0.00 (4.00)	0.184+	44.77±4.77	44.67±6.22	0.10±3.90	0.855
Dental parameters								
Open bite (mm)	-0.20 (1.78)	1.65 (1.20)	0.00 (4.00)	<0.001+	-1.00 (2.30)	1.60 (1.30)	-2.70 (2.50)	<0.001+
Upper dental								
x U1c	41.80±4.37	43.27±3.76	-1.47±3.29	**0.021***	45.60±4.98	46.90±4.70	-1.40±4.21	**0.030***
y U1c	67.79±6.70	65.28±5.80	2.51±5.78	**0.024***	67.48±7.38	65.43±7.49	2.06±5.79	**0.017***
x U1lt	53.07±4.71	54.07±4.16	-0.99±3.40	0.184*	56.90±5.52	57.63±5.08	-0.82±4.23	0.235*
y U1lt	68.41±7.28	65.28±6.38	3.13±6.56	**0.014***	68.10±8.02	64.77±7.91	3.31±6.30	**<0.001***
Lower dental								
x L1t	52.89±4.81	51.94±4.07	0.95±3.58	0.155*	57.20 (6.30)	54.30 (6.00)	2.59±5.62	**<0.001+**
y L1t	65.12±7.39	62.55±6.05	2.57±5.14	**0.010***	62.64±7.87	61.35±7.89	1.38±6.13	0.123*
x L1c	61.05±5.77	60.23±4.43	0.83±5.65	0.430*	66.76 (6.58)	62.50 (5.98)	2.42±4.36	**<0.001+**
y L1c	63.63±7.63	61.52±6.75	2.11±5.32	**0.038***	60.38±7.82	59.98±8.11	0.52±5.99	0.547*

*Paired sample t test.
+Wilcoxon Sign-Rank test.
Values are presented as mean ± standard deviation or median. Bold values indicate statistically significant differences. Statistical significance: p<0.05.
NVP, normal vertical growth pattern; HVP, high vertical growth pattern.

Table 3. Statistical comparisons by T0-T1 changes in soft tissue parameters in NVP and HVP groups

	NVP (n=30)				HVP (n=49)			
Soft tissue parameters	T0	T1	T0- T1 difference	p-value	T0	T1	T0- T1 difference	p-value
Upper lip								
xSls	38.43±4.44	39.00±4.22	-0.57±4.13	0.453*	41.12±4.34	40.73±4.65	0.39±4.29	0.525*
ySls	79.27±6.99	77.07±6.32	2.20±6.56	0.076*	79.22±7.51	77.73±8.03	1.49±6.46	0.114*
xLs	45.60±5.05	46.40±3.76	-0.80±4.04	0.290*	48.79 (7.28)	48.25 (7.23)	0.16 (4.74)	0.453+

Table 3. Continued

	NVP (n=30)				HVP (n=49)			
Soft tissue parameters	T0	T1	T0- T1 difference	p-value	T0	T1	T0- T1 difference	p-value
yLs	81.15±7.46	79.18±7.00	1.97±6.97	0.132*	81.47 (8.76)	78.61 (12.86)	1.84 (6.64)	**0.006⁺**
Ls-U1c (Upper lip thickness)	12.07±2.17	13.01±2.08	-0.94±2.53	**0.050***	12.20±2.19	13.34±2.52	-1.14±2.50	**0.002***
Sn-Sts (Upper lip height)	23.80±3.50	21.57±3.05	2.23±2.81	**<0.001***	24.24 (4.19)	22.30 (3.95)	1.34±4.05	**<0.001⁺**
Upper lip strain	-2.84 (3.61)	-1.35 (1.95)	-1.18 (3.14)	**<0.001⁺**	-3.72 (4.07)	-1.12 (2.49)	-2.51 (4.92)	**<0.001⁺**
Lower lip & Chin								
xLi	61.97±6.03	62.27±4.78	-0.31±5.37	0.757*	66.06±6.07	65.59±6.15	0.47±4.99	0.509*
yLi	77.52±8.32	75.28±7.39	2.24±6.42	0.066*	75.75±8.34	74.27±9.21	1.48±7.01	0.146*
xLmf	71.04±6.97	71.39±5.62	-0.35±5.58	0.731*	75.47±7.24	75.16±7.32	0.30±4.39	0.631*
yLmf	69.69±8.59	67.19±7.93	2.50±5.88	**0.027***	66.41±8.19	64.76±9.08	1.66±6.97	0.102*
Li_L1c (lower lip thickness)	14.26 (4.85)	15.32 (3.93)	-0.53 (5.08)	0.360⁺	14.84 (4.35)	15.75 (3.64)	-0.24 (3.37)	0.280⁺
St-Me ' (lower lip height)	51.50 (6.45)	51.41 (5.11)	0.30 (6.81)	0.629⁺	56.00 (7.84)	55.87 (6.95)	1.15 (6.45)	0.117⁺
Lower lip strain	1.95 (3.21)	2.57 (2.26)	-0.62 (3.62)	0.329⁺	1.23 (3.70)	2.52 (4.21)	-1.11 (3.72)	0.014⁺

*Paired sample t test.
⁺Wilcoxon Sign-Rank test.
Values are presented as mean ± standard deviation or median. Bold values indicate statistically significant differences. Statistical significance: p<0.05.
NVP, normal vertical growth pattern; HVP, high vertical growth pattern.

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Table 4. Relationship between dental parameters and soft tissue parameters T0-T1 difference for group HVP and NVP

HVP			Soft tissue parameters				
Dental parameters			Upper lip				Lower lip & Chin
	Variables		yLs*	Ls-U1c⁺	Sn-Sts*	Upper lip strain⁺	Lower lip Strain⁺
Upper dental	xU1c⁺	r	0.164	0.223	0.156	0.026	0.179
		p-value	0.259	0.123	0.285	0.858	0.218
	yU1c*	r	0.850	0.299	0.355	0.002	-0.030
		p-value	**<0.001**	**0.039**	**0.013**	0.989	0.838
	y U1t*	r	0.813	0.196	0.307	-0.041	-0.001
		p-value	**<0.001**	0.177	**0.032**	0.777	0.995
Lower dental	x L1t*	r	0.261	0.107	0.226	-0.009	-0.024
		p-value	0.070	0.466	0.118	0.951	0.868
	x L1c*	r	0.293	0.166	0.242	-0.088	0.113
		p-value	**0.041**	0.255	0.094	0.546	0.438
NVP	Variables		-	Ls-U1c⁺	Sn-Sts⁺	Upper lip strain*	ylmf⁺
Upper dental	xU1c	r	-	0.290	0.563	-0.082	0.536
		p-value	-	0.120	**0.001**	0.669	**0.002**
	yU1c	r	-	0.140	0.619	-0.250	0.900
		p-value	-	0.462	**<0.001**	0.182	**<0.001**
	yU1t	r	-	0.081	0.575	-0.378	0.892
		p-value	-	0.669	**<0.001**	**0.039**	**<0.001**
Lower dental	yL1t	r	-	0.124	0.410	-0.254	0.936
		p-value	-	0.513	**0.025**	0.175	**<0.001**
	yL1c	r	-	0.097	0.384	-0.267	0.950
		p-value	-	0.609	**0.036**	0.154	**<0.001**

⁺Pearson correlation coefficients; *Spearman correlation coefficients. Bold values indicate statistically significant differences. Statistical significance: p<0.05.
NVP, normal vertical growth pattern; HVP, high vertical growth pattern.

Table 5. Regression models for the horizontal movement of U1c and soft-tissue variables in NVP and HVP groups

NVP	Unstandardized coefficients		Standardized coefficients	Variation (mm) with each mm of yU1c movement	p-value	95% CI for B
Variables	B	SE	Beta			
yLs	0.805	0.062	0.925	0.855	**<0.001**	0.679; 0.931
yLi	0.864	0.062	0.933	0.870	**<0.001**	0.738; 0.991
SnSts	1.215	0.234	0.695	0.482	**<0.001**	0.737; 1.693
Ls-U1c	-0.057	0.433	-0.024	0.001	0.897	-0.943; 0.830
Upper lip strain	-0.876	0.340	-0.432	0.187	**0.015**	-1.570; -0.181
HVP						
yLs	0.629	0.062	0.827	0.685	**<0.001**	0.503; 0.754
yLi	0.806	0.047	0.929	0.863	**<0.001**	0.712; 0.901
SnSts	0.358	0.205	0.246	0.061	0.088	-0.055; 0.771
Ls-U1c	0.370	0.320	0.166	0.028	0.255	-0.275; 1.014
Upper lip strain	-0.243	0.234	-0.150	0.022	0.304	-0.713; 0.227

Bold values indicate statistically significant differences. Statistical significance: p<0.05.
NVP, normal vertical growth pattern; HVP, high vertical growth pattern; CI: confidence interval.

Table 6. Regression models for the horizontal movement of L1c and soft-tissue variables in NVP and HVP groups

NVP Variables	Unstandardized coefficients		Standardized coefficients	Variation (mm) with each mm of yL1c movement	p-value	95% CI for B
	B	SE	Beta			
yLi	0.772	0.063	0.916	0.840	**<0.001**	0.679; 0.931
Li-L1c	0.014	0.086	0.030	0.001	0.874	-0.163; 0.190
ylmf	0.858	0.048	0.957	0.917	**<0.001**	0.760; 0.957
Sti-Me'	0.241	0.099	0.412	0.170	0.021	0.038; 0.443
Lower lip strain	-0.005	0.080	-0.011	0.000	0.955	-0.168; 0.159
HVP						
yLi	0.791	0.041	0.942	0.888	**<0.001**	0.709; 0.873
Li-L1c	0.122	0.335	0.052	0.003	0.718	-0.552; 0.796
ylmf	0.779	0.045	0.928	0.862	**<0.001**	0.689; 0.870
Sti-Me'	0.092	0.099	0.133	0.018	0.358	-0.107; 0.290
Lower lip strain	-0.430	0.319	-0.191	0.037	0.184	-1.071; 0.211

Bold values indicate statistically significant differences. Statistical significance: p<0.05.
NVP, normal vertical growth pattern; HVP, high vertical growth pattern; CI: confidence interval.

~0.9). In HVP, upper lip retraction was strongly correlated with maxillary incisor retraction (r ~0.8). Results of the regression analysis are presented in Tables 5 and 6.

DISCUSSION

Extraction of premolars and retraction of anterior teeth are known to affect the facial profile, but growth status and skeletal patterns can modulate the soft tissue response.[24-27] To isolate the effects of tooth movement, we included only non-growing adult patients in this study, eliminating growth-related changes.[28,29]

In the present study, patients were not subdivided according to extraction pattern, as the primary objective was to evaluate the influence of vertical growth pattern on soft tissue response. This approach is supported by the findings of Albertini et al.,[30] who reported that extraction pattern did not significantly influence soft tissue profile changes following premolar extraction therapy.

Previous studies have often used the incisal tip or soft-tissue points to assess tooth-lip relationships. However, some findings suggest that measurements at the incisor's cervical point may better capture the effect of tooth movement on upper lip position.[29,31] Ramos et al.[32] found a significant correlation between upper lip retraction and retraction of the upper incisor's cervical point. Hayashida et al.[33] similarly reported significant correlations between upper lip movement and upper incisor retraction. In our study, we evaluated both the incisal tip and the cervical point of the incisors as reference landmarks for tooth movement, since lower lip position can also be influenced by the upper incisal tip position.[34]

In our study, the backward movement of the upper teeth at the cervical level was found to be statistically significant in both the HVP (2.05 mm) and NVP (2.51 mm) groups. Qadeer et al.[14] conducted a comparative analysis of groups with competent and incompetent lips in their premolar extraction study, revealing a 1.4 mm retraction in the competent group, whereas the incompetent group exhibited a retraction of 3.39 mm. The reason for the incompetency in their group may be an increased proclination of the incisors; thus, they might require more retraction. In our study, both groups exhibited lip incompetence, and a similar degree of retraction (1.47 mm in the HVP group and 1.40 mm in the NVP group) was observed.

In the HVP group, upper lip retraction (2.86 mm) was statistically significant, whereas in the NVP group, upper lip retraction (1.97 mm) was not statistically significant. This difference in soft tissue response might be attributable to differences in lip strain between the groups. Fang et al.[35] observed that patients with lip incompetence experience greater retraction of the lips after incisor retraction than those with competent lips. The HVP group in our study had higher initial lip strain (greater lip incompetence) than the NVP group. This higher initial lip strain likely contributed to the greater retraction of the upper lip observed in the HVP group.

The only soft-tissue vertical dimension that changed significantly was upper-lip height, which decreased in both groups. This likely reflects improved lip competence: patients who initially had lip separation at rest could comfortably close their lips after treatment, thereby effectively shortening the upper lip at rest. However, because all cephalograms were taken with the lips closed, these vertical changes should be interpreted cautiously. The initial closed-lip position at T0 required some patients to stretch their lips; thus, the measured reduction in Sn-Sts primarily indicates a reduction in lip strain rather than true tissue shortening.

We also observed that upper lip thickness increased after treatment in both groups, while changes in lower lip thickness were minimal and not significant. These outcomes are consistent with the reduction in lip strain; at T0, some patients' lips were stretched thin to achieve closure, and after treatment, the lips relaxed and became slightly thicker. This also suggests that the upper lip undergoes greater elongation and thinning than the lower lip to achieve a lip seal in patients with lip incompetence.

Although there were no skeletal vertical changes in our patients, lip strain decreased after incisor retraction. This suggests that the improved lip seal was due to dental changes rather than alterations in vertical skeletal dimensions. Lee et al.[36] similarly found that the inclination and anteroposterior position of maxillary incisors affected upper lip strain more than the vertical skeletal pattern.

In our study, the labiomental sulcus deepened significantly with incisor retraction in the NVP group, whereas no significant change occurred in the HVP group. This is in line with Baek et al.[37] found that younger patients with more elastic soft tissue show greater fold deepening after retraction, whereas patients with less elasticity show minimal change. The higher initial lip strain in the HVP group suggests reduced soft tissue elasticity, which could explain the limited change in their labiomental fold.

Several studies have quantified soft tissue response relative to incisor retraction.[32,33,36,37] In our study, the ratio of upper incisor retraction at the cervical point to upper lip retraction was approximately 1:0.85 in NVP and 1:0.68 in HVP; the lower lip response was about 1:0.86 in both groups. Thus, the upper lip showed a greater change per unit of incisor retraction in the NVP group than in the HVP group. In HVP patients, the upper lip may initially have been stretched and thinned to ensure closure; when lip strain was relieved after retraction, the lip became shorter and thicker, possibly shifting slightly forward. This would reduce the net posterior movement of the upper lip in HVP patients compared with that in NVP patients.

The morphology of the labiomental fold is a prominent aesthetic feature of the facial profile that often captures the attention of observers assessing the lower face.[38] As its position and movement are influenced by various anatomical factors, understanding these relationships is essential. In our study, within the NVP group, a strong positive correlation was found between the horizontal displacement of the labiomental fold and the horizontal movements of both the cervical point and the incisor tip. However, regression analysis (Tables 5 and 6) revealed that despite this correlation, the horizontal position of the labiomental fold was more significantly influenced by other factors, such as the horizontal movement of the lower lip, than by the cervical point or the incisor tip. A similar pattern was observed in the HVP group, where the horizontal position of the labiomental fold was predominantly influenced by the movement of the lower lip, although the cervical point and incisor tip were also somewhat correlated. These findings are particularly relevant in the context of facial aesthetics. A deeper labiomental fold may enhance attractiveness in individuals with increased lower anterior facial height, as it helps deemphasize that lower facial height. Conversely, a shallower fold may be preferred in individuals with shorter faces, as a deeper fold could further accentuate facial shortness.[38] In our study, both groups exhibited greater posterior displacement of the labiomental fold relative to the lower lip, leading to its deepening. This change may contribute to an improvement in aesthetic outcomes, particularly for individuals in the HVP group.

Study Limitations

In the present study, no formal correction for multiple comparisons was applied to secondary analyses; this may increase the risk of type I error. Additionally, soft tissue changes were evaluated using two-dimensional lateral cephalometric radiographs obtained in a closed-lip position. Two-dimensional imaging does not fully capture the three-dimensional behavior and volumetric changes of the soft tissues. Therefore, the findings should be interpreted within the limitations inherent to two-dimensional assessment. Future studies using radiation-free stereophotogrammetric techniques capable of capturing images in both open- and closed-lip positions may offer a more comprehensive assessment of soft tissue responses.

CONCLUSION

In patients with a HVP, upper lip retraction following incisor retraction was significantly greater than in patients with a NVP. Upper lip strain was reduced in both groups after treatment, with a more pronounced reduction in the HVP group. The labiomental sulcus deepened significantly in the NVP group, and strong correlations were observed between lower incisor retraction and changes in the labiomental sulcus. A stronger correlation between maxillary incisor retraction and upper lip retraction was observed in the NVP group than in the HVP group. These findings suggest that the vertical growth pattern should be considered when planning the degree of incisor retraction to achieve the desired soft-tissue profile changes without adversely affecting facial aesthetics.

Ethics

Ethics Committee Approval: The study protocol received approval from the Marmara University Non-Drug and Non-Medical Device Research Ethics Committee (approval no: 09.2024.673, date: 17.05.2024).

Informed Consent: Written and informed consents were previously signed by the participants.

Footnotes

Author Contributions: Concept – B.E., E.B.; Design – B.E., E.B.; Data Collection and/or Processing – B.E., E.B.; Analysis and/or Interpretation – B.E., E.B., B.Em,;Literature Search – B.E., E.B.; Writing – B.E.

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Original Article

Assessing Best Locations for Mini-Implants in the Mandibular Symphysis Based on Different Mandibular Growth Patterns: A CBCT Study

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Main Points

- The mandibular symphysis is a reliable site for orthodontic mini-implant placement.
- Low-angle growth patterns exhibit greater complete and cortical bone width.
- Bone thickness increases with greater insertion depth and angulation.

ABSTRACT

Objective: The aim was to evaluate optimum site for insertion of orthodontic mini-implants at mandibular symphysis in patient with different mandibular growth patterns using cone-beam computed tomography (CBCT). The objectives were to evaluate and measure complete bone width (CBW) and cortical bone width (CtBW) in the symphysis area at various heights [2 mm, 4 mm, 6 mm, 8 mm, 10 mm, and 12 mm from cementoenamel junction (CEJ)] and at various angles (0º, 10º, 20º, 30º, 40º, 50º, and 60º to the occlusal plane), and to assess the effect of mandibular growth patterns (low, average, and high angle) on these measurements.

Methods: The study sample included 45 patients aged 16-30 years. Patients were categorized into three groups (n=15) corresponding to the mandibular growth pattern for the assessment of CBW and CtBW. Individual data for each patient were entered into a master table in Microsoft Excel and subjected to statistical analysis using SPSS version 22.0. Analysis of variance was applied to investigate the influence of insertion location, facial type, insertion height and insertion angle on overall bone thickness and CtBW. A p-value <0.05 was considered statistically significant. Intra-observer reliability was assessed using the intraclass correlation coefficient.

Results: CBW was notably greater in patients with a low-angle mandibular growth pattern than in patients with other mandibular growth patterns at insertion heights of 8, 10, and 12 mm. CtBW was greater in cases with a low-angle mandibular growth pattern than in cases with other mandibular growth patterns. Similar results were observed for CtBW.

Conclusion: The mandibular symphysis in patients with a low-angle growth pattern provides more favorable anatomical conditions for mini-implant placement. The ideal insertion site lies between 6 and 10 mm below the CEJ of the central incisors, with angulation ranging from 0° to 60° relative to the occlusal plane. CBCT assessment should be considered essential in treatment planning to customize implant positioning based on individual growth patterns, thereby enhancing implant stability and success.

Keywords: Orthodontic mini-implants, CBCT, mandibular symphysis, cortical bone, occlusal plane

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INTRODUCTION

Orthodontic mini-implants, also known as temporary anchorage devices have become indispensable tools in modern orthodontics due to their ability to provide absolute anchorage and support for complex tooth movements without relying on patient compliance.[1] These devices have revolutionized biomechanical planning, allowing greater control and precision in tooth movements such as molar distalization, anterior retraction, intrusion of overerupted teeth, midline correction, and en masse retraction.[2]

The mandibular symphysis region, offers a strategic site for mini-implant placement, especially in cases where traditional inter-radicular spaces are inadequate or at high risk for root damage.

Clinical applications include intrusion of lower anterior teeth, correction of incisor proclination, management of anterior open bite cases, torque control during camouflage treatment, and en masse anterior retraction.

Despite the biomechanical benefits, mini-implant placement in the anterior mandible is often limited by narrow interradicular spaces and close proximity to dental roots.[3] Historically, most research has focused on interradicular areas, which are commonly considered contraindicated for implant placement in the anterior mandible because of spatial limitations.[4]

Recent studies suggest that the mandibular symphysis possesses a thick layer of cortical bone and favorable bone morphology that can support mini-implants without compromising dental or periodontal structures.[1] However, bone morphology in the symphysis is not uniform across individuals. Growth pattern variations-particularly vertical skeletal discrepancies-can significantly influence both cortical and medullary bone characteristics.

According to Handelman et al.,[5] patients with a low plane (MP) angle typically exhibit greater cortical bone thickness, particularly on the lingual side, while high-angle individuals tend to have thinner alveolar bone on the labial aspect of the symphysis. These variations are clinically relevant, as bone thickness directly affects primary stability, a key determinant of mini-implant success.

Although cone-beam computed tomography (CBCT) has become the gold standard for assessing alveolar bone dimensions and quality,[6] there is limited literature evaluating the mandibular symphysis region as a site for mini-implant placement across different mandibular growth patterns.

The focus of the study is to evaluate the optimal site for insertion of an orthodontic mini-implant at the mandibular symphysis in patients with different mandibular growth patterns using CBCT, with the objective of evaluating and measuring complete bone width (CBW) and cortical bone width (CtBW) in the mandibular symphysis at different heights [2 mm, 4 mm, 6 mm, 8 mm, 10 mm, and 12 mm from cementoenamel junction (CEJ)] and angles (0º, 10º, 20º, 30º, 40º, 50º and 60º to the occlusal plane).

METHODS

This research obtained approval from the Rungta College of Dental Sciences and Research Institute Institutional Ethical Committee (approval no: RCDSR/IEC/MDS/2022/D-11, date: 29.05.2023). The study involved 45 patients aged between 16-30 years attending the outpatient Rungta College of Dental Sciences and Research, Department of Orthodontics and Dentofacial Orthopaedics, Bhilai, India. Consent was secured from the patients themselves or from their guardians; for those under 18 years old, additional consent was obtained from parents.

Each patient underwent a lateral cephalogram and a CBCT scan using the cephalostat machine (NewTom GiANO HR 3D CEPH-CBCT Machine from Imola, Italy). The settings of the scanner were as follows: 85 kV, 5.0 mA, exposure time of 17.5 s, and a field of view of 8×8 cm or 10×10 cm, resulting in voxel sizes of 0.165 mm and 0.25 mm, respectively. Inclusion criteria included fully erupted mandibular incisors and the absence of hereditary or developmental craniofacial abnormalities. Exclusion criteria included dental implants and missing incisors and canines in the mandibular anterior arch, indeterminate CBCT and lateral cephalogram images, a history of bone metabolism-related conditions, and previous orthodontic treatment.

Data Collection

This was a descriptive cross-sectional study employing purposive sampling. Patients were categorized into three groups based on their mandibular growth pattern as observed on lateral cephalograms: Group A [low-angle mandibular growth pattern; frankfort horizontal-MP (FH-MP) angle <22°], Group B (average-angle mandibular growth pattern; FH-MP angle 22°-28°), and Group C (high-angle mandibular growth pattern; FH-MP angle >28°).

The sample size was calculated using G*Power software (version 3.1.9.2) based on data from Hoang et al.[7] An a priori power analysis was performed using a two-tailed test with an alpha level of 0.05, a beta level of 0.20 (power=80%), and an effect size of 1.11. The analysis indicated that at least 14 subjects per group were required to detect statistically significant differences. To ensure equal representation across the three mandibular growth pattern groups and to strengthen statistical reliability, the total sample size was rounded up to 45 participants, with 15 individuals allocated to each group.

Method of Measurement

CBW is the measurement between the labial and lingual edges of the bone, or between the lamina dura and the labial edge of the bone where it meets the tooth root. CtBW was measured between the outer and inner sides of the labial cortical plate (Figure 1). Complete and CtBWs were evaluated using CBCT with a slice thickness of 1 mm. Measurements were taken at seven anatomical locations using the Federation Dentaire

Internationale tooth numbering system: 42 (along the long axis of the right lateral incisor), 41-42 (between the right central and lateral incisors), 41 (along the long axis of the right central incisor), 41-31 (between the right and left central incisors), 31 (along the long axis of the left central incisor), 31-32 (between the left central and lateral incisors), and 32 (along the long axis of the left lateral incisor). These locations correspond to D, C, B, A, B', C', and D' respectively (Figure 2). Each location was measured at six heights (2 mm, 4 mm, 6 mm, 8 mm, 10 mm, and 12 mm from the CEJ) and seven angles (0°, 10°, 20°, 30°, 40°, 50°, and 60° to the occlusal plane) (Figure 3).

For assessment of the mandibular symphysis, a longitudinal slice was positioned along the mandibular midline (Figure 4). Symphysis height was recorded from the midpoint of the anterior alveolus (Idm) to menton (Me), while symphysis width was recorded from the buccal pogonion (Pog) to the lingual Pogl (Figure 5). Subsequently, the height-to-width ratio of the symphysis was computed (Figure 6).

Statistical Analysis

Statistical was performed using SPSS version 22 (IBM, Corporation, Armonk, New york, USA). Analysis of variance (ANOVA) was applied to investigate the influence of insertion location, facial type, insertion height, and insertion angle on overall bone thickness and CtBW. A p-value less than 0.05 was considered statistically significant. Also symphysis height and width ratio was significant. After a two-week interval, twenty percent of the sample were randomly selected for repeated measurements by the same investigator to assess intra-observer reliability using the intraclass correlation coefficient.

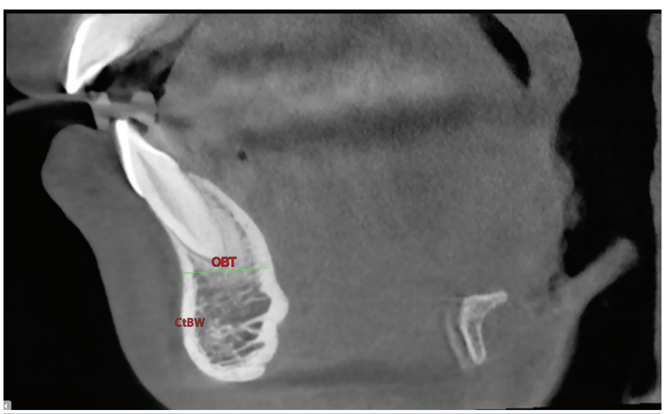


Figure 1. OBT and CtBW between the incisors.
OBT, overall bone thickness; CtBW, cortical bone width.

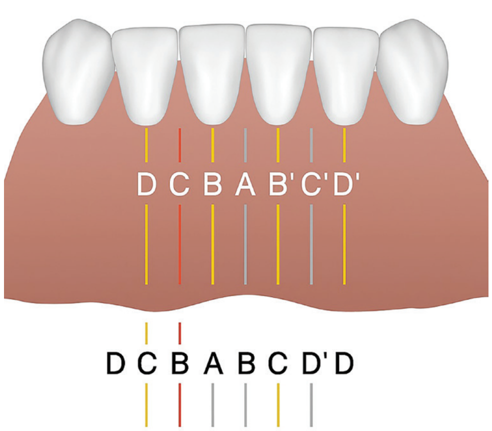


Figure 2. Different locations for placement of orthodontic mini-implants.

RESULTS

No statistically significant differences were found between the right and left sides for CBW and CtBW at any of the seven locations (A, B, C, D, B', C', and D'). Therefore, data from both sides were combined, and the analysis focused on four locations (A, B, C, and D).

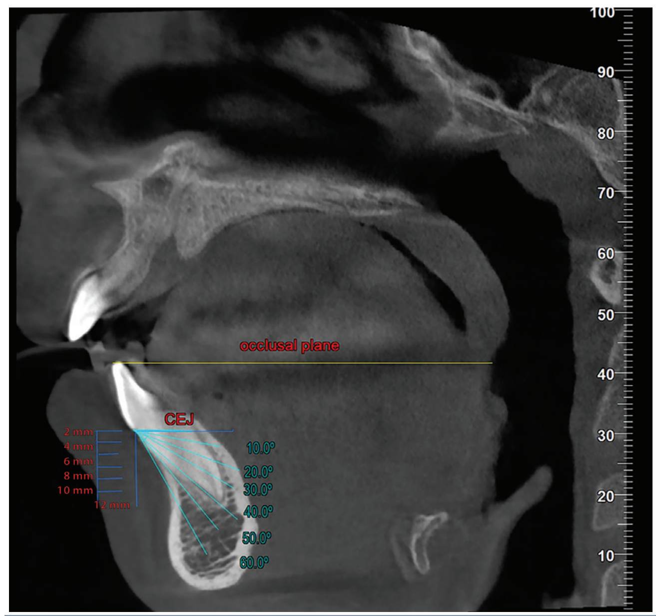


Figure 3. Different heights and angulations for placement of orthodontic mini-implant.
CEJ, cementoenamel junction.

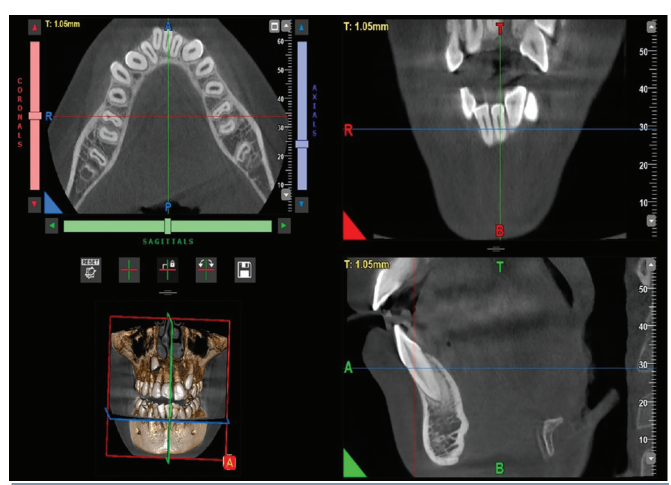


Figure 4. Symphysis dimension measurements, a sagittal slice was placed along the mandibular plane.

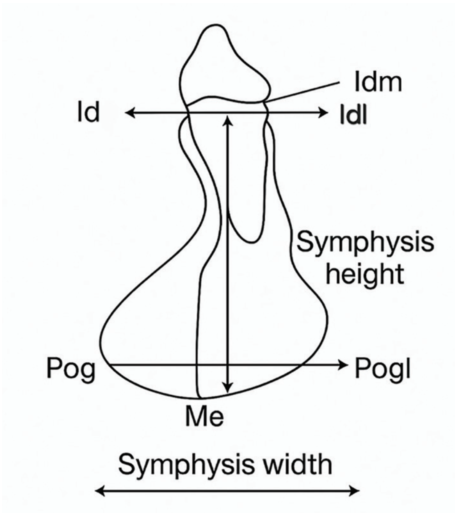


Figure 5. Sagittal cross section of the mandibular symphysis displaying symphysis region landmarks and variables.

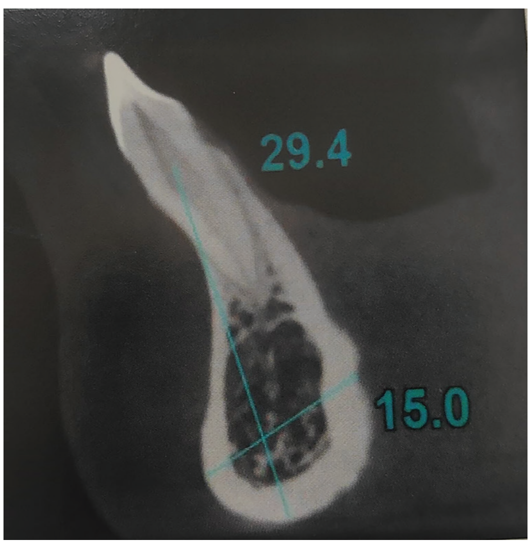


Figure 6. Symphysis height and width ratio.

- **Comparisons of CBW and CtBW among different mandibular growth patterns**

CBW was greater in cases with a low-angle mandibular growth pattern than in those with average- and high-angle mandibular growth patterns. This difference was observed at location A for insertion heights of 6, 8, 10, and 12 mm, and at location C for insertion heights of 4, 8, 10, and 12 mm. Almost identical results were observed for CtBW at locations B (10 and 12 mm) and D (6, 10, and 12 mm), as detailed in Graph 1.

- **Comparison of CBW and CtBW at different insertion locations and insertion angles**

Tukey's post hoc test revealed differences in CBW among the four insertion locations. It was highest at location A, with width measurements in descending order: A > C > B > D, as shown in Graph 1. Similar findings were observed for CtBW, except that no such variation was observed between locations A and C. The thickness order was A > C > B > D, as shown in Graph 1. Specifically, CBW was uniform across the four insertion locations at a height of 12 mm, but varied at heights below 12 mm. CBW increased with higher insertion angles at all locations except at the 2 mm insertion height, as illustrated in Graph 2. Similar trends were observed for CtBW, as depicted in Graph 3.

- **Comparison of symphysis dimensions among different mandibular growth patterns**

One-way ANOVA indicated a significant difference in the symphysis height-width ratio among mandibular growth patterns. The ratio in cases with a low-angle mandibular growth pattern was lower than that of cases with average- and highangle mandibular growth patterns, as shown in Graph 4.

DISCUSSION

Mini-implants are commonly used in the anterior mandible (mandibular symphysis) to intrude incisors.[1] However, their clinical application is often limited in cases of anterior crowding due to a interradicular space.[3]

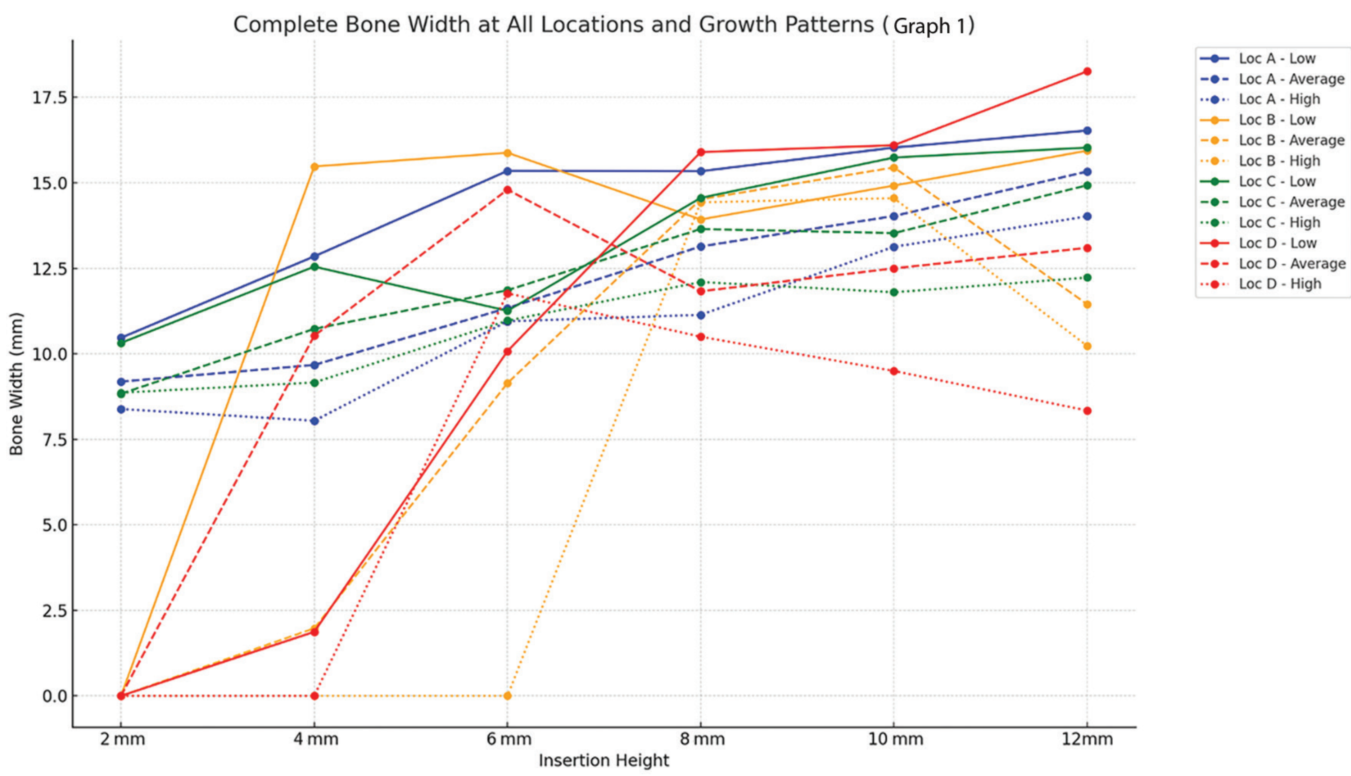
This study found no significant differences in CBW or CtBW (CtBW) between the right and left sides across seven evaluated locations (A, B, C, D, B', C', and D'). These findings are consistent with those of Zhang et al.,[1] supporting the anatomical symmetry of the anterior mandibular region and confirming its suitability for bilateral implant placement.

Alveolar bone width is known to vary with mandibular growth patterns. Our results revealed that both CBW and CtBW were significantly greater in patients with low-angle mandibular growth patterns than in those with average- or high-angle patterns. This observation supports the findings of Hoang et al.,[7] but contrasts with those of Sadek et al.,[8] potentially due to differences in insertion depth or landmark selection between the studies.

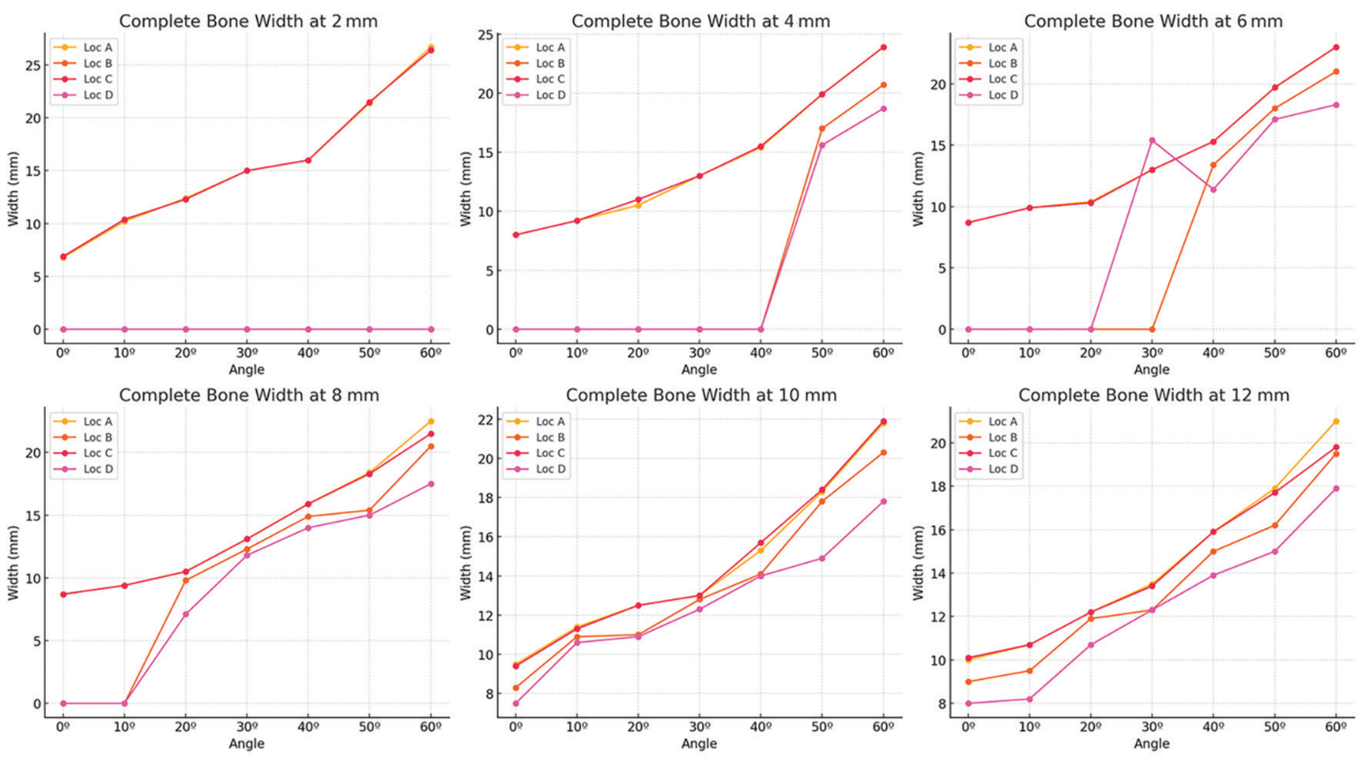
Across all locations, CBW and CtBW were lowest at point D and highest at point A. This pattern reflects the natural fusion and lateral growth of the mandibular symphysis, where bone tends to be thickest at the midline and thins toward the lateral regions. Specifically, CBW followed the order A > C > B > D up to a depth of 10 mm. Beyond 12 mm, bone width was more uniform, likely due to reduced influence of dental roots.

Interdental regions (locations A and C) consistently exhibited higher CBW than root-adjacent locations (B and D), in which the presence of roots limited bone volume. At depths beyond 12 mm, root interference decreased, resulting in more consistent bone width across all locations. A similar trend was noted for CtBW, which was thinner at root-adjacent sites and thicker in interdental areas.[1]

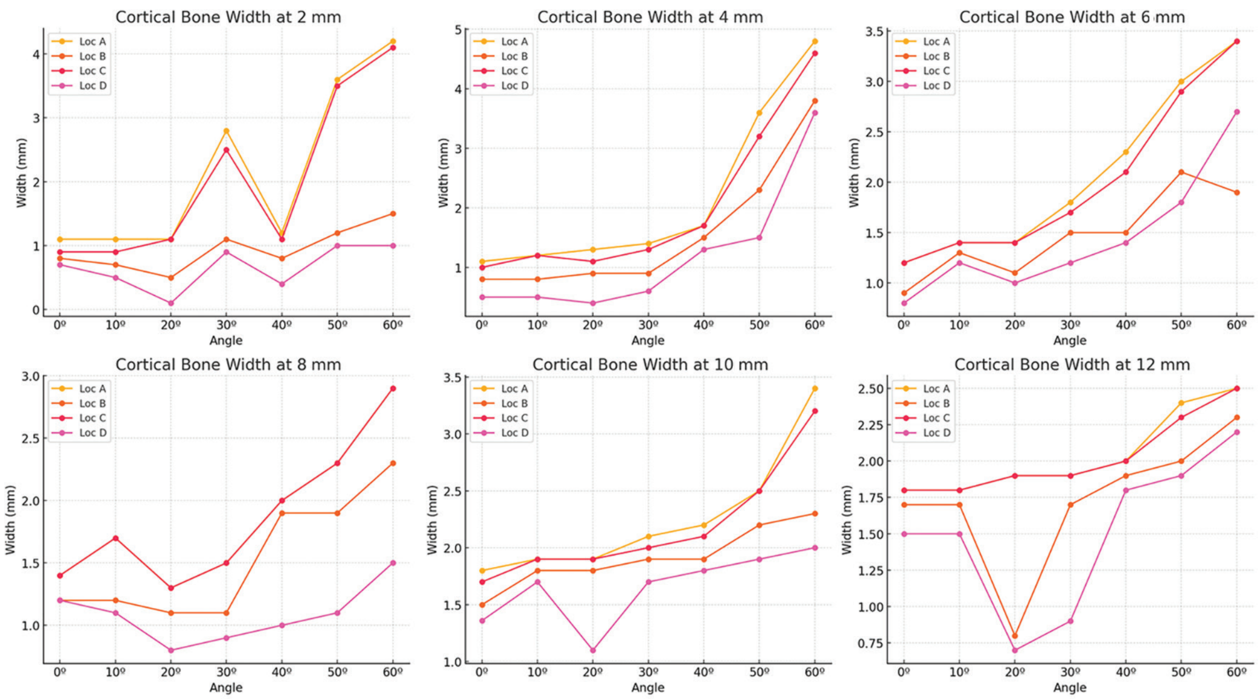
In clinical situations where bone quality or quantity is inadequate, mini-implants should be placed deeper and angled strategically to avoid root contact. This recommendation is supported by anatomical observations showing that root size decreases and inter-radicular space increases with depth.



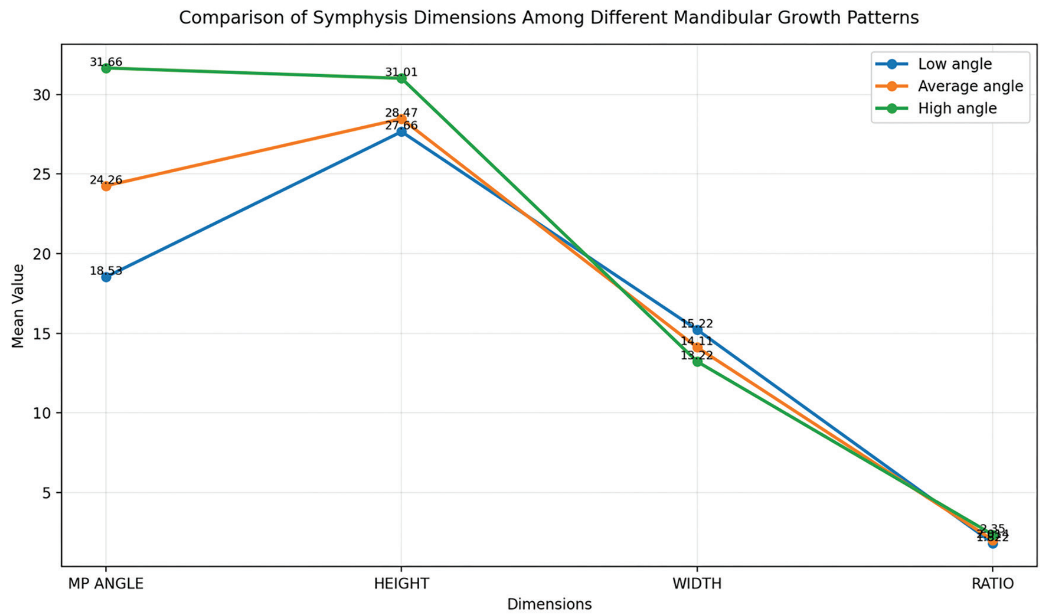
Graph 1. CtBW, cortical bone width. Comparison of complete bone width and CtBW among different mandibular growth pattern at each location.



Graph 2. Comparison of the complete bone width among four insertion locations at each insertion height & insertion angles.



Graph 3. CtBW, cortical bone width. Comparison of the CtBW among four insertion locations at each insertion height & angles.



Graph 4. Comparison of symphysis dimensions among different mandibular growth pattern

Additionally, buccal cortical bone thickens with increasing insertion angle.[9,10] Our findings confirmed that both CBW and CtBW increased with greater insertion depth and insertion angle, contributing to enhanced implant stability.

Implant reliability is influenced by several factors, with insertion depth and cortical bone thickness being particularly important.[11] Studies have shown that mini-implants are more stable when inserted to a depth greater than 5 mm.[12] However, an increased risk of cortical fracture has been reported when cortical thickness exceeds 2 mm.[13] Therefore, a cortical thickness of 1-2 mm is generally considered ideal for safe and stable mini-implant placement. Our results support the clinical recommendation of using steeper insertion angles at shallower depths, as proposed by Zhang et al.,[1] to maximize stability while minimizing soft tissue irritation and implant slippage.

The anatomical structure of the mandibular symphysis, especially the bony projection formed during fusion of the mandibular halves, makes location A particularly favorable for mini-implant placement. Based on our measurements, the optimal insertion site is located between the central incisors, at a depth of 6-10 mm apical to the CEJ, and at an angle of 0º-60º.[1]

Finally, we observed that the height-to-width ratio of the symphysis was lowest in individuals with a low-angle mandibular growth pattern. A wider symphysis was associated with denser apical alveolar bone on the lingual side. Conversely, a tall and narrow symphysis suggested reduced bone support, aligning with the findings of Wehrbein et al.,[14] who noted compromised bone stability in elongated symphyses.

Although only intraobserver reliability was assessed, the methodology aligns with several prior studies in which single calibrated observers yielded consistent and reproducible measurements in CBCT-based evaluations. Zhang et al.[1] and Sadek et al.[8] have validated this approach. Nonetheless, future studies would benefit from including multiple observers to enhance the reproducibility of findings.

Study Limitations

A limitation of this study was the lack of consideration of sagittal discrepancy, as the thickness of the mandibular symphysis might vary among individuals with different mandibular growth patterns. Further research is necessary to explore this concept fully. Another limitation was the relatively small sample size. However, future studies with larger sample sizes and more diverse ethnicities are warranted to enhance generalizability. Interobserver reliability assessment was not conducted, which may limit the generalizability of the findings. However, previous CBCT-based studies have reported high intraobserver consistency when conducted by a calibrated examiner Zhang et al.[1], Sadek et al.[8], supporting the reliability of single-observer measurement in similar research contexts.

CONCLUSION

The mandibular symphysis is an appropriate site for placement of orthodontic mini-implants, particularly between the central incisors. Complete Bone Thickness and CtBW is more between two central incisors. The ideal site for implant placement is located 6-10 mm below the CEJ of the two central incisors, with an insertion angle of 0°-60°. The symphysis height-to-width ratio is lower in individuals with low-angle mandibular growth patterns than in those with average- and high-angle patterns.

Ethics

Ethics Committee Approval: This research obtained approval from the Rungta College of Dental Sciences and Research Institute Institutional Ethical Committee (approval no: RCDSR/IEC/MDS/2022/D-11, date: 29.05.2023).

Informed Consent: Consent was secured from the patients themselves or from their guardians; for those under 18 years old, additional consent was obtained from parents.

Footnotes

Author Contributions: Concept – G.A.; Design - G.A.; Data Collection and/or Processing – S.J.; Analysis and/or Interpretation – S.G., S.H.; Literature Search – H.M., P.P.; Writing – S.J.

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

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Original Article

Investigation of the Effects of Tooth-Borne, Tooth-Bone-Borne and Bone-Borne Rapid Maxillary Expansion Appliances on the Nasomaxillary Complex Using CBCT

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Main Points

- All three rapid maxillary expansion modalities (tooth-borne, tooth-bone-borne, and bone-borne) provide significant skeletal expansion in the nasomaxillary complex.
- Bone-borne appliances demonstrate greater skeletal effects compared to hybrid and traditional tooth-borne (Hyrax) appliances.
- The expansion observed in the mandibular dental arch during active treatment tends to show partial relapse or lose statistical significance during the retention period.
- Cone-beam computed tomography-based analysis is highly reliable for evaluating the multidimensional changes associated with different maxillary expansion protocols.

ABSTRACT

Objective: This study aimed to investigate the effects of tooth-borne, tooth-bone-borne, and bone-borne rapid maxillary expansion (RME) on the nasomaxillary complex in individuals with maxillary transverse constriction using cone-beam computed tomography (CBCT), and to compare the outcomes of these expansion modalities.

Methods: CBCT images from 45 patients (aged 10-17 years) with maxillary transverse constriction who were treated with RME were evaluated. Patients were divided into three groups according to the appliance used: tooth-borne (Hyrax), tooth-bone-borne (hybrid), and bone-borne. CBCT records were obtained at three time points: before treatment, after active expansion, and after a 3-month retention period. Dentoalveolar and skeletal measurements were performed on the CBCT images. Intergroup comparisons were conducted using one-way ANOVA and Kruskal-Wallis tests, while intragroup comparisons were performed using repeated-measures ANOVA and Friedman tests.

Results: CBCT evaluation revealed no statistically significant intergroup differences in dental and skeletal measurements. However, all RME groups showed significant increases between time points, most of which were maintained after the retention period. In the mandible, increases in intercanine, interpremolar, and intermolar widths, observed during the active expansion phase, partially relapsed or lost their statistical significance following retention.

Conclusion: All RME modalities produced significant skeletal and dental expansion in the maxilla, with the bone-borne appliance showing greater skeletal effects than the hybrid and tooth-borne appliances.

Keywords: Maxillary expansion, palatal expansion technique, cone-beam computed tomography, orthodontic appliances

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INTRODUCTION

One of the most common skeletal anomalies affecting the maxilla is maxillary transverse deficiency, which is typically characterized by a narrow palatal arch and is often accompanied by an anterior and/or posterior crossbite.[1] The most commonly used treatment for this condition is rapid maxillary expansion (RME).[2,3]

However, forces transmitted to the teeth during RME may cause several undesirable effects, including buccal tipping of the posterior teeth,[4] alveolar bone fenestrations,[5] and root resorptions.[6] To minimize these complications, Ludwig et al.[7] proposed using a hybrid Hyrax appliance. Accordingly, various types of RME appliances have been introduced, including tooth-borne, tooth-bone-borne, and bone-borne expanders.[8,9]

The concept of RME has been gradually developed and refined by researchers such as Haas,[10] Biederman,[11] and Coffin. Haas reported that his acrylic-supported appliance reduced buccal tipping of the teeth and promoted greater skeletal expansion.[10] In 1973, Biederman[11] introduced a hygienic RME appliance supported by the permanent first molars and premolars, noting that it was more flexible than earlier designs. Subtelny later suggested that in patients with an increased vertical dimension, incorporating a bite plane into the RME appliance could help limit dental tipping and improve the transmission of expansion forces through the tooth roots to the nasomaxillary complex.[12]

Recent technological advances have enabled digitally guided expansion protocols that allow precise and safe placement of mini-implants for skeletal anchorage. Wilmes et al.[13] described the digitally planned quadexpander, a device that facilitates maxillary expansion through purely bone-borne support. Through virtual implant insertion planning and computer-aided design/computer-aided design-manufactured guides, this approach ensures optimal implant positioning in areas of adequate bone while minimizing the risk of root damage and other complications. Such innovations demonstrate how digital planning enhances both accuracy and clinical efficiency in modern expansion therapy.

Recent studies have increasingly focused on the skeletal and airway effects of microimplant-assisted rapid palatal expansion (MARPE) using three-dimensional imaging modalities. Li et al.[14] demonstrated that MARPE can induce significant long-term increases in nasal and nasopharyngeal volumes, emphasizing MARPE's potential effects beyond skeletal expansion. These findings highlight the value of cone-beam computed tomography (CBCT)-based analyses in understanding the multidimensional changes associated with skeletal anchorage-assisted expansion and underscore the need for further high-quality research to clarify its comprehensive clinical benefits.[15]

Although many studies have examined various RME protocols, relatively few have directly and comparatively investigated their effects on the nasomaxillary complex. Based on this gap in the literature, the present study aims to contribute to a more comprehensive understanding of this topic.

Accordingly, the aim of this study is to evaluate the effects of tooth-borne, tooth-bone-borne, and bone-borne RME appliances on the nasomaxillary complex using CBCT and to identify differences among these appliances. The research hypothesis (H_1) is that tooth-borne, tooth-bone-borne, and bone-borne RME methods have significantly different effects on the nasomaxillary complex, whereas the null hypothesis (H_0) is that no significant differences exist among them.

METHODS

This prospective clinical study was approved by the Atatürk University Faculty of Medicine Clinical Research Ethics Committee (approval no: 1, date: 30.09.2021). All participants were informed in detail about the purpose, methodology, potential risks, and benefits of the study, and written and verbal informed consent was obtained prior to participation.

Sample size estimation was performed using G*Power software, software based on previously reported data, and a minimum of 10 patients per group was required to detect a statistically significant difference with 80% power and 95% confidence.

The study sample were divided into three groups (n=15 per group) based on the type of RME appliance used: Group 1, tooth-borne (Hyrax); Group 2, tooth-bone-borne (Hybrid Hyrax); Group 3, bone-borne (mini-screw-supported system). The age distribution of the groups is shown in Table 1.

The inclusion criteria for this study were patients aged between 10 and 17 years, clinically and/or radiographically diagnosed with maxillary transverse deficiency, with no prior orthodontic treatment, no congenital or genetic craniofacial anomalies, and no history of systemic or neuromuscular disorders. The exclusion criteria included poor-quality CBCT images, missing posterior teeth in the maxilla, prior dentofacial orthopedic treatment, skeletal Class III malocclusion, anterior open bite, or significant facial asymmetry.

As part of the imaging protocol, CBCT scans were obtained at three standardized time points: before treatment (T0), after completion of active maxillary expansion (T1), and after a 3-month retention period (T2). All scans were performed at the Atatürk University Faculty of Dentistry, with the patient's head and neck stabilized, in accordance with the (as low as reasonably achievable) principle. Imaging was carried out using a NewTom VGi EVO 3D CBCT unit (NewTom FP, Quantitative Radiology, Milano, Italy) with standardized acquisition parameters (110 kVp, 3.0 mA, 1.8 s exposure time, 0.3-mm focal spot, 19Å~24 cm field of view). The images were obtained in (Digital Imaging and Communications in Medicine) format and analyzed using Dolphin Imaging Software. Each CBCT scan delivered an effective dose of approximately 0.087 mSv.

The first group was treated with a Hyrax appliance (Figure 1), the second group with a hybrid appliance (Figure 2), and the third group with a mini-screw-assisted expansion appliance (Figure 3). In the hybrid appliance group, two miniscrews (2 mm in diameter and 7 mm in length; Lomas, Mondeal, Germany) were inserted under local anesthesia into the anterior maxilla, positioned perpendicular to the palate, between the roots of the upper canine and first premolar, and approximately 4-6 mm from the midline. In the bone-supported appliance group, four mini-screws of the same dimensions were placed in the anterior and posterior palatal regions of the maxilla: in the anterior region, between the canine and premolar roots or between premolar roots, depending on the case; in the posterior region, between the premolar and molar roots. The anterior screws were positioned 4-6 mm from the midline, while the posterior screws were positioned approximately 8-10 mm from the midline.

No screw activation was performed on the day of appliance placement. Starting the next day, activation was performed at a rate of two quarter-turns per day. On the 5th day, an occlusal radiograph was taken to assess midpalatal suture opening. If opening was observed, activation was continued at the same rate up to 20 quarter turns; then it was reduced to 1 quarter turn per day until 40 quarter turns, and follow-up was performed every 10 turns. In patients in whom no opening of the midpalatal suture was observed, the screw was activated for an additional 10 quarter-turns, followed by a waiting period of 5-7 days without further activation. The patients were then recalled for evaluation; an occlusal radiograph was taken; and upon observing suture opening, activation was continued until a total of 40 quarter-turns was achieved. After completion of the expansion, the screw was stabilized and a 3-month retention phase was initiated.

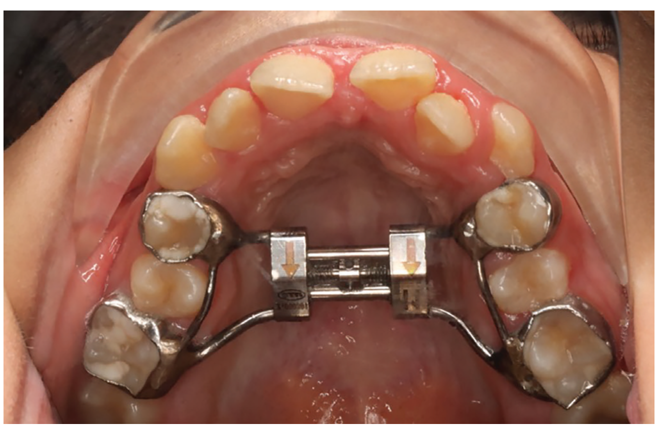

Figure 1. Hyrax expansion appliance.

Only individuals with skeletal maxillary constriction were included in the study. The diagnosis was established through a combined evaluation of the patients' digital dental models and cone beam computed tomography images. Palatal morphology was assessed on dental models, while nasal, zygomatic, and maxillary widths were evaluated on CBCT images. Cases showing significant dentoalveolar compensation, such as buccal tipping without basal deficiency, were excluded.

CBCT measurement parameters and their definitions are provided in Table 2 and detailed images of the measurement landmarks are shown in Figures 4 and 5. Skeletal transverse measurements included orbital, nasal, zygomatic, and maxillary widths. Dental measurements included maxillary and mandibular intercanine, interpremolar, and intermolar distances, defined as the distances between reference points on the respective teeth.

The intraclass correlation coefficient (ICC) was used, and all measurements demonstrated excellent agreement (ICC >0.90).[16] Tomographic measurements for 21 randomly selected patients were repeated after one month to assess intra-observer reliability.[17]

Statistical Analysis

All statistical analyses were performed using IBM SPSS 20 (Statistical Package for Social Sciences) software (IBM Corp., Chicago, IL, USA). Descriptive statistics were calculated for all variables, and normality was evaluated using the Shapiro-

Figure 2. Hybrid expansion appliance: (A) miniscrew placement; (B) appliance design.

Figure 3. Mini-screw-assisted expansion appliance: (A) screw insertion sites; (B) appliance design.

Table 1. Age distribution of the RME groups

Group	Hyrax	Hybrid	Mini-screw	p
Mean±Sd. (year)	15.50±2.096624	14.30±1.494523	15.08±1.652079	NS

NS, non-significant; RME, rapid maxillary expansion; Sd, standard deviation

Table 2. CBCT measurement parameters used in the study

Measurement name (code)	Definition
Orbital width (OrR-OrL)	The distance between the right and left orbital (Or) points
Nasal width (NcR-NcL)	The distance between the right and left nasal (Nc) points
Zygomatic width (ZygR-ZygL)	The distance between the right and left zygomatic (Zyg) points
Maxillary width (MxR-MxL)	The distance between the right and left maxillary (Mx) points
Maxillary canine distance (maxillary canine)	The distance between the reference points of the maxillary canine teeth
Maxillary premolar distance (maxillary premolar)	The distance between the reference points of the maxillary premolar teeth
Maxillary molar distance (maxillary molar)	The distance between the reference points of the maxillary molar teeth
Mandibular canine distance (mandibular canine)	The distance between the reference points of the mandibular canine teeth
Mandibular premolar distance (mandibular premolar)	The distance between the reference points of the mandibular premolar teeth
Mandibular molar distance (mandibular molar)	The distance between the reference points of the mandibular molar teeth

Wilk and Kolmogorov-Smirnov tests. For comparisons among groups, one-way ANOVA or the Kruskal-Wallis test was used as appropriate. For within-group comparisons across time points, repeated measures ANOVA or the Friedman test was applied. Post-hoc analyses were performed where necessary, and a p-value <0.05 was considered statistically significant.

RESULTS

Analysis of skeletal measurements in the transverse direction revealed that, in general, there were no significant differences between the groups (p>0.05). In contrast, there were statistically significant differences between periods (p<0.05; Table 3). The abbreviations and descriptions of the related measurements are as follows: OrR-OrL: The distance between the right and left orbital (Or) points; NcR-NcL: The distance between the right and left nasal (Nc) points; ZygR-ZygL: The distance between the right and left zygomatic (Zyg) points; MxR-MxL: The distance between the right and left maxillary (Mx) points.

Evaluation of maxillary dental measurements indicated no significant intergroup differences (p>0.05), whereas statistically significant differences were observed between periods ($p<0.05$) (Table 4). In contrast, mandibular dental measurements showed no statistically significant differences either between groups or across time periods ($p>0.05$) (Table 4).

DISCUSSION

Midpalatal suture opening and dental changes between two RME appliances-one supported by molars alone and the other supported by both premolars and molars-have previously been compared using occlusal radiographs and dental casts. From a perspective comparable to that of the present study, the intragroup evaluations of the appliance supported by four teeth can be considered with respect to dental effects at different time points. The study included 9 males and 6 females, which is comparable to the present sample (9 females, 6 males). Similarly, the measurement time points were comparable: T1, pretreatment; T2, post-active expansion; T3, after 3 months of retention.[18]

Statistically significant increases in intermolar and intercanine distances between T1 and T3 in the four-tooth-supported RME group and noted no significant relapse in intercanine width between T2 and T3 by Lamparski et al.[18] In contrast, the present study demonstrated statistically significant differences in intercanine width between T1 and T0 ($p<0.001$) and between T2 and T1 ($p<0.01$); in intermolar width between T1 and T0 ($p<0.001$), between T2 and T1, and between T2 and T0 ($p<0.01$) within the same group. These discrepancies may be attributed to differences in measurement methods and age ranges of the study populations. While previous measurements were performed on dental casts, the present study used measurements digitally from CBCT images. Furthermore, the previously reported age range was 7-13 years, whereas the present study included individuals aged 10 to 17

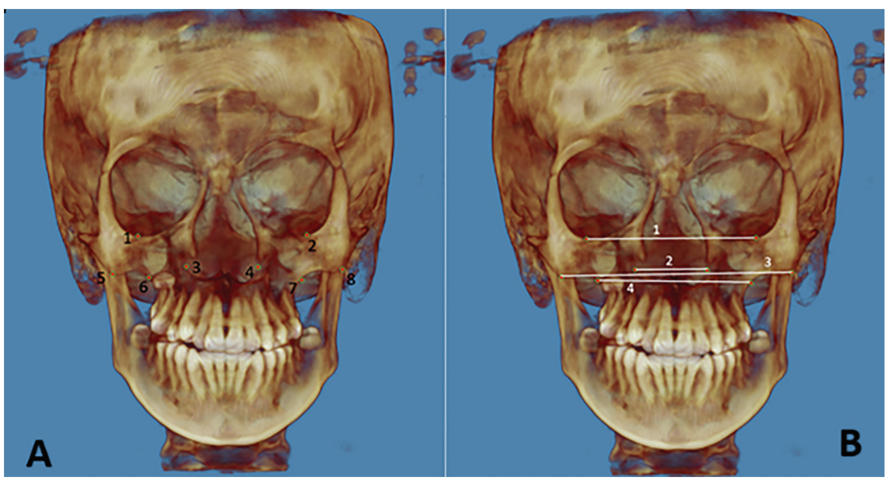

Figure 4. CBCT frontal reference points and skeletal transverse measurements. (A) Reference points: 1. right orbital point; 2. left orbital point; 3. right nasal point; 4. left nasal point; 5. right zygomatic point; 6. right maxillary point; 7. left maxillary point; 8. left zygomatic point (B) Linear measurements: OrR-OrL (The distance between the right and left orbital) 2) NcR-NcL [The distance between the right and left nasal (Nc) points] 3) ZygR-ZygL (The distance between the right and left zygomatic (Zyg) points) 4) MxR-MxL (The distance between the right and left maxillary (Mx) points).
CBCT, cone-beam computed tomography.

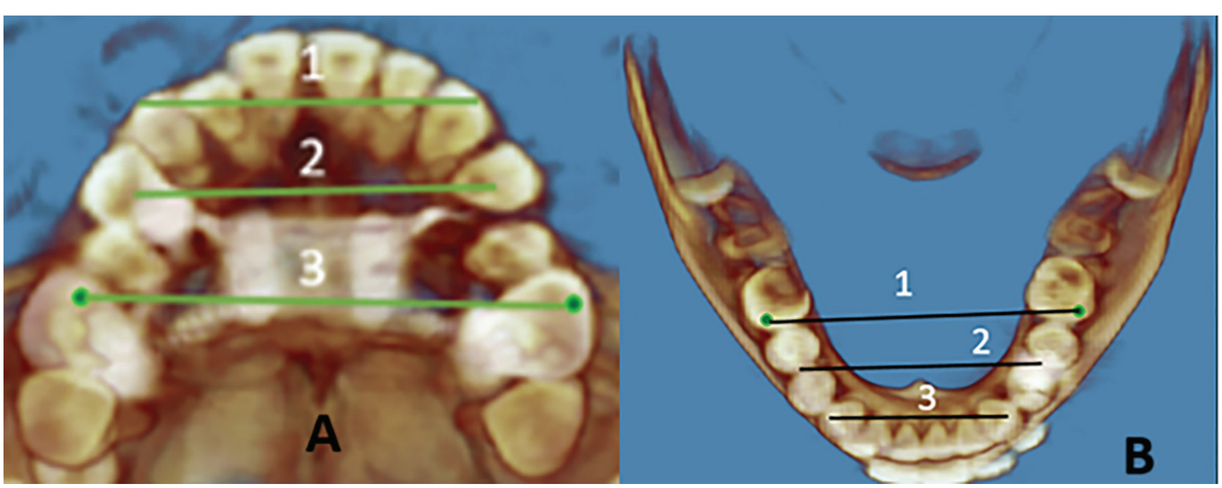

Figure 5. Dental arch measurements. (A) Maxillary measurements: 1. Intercanine distance; 2. Interpremolar distance; 3. Intermolar distance (B) Mandibular measurements: 1. Intermolar distance in the mandible; 2. Interpremolar distance in the mandible; 3. Intercanine distance in the mandible.

Table 3. Changes in skeletal transverse dimensions following RME

Measurement timepoint	Hyrax (1) Mean±SD	Hybrid (2) Mean±SD	Mini-Screw (3) Mean±SD	Intergroup p-value/post-hoc
OrR-OrL (T0)	63.62±3.00	64.91±3.64	66.95±3.40	0.057$^{\varphi}$
OrR-OrL (T1)	64.28±3.28	65.55±3.83	67.65±3.32	0.037$^{*\delta}$ (1-3/0,035*)
OrR-OrL (T2)	63.90±3.16	65.27±3.83	67.31±3.38	0.063$^{\varphi}$
Intragroup p	<0.001$^{\omega}$***	<0.001$^{\omega}$***	0.001$^{\sigma}$***	
Post-hoc	T1-T0 (0.000***), T2-T1 (0.01**)	T1-T0 (0.000***), T2-T1 (0.006**)	T1-T0 (0.000***), T2-T1 (0.006**)	
NcR-NcL (T0)	24.12±2.74	22.89±1.50	23.08±1.67	0.447$^{\varphi}$
NcR-NcL (T1)	27.72±2.61	27.39±2.17	27.54±2.09	0.967$^{\varphi}$
NcR-NcL (T2)	26.45±2.48	26.69±2.28	26.61±2.09	0.960$^{\delta}$
Intragroup p	<0.001$^{\omega}$***	<0.001$^{\sigma}$***	<0.001$^{\sigma}$***	
Post-hoc	T1-T0 (0.006**), T2-T1 (0.006**), T2-T0 (0.000***)	T2-T0 (0.003**), T1-T0 (0.000***), T2-T1 (0.006**)	T1-T0 (0.006**), T2-T1 (0.006**), T2-T0 (0.000***)	
ZygR-ZygL (T0)	97.14±5.91	94.45±4.37	97.70±4.41	0.611$^{\delta}$
ZygR-ZygL (T1)	98.67±5.59	95.91±4.39	99.61±3.56	0.417$^{\delta}$
ZygR-ZygL (T2)	97.68±5.74	95.00±4.20	98.54±3.81	0.666$^{\delta}$
Intragroup p	<0.001$^{\omega}$***	<0.001$^{\omega}$***	<0.001$^{\omega}$***	
Post-hoc	T1-T0 (0.000***), T2-T1 (0.003**), T2-T0 (0.018*)	T1-T0 (0.000***), T2-T1 (0.005**), T2-T0 (0.016*)	T1-T0 (0.000***), T2-T1 (0.006**), T2-T0 (0.014*)	
MxR-MxL (T0)	58.21±3.65	59.69±2.74	60.01±2.16	0.051$^{\varphi}$
MxR-MxL (T1)	61.78±4.16	64.63±2.71	64.97±2.81	0.021$^{\delta*}$ (1-3 /0.029*)
MxR-MxL (T2)	60.86±4.19	62.59±3.01	63.58±2.81	0.087$^{\varphi}$
Intragroup p	<0.001$^{\omega}$***	0.001$^{\omega}$***	<0.001$^{\sigma}$***	
Post-hoc	T1-T0 (0.000***), T2-T1 (0.011*), T2-T0 (0.005**)	T1-T0 (0.000**), T2-T1(0.011*), T2-T0 (0.001**)	T1-T0 (0.000***), T2-T1(0.011*), T2-T0 (0.005***)	

$^{\varphi}$Kruskal-Wallis Test, $^{\delta}$ANOVA test, $^{\Sigma}$: Friedman Test, $^{\Omega}$: Repeated measure ANOVA.
*p<0.05; **p<0.01; ***p<0,001.
OrR-OrL, right and left orbital width; NcR-NcL, right and left nasal width; ZygR-ZygL, right and left zygomatic width; MxR-MxL, right and left maxillary width; T0, prior to treatment; T1, after active expansion; T2, following a 3-month retention period, SD, standard deviation; RME, rapid maxillary expansion; ANOVA, analysis of variance.

Table 4. Changes in dental arch dimensions following RME

Measurement & timepoint	Hyrax (1) Mean±SD	Hybrid (2) Mean±SD	Mini-screw (3) Mean±SD	Intergroup p/ Post-hoc
Max. distance between canines (mm) - T0	31.09±3.63	32.90±4.07	32.25±3.38	0.408$^{\delta}$
Max. distance between canines (mm) - T1	34.86±4.14	37.42±5.14	37.72±4.07	0.170$^{\delta}$
Max. distance between canines (mm) - T2	33.29±3.90	35.81±4.69	35.76±3.50	0.164$^{\delta}$
Intragroup p	<0.001$^{\Omega}$***	<0.001$^{\Omega}$***	<0.001$^{\Omega}$***	
Post-hoc	T1-T0 (0.000***), T2-T1 (0.003**)	T1-T0 (0.000***), T2-T0 (0.003**)	T1-T0 (0.006**), T2-T1 (0.006**), T2-T0 (0.000***)	

Table 4. Continued

Measurement & timepoint	Hyrax (1)	Hybrid (2)	Mini-screw (3)	Intergroup p/
	Mean±SD	Mean±SD	Mean±SD	Post-hoc
Max. distance between premolars (mm) - T0	30.05±2.40	31.29±2.39	31.09±2.50	0.423$^{\varphi}$
Max. distance between premolars (mm) - T1	37.27±2.88	36.73±3.24	37.05±4.23	0.916$^{\delta}$
Max. distance between premolars (mm) - T2	36.09±2.78	35.48±3.21	35.55±4.13	0.869$^{\delta}$
Intragroup p	<0.001$^{\Omega}$***	<0.001Ω***	<0.001$^{\Omega}$***	
Post-hoc	T1-T0 (0.000***), T2-T0 (0.003**)	T1-T0 (0.000***), T2-T1 (0.011*), T2-T0 (0.005**)	T1-T0 (0.000***), T2-T1 (0.006**), T2-T0 (0.006**)	
Max. intermolar distance (mm) - T0	42.26±3.58	42.26±2.45	41.36±2.08	0.240$^{\delta}$
Max. intermolar distance (mm) - T1	49.85±3.00	49.66±3.08	46.22±3.57	0.011$^{\delta}$* (1-3)
Max. intermolar distance (mm) - T2	48.49±2.90	48.24±3.17	45.03±3.68	0.018$^{\delta}$* (1-3)
Intragroup p	<0.001$^{\Omega}$***	<0.001$^{\Omega}$***	<0.001$^{\Omega}$***	
Post-hoc	T1-T0 (0.000***), T2-T1 (0.008**), T2-T0 (0.008**)	T1-T0 (0.000***), T2-T1 (0.008**), T2-T0 (0.008**)	T0-T1 (0.000***), T2-T1 (0.014*), T2-T0 (0.014*)	
Mandibular canine distance (mm) - T0	26.07±2.92	27.42±2.04	26.87±2.50	0.113$^{\varphi}$
Mandibular canine distance (mm) - T1	26.65±2.85	27.62±1.84	27.04±2.45	0.545$^{\delta}$
Mandibular canine distance (mm) - T2	26.30±2.97	27.62±1.96	26.93±2.47	0.087$^{\varphi}$
Intragroup p	0.004$^{\Sigma}$**	0.215$^{\Omega}$	0.110$^{\Omega}$	
Post-hoc	T2-T1 (0.000***), T2-T0 (0.005**)			
Mandibular premolar distance (mm) - T0	34.16±2.49	34.50±3.29	35.26±2.35	0.534$^{\delta}$
Mandibular premolar distance (mm) - T1	34.90±2.48	34.98±3.07	35.62±2.26	0.713
Mandibular premolar distance (mm) - T2	34.59±2.54	34.79±3.20	35.41±2.26	0.691$^{\delta}$
Intragroup p	0.006$^{\Omega}$**	0.029$^{\Omega}$*	0.008$^{\Omega}$**	
Post-hoc	T1-T0 (0.000***), T2-T1 (0.005**)	T1-T0 (0.008**)	T1-T0 (0.001***)	
Mandibular intermolar distance (mm) - T0	42.73±2.99	42.04±2.94	41.75±3.24	0.681$^{\delta}$
Mandibular intermolar distance (mm) - T1	43.76±2.76	42.44±3.05	42.45±3.11	0.391$^{\delta}$
Mandibular intermolar distance (mm) - T2	43.01±2.90	42.17±3.00	42.25±3.07	0.633$^{\delta}$
Intragroup p	<0.001$^{\Omega}$***	0.008$^{\Omega}$**	0.005$^{\Omega}$**	
Post-hoc	T1-T0 (0.000***), T2-T1 (0.003**)	T1-T0 (0.001***)	T2-T0 (0.000***)	

$^{\varphi}$Kruskal-Wallis Test, $^{\delta}$ANOVA test, $^{\Sigma}$Friedman Test, $^{\Omega}$Repeated measure ANOVA.
*p<0,05; ** p<0,01; *** p<0,001.
T0, prior to treatment; T1, after active expansion; T2, following a 3-month retention period; SD, standard deviation; RME, rapid maxillary expansion.

years. Age differences between study samples may be more influential than differences in measurement methodology.

Increases in interdental width achieved with monocortical and bicortical miniscrew-assisted hybrid Hyrax appliances were evaluated in individuals aged 18-21 years using CBCT at pretreatment (T0) and at the end of expansion (T1). Since it was unclear whether the second scan corresponded precisely to T1 or T2 in the present study, comparisons were made for both the T1-T0 and T2-T0 periods. Statistically significant increases in intermolar, interpremolar, and intercanine widths were reported in both groups between T0 and T1 ($p<0.001$).[19] Similarly, the present study demonstrated statistically significant differences in the same parameters between T1 and T0 ($p<0.001$) and between T2 and T0 ($p<0.01$). Despite differences in miniscrew diameter (e.g., 1.6 mm), length (8-10 mm), and age range, the findings are consistent. However, because bicortical engagement of miniscrews was not considered in the design of the present study, a direct comparison regarding this aspect was not possible.

The skeletal and dental effects of RME with MARPE and Hyrax appliances have also been evaluated using CBCT and dental models before expansion (T1) and shortly after active expansion (T2). Significantly greater increases in nasal and maxillary widths were reported in the MARPE group, whereas increases in intermolar width were not statistically significant.[20] In contrast, the present study found no significant difference between the same groups in the increase in nasal width after active expansion ($p>0.05$), whereas the increase in maxillary width was statistically significant ($p<0.05$). Intermolar width increases differed significantly between groups at both time points: after active expansion (T1) and after the retention period (T2) ($p<0.05$). These discrepancies may be explained by differences in sample size, appliance design, miniscrew characteristics, and the timing of post-expansion records.

Long-term effects of MARPE and RPE on the nasal cavity and interdental region have also been investigated using CBCT, including a control group. Significant increases in multiple skeletal and dental parameters were observed in the short term, whereas in the long term, MARPE demonstrated a greater increase in posterior nasal cavity width. Although intermolar width increased significantly in the RPE group in the short term ($p<0.05$), no differences were observed in later periods ($p>0.05$).[21] The anterior nasal width, comparable to nasal width in the present study, did not differ significantly between MARPE and RPE at any time point. Only the pretreatment and immediate post-expansion periods are comparable to the present study, due to the shorter retention period used. In the present study, although no significant between-group difference in nasal width increase was observed ($p>0.05$), the increase in intermolar width was significantly greater in the Hyrax group ($p<0.05$). Despite differences in miniscrew protocols, the findings regarding nasal width and intermolar distance were similar.

The effects of hybrid and Hyrax appliances have also been evaluated before treatment and after a longer retention period. Greater increases in nasal cavity and maxillary widths were reported in the hybrid group, whereas interdental changes were not statistically significant.[22] In contrast, the present study demonstrated no significant intergroup differences in either orthopedic or interdental changes during the T2-T0 period ($p>0.05$). The discrepancy in orthopedic outcomes may be attributed to the longer retention period (approximately 11 months) used in prebious studies compared with the approximately 3-month retention period used in the present study.

Study Limitations

The main limitation of the present study is the three-month follow-up, which limits assessment of the long-term stability of treatment outcomes. However, tthe inclusion of individuals in the pubertal growth period-considered optimal for orthopedic interventions-was a deliberate methodological choice to enhance the skeletal response to maxillary expansion.

CONCLUSION

RME provided significant skeletal and dental improvements in the maxilla across all appliance groups. Among them, the bone-borne appliance produced the greatest skeletal changes, underscoring its clinical value in cases with pronounced transverse deficiencies. While mandibular dental changes partially relapsed and soft-tissue effects were minimal, the overall findings underscore the effectiveness of RME and the importance of selecting appliances according to clinical needs. Nevertheless, concerns remain regarding the long-term stability of these outcomes, and further well-designed longitudinal studies are warranted.

Ethics

Ethics Committee Approval: This prospective clinical study was approved by the Atatürk University Faculty of Medicine Clinical Research Ethics Committee (approval no: 1, date: 30.09.2021).

Informed Consent: All participants were informed in detail about the purpose, methodology, potential risks, and benefits of the study, and written and verbal informed consent was obtained prior to participation.

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Footnotes

Author Contributions

Surgical and Medical Practices – G.Y.Ö, İ.C.; Concept – G.Y.Ö, İ.C.; Design – G.Y.Ö.; Data Collection and/or Processing – G.Y.Ö, İ.C.; Analysis and/or Interpretation – G.Y.Ö, İ.C.; Literature Search – G.Y.Ö.; Writing – G.Y.Ö, İ.C.

Conflict of Interest: No conflict of interest was declared by the authors.

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Original Article

Influence of Vertical Facial Patterns on Dental Arch Parameters in Class III Malocclusions: A Cross-Sectional Study

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Main Points

- Sagittal and vertical patterns affect intermolar width.
- The Class III low-angle subgroup had the greatest intermolar width in both the maxilla and the mandible. This difference should be considered in diagnosis, treatment planning, wire selection, or restorative procedures.
- Intercanine width, arch length, and arch depth are not affected by sagittal and vertical-patterns

ABSTRACT

Objective: To evaluate how vertical-patterns influence dental arch dimensions in class I (CI) and class III (CIII) malocclusions.

Methods: Pretreatment patient files, lateral cephalometric parameters, and initial intraoral digital models of adult patients were retrieved from the archive in an academic setting. Skeletal and dental CI and CIII individuals were divided into three subgroups (n=20 for each group) according to frankfort-mandibular plane angle (FMA) values (angle between Frankfurt horizontal and mandibular planes): FMA <22° for low-angle (L), FMA=22-28° for normal-angle (N), and FMA >28° for high-angle (H) vertical patterns. Dental arch parameters were measured on digital models using 3D Slicer software (version 5.6.1; www.slicer.org). One-way analysis of variance, Kruskal-Wallis test, and Spearman correlation analysis were performed. The significance level was set at p<0.05.

Results: A significant difference in maxillary intermolar width was found between CI-H and CIII-L groups (p=0.004). A significant difference in the maxillary intermolar angle was found between the CIII-N and CI-N groups and between the CIII-N and CI-L groups (p=0.003). A significant difference in intermolar mandibular width was observed between the CI-H and CI-L groups (p=0.002). Occlusal angle differed significantly between the CI-N and CIII-H groups and between the CI-N and CIII-L groups (p=0.002). No differences were observed in intercanine width, arch length, or arch depth.

Conclusion: CIII-L group has a significantly greater intermolar width for both maxillary and mandibular arches. The clinical implications of this result can be particularly important when selecting prefabricated archwires. Therefore, it is recommended that this difference be taken into consideration in diagnosis and treatment planning to achieve effective and stable outcomes.

Keywords: Digital models, class III diagnosis, dental cast analysis

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INTRODUCTION

Dentoalveolar structures are the primary focus of orthodontics and play a crucial role in the planning and execution of orthodontic treatment. While recent advancements in orthodontics focus on craniofacial and 3-dimensional effects of orthodontic treatment, the importance of incorporating dentoalveolar features into treatment strategies has been well documented.[1,2]

The literature includes research on various malocclusions and dental characteristics. Increased backward rotation of the mandible was associated with decreased maxillary intermolar width (IMW).[3] Similarly, Nasby et al.[4] reported that a greater Sella-Nasion-Mandibular plane (SN-MP) angle was linked to a reduction in both maxillary and mandibular IMW. Sex is another factor found to influence dental features and vertical parameters.[5,6] For example, Forster et al.[5] observed that the arch widths of males were significantly larger than those of females. They also noted that arch widths in both males and females decreased as the SN-MP angle increased.[5]

Class III (CIII) malocclusion is a frequently encountered clinical condition. Its incidence may vary across racial groups and geographic regions.[7] The highest prevalence (15.80%) is reported in Southeast Asian populations, while the average prevalence is 7.04%.[7] The treatment strategy for CIII malocclusion depends on several factors, including case severity, genetic predisposition, patient maturation stage, and the presence of comorbidities.[8] In borderline adult cases, the decision between orthognathic surgery and camouflage treatment can be challenging. Camouflage therapies are interventions that adjust the patient's malocclusion to the extent permitted by biological factors. The vertical components of the problem and the dental features are critical in such cases.[9,10]

Previous studies of dental arch parameters in patients with CIII malocclusions have not assessed vertical growth direction.[11-13] Therefore, the primary aim of this study was to investigate the effect of vertical patterns on dental arch parameters in a group of nongrowing CIII patients. The secondary aim was to compare the results of these patients with those of Class I (CI) patients and investigate the differences between the groups with respect to sagittal and vertical dimensions. The null hypothesis was that there would be no significant differences in dental arch parameters among different sagittal-vertical subgroups.

METHODS

This retrospective study was conducted in the Department of Orthodontics, Faculty of Dentistry, Marmara University. Ethical approval was obtained from the Faculty of Medicine, Marmara University (approval number: 09.2024.1183, date: 16.11.2024). The records of patients who presented to the university clinic for orthodontic treatment between 2018 and 2024 were reviewed using the following inclusion and exclusion criteria.

Inclusion criteria were:

- Cervical vertebral maturation stage 6
- All permanent teeth are present and normally erupted (3rd molars not evaluated)
- Having no impacted or supernumerary teeth
- Good-quality digital cephalometric radiographs and initial digital diagnostic models

Exclusion criteria were:

- Patients with craniofacial syndrome or deformity
- History of trauma
- Having previous orthodontic treatment
- Crowding greater than 8 mm
- Any environmental interventions or hereditary deviations that affect the size or form of teeth
- Patients with maxillary constriction

Missing Records

Two researchers reviewed more than 2000 patient records. Based on the inclusion and exclusion criteria, 200 patients were selected. A priori power analysis (G*Power software version 3.1.9.6; Heinrich-Heine-Universität, Düsseldorf, Germany) was performed based on the "Arch Length" parameter of the CI hyperdivergent group from a reference study.[14] Using an effect size of 0.52, an alpha level of 0.05, and a power of 95% for an F-test (ANOVA) across the six subgroups, the minimum total sample size required was calculated to be 84 subjects (14 per subgroup). To ensure robust statistical power, the final sample size was set at 20 patients per subgroup, resulting in a total of 120 patients. Lateral cephalometric radiographs were traced and analyzed using the NemoCeph program (Nemotec, Madrid, Spain) (Figure 1).

The initial data pool contained digital models acquired by both laboratory and intraoral scanners. To standardize the data acquisition method, models obtained via intraoral scanners were excluded from the study. The final sample consisted entirely of models digitized using a 3Shape E3 laboratory scanner (3Shape, Copenhagen, Denmark). Images were then saved as .stl (stereolithography) files.

The patients' sagittal and vertical skeletal parameters, dental parameters, ages, sexes, and the method of digital model acquisition were recorded in an Excel spreadsheet. Skeletal and dental characteristics were evaluated using frankfort-mandibular plane angle (FMA) (the angle between the Frankfort horizontal and mandibular plane), angles between the S-N plane and points A and B, respectively (SNB-SNA), UI-SN (the angle between the upper incisor axis and the S-N plane), and IMPA (the angle between the lower incisor axis and the mandibular plane) (Figure 1).

Sexual dimorphism is a well-established factor influencing dental arch dimensions, with males typically exhibiting larger

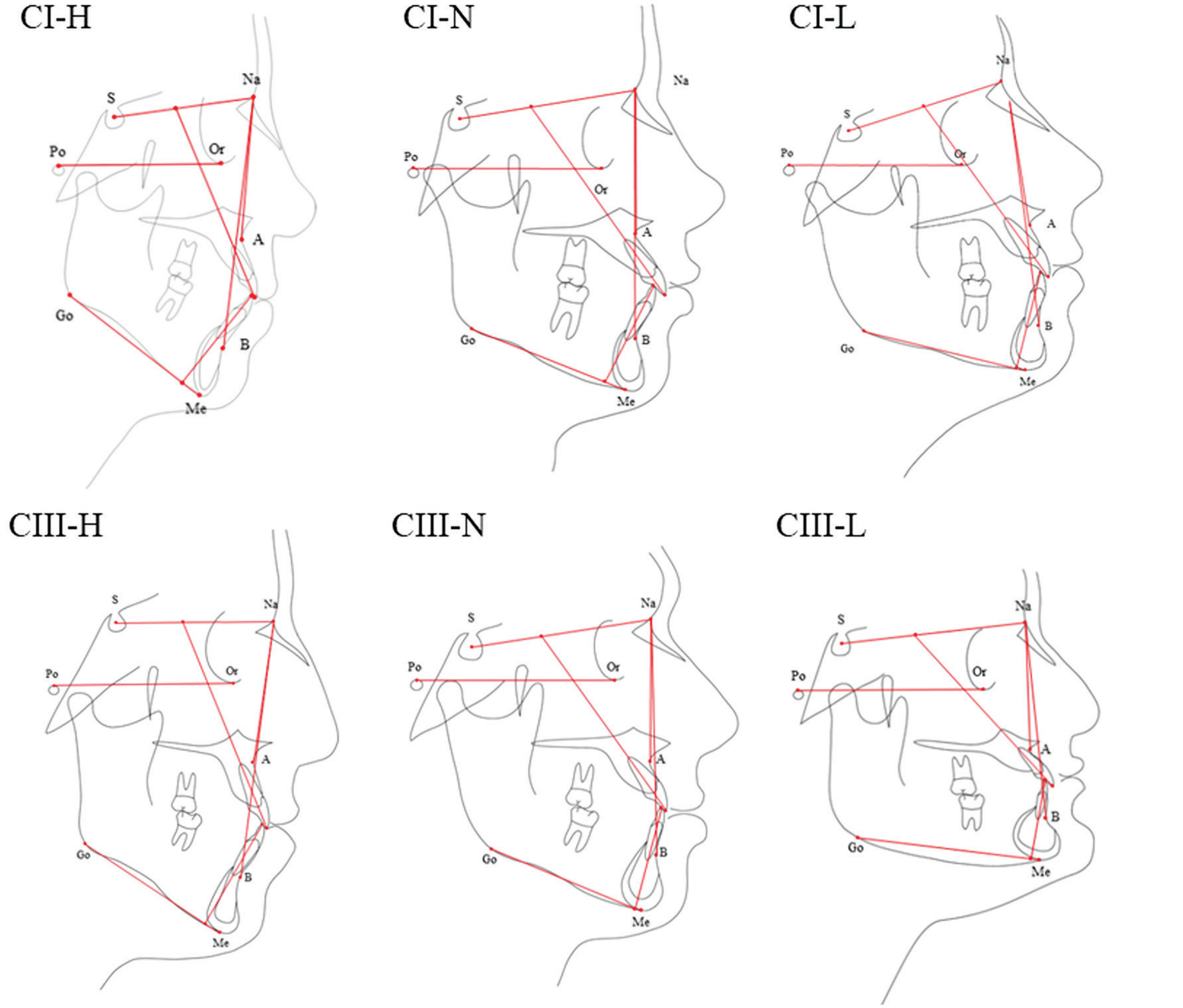

Figure 1. Lateral cephalometric measurement of each subgroup. CI: Class I; CIII: Class III; H: high-angle; N: normal-angle; L: low-angle. FMA inditcates angle between Frankfurt Horizontal plane (Po-Or) and mandibular plane (Go-Me). ANB indicates angle between A, N and B points, SNA indicates angle between S, N and A points. SNB indicates angle between S, N and B points. UI-SN indicates angle between upper incisor long axis and Sella-Nasion plane. IMPA indicates angle between lower incisor long axis and mandibular plane.

arch widths than females.[5] In the initial pool, the number of male patients was insufficient to form subgroups with statistical power. To eliminate sex as a confounding variable and to ensure high internal validity, male patients were excluded. Thus, homogeneity was maintained by restricting the sample to female patients.

Six subgroups were formed in total by combining two distinct sagittal groups (based on ANB angles and molar relationships) with three FMA-based groupings. The CI group was selected based on a bilateral CI molar relationship and an angle formed by point A, Nasion, and point B (ANB) of 0°-4°, whereas the CIII group was selected based on a bilateral CIII molar relationship and an ANB of <0°. Three subgroups were created within each sagittal group according to their FMA angles: low-angle vertical patterns (L) were those with FMA <22°, normal-angle vertical patterns (N) were those with FMA between 22 and 28°, and high-angle vertical patterns (H) were those with FMA >28°.[15,16] Finally, six groups were formed, each with 20 patients: CI-H, CI-N, CI-L, CIII-H, CIII-N, and CIII-L.

The dental parameters were measured separately for the maxilla and the mandible using 3D Slicer software (version 5.6.1; www.slicer.org) (Figure 2).[17] Dental measurements are:

Intermolar width (mm): Three-dimensional distance between mesiobuccal cusp tips of first molars on both sides (Figure 2).[14]

Intercanine width (ICW) (mm): Three-dimensional distance between cusp tips of canines on both sides (Figure 2).[14]

Intermolar angle (IMA) (°): Angle formed by the lines crossing the mesiobuccal and distobuccal cusps of the left and right first permanent molars (Figure 2).[18]

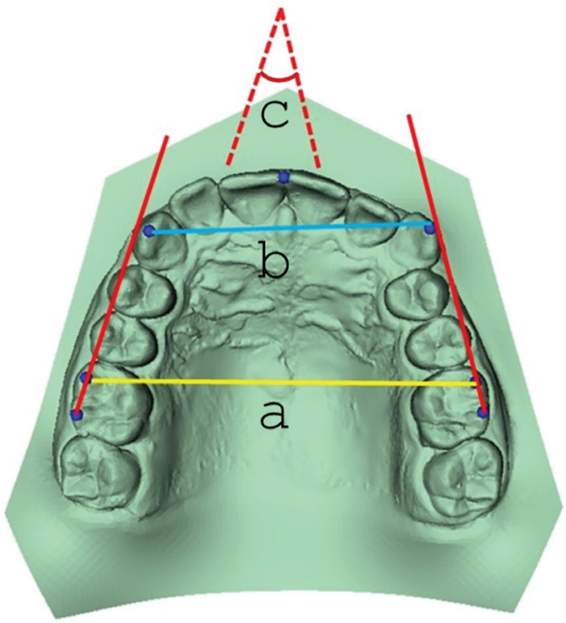

Figure 2. (a) Intermolar width; (b) Intercanine width; (c) Intermolar angle.

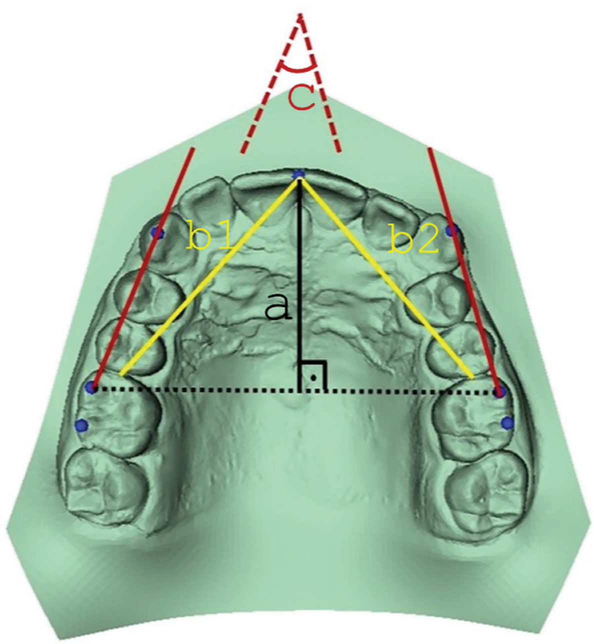

Figure 3. (a) Arch depth; (b) Arch length is the sum of b1 + b2; (c) Occlusal angle.

Arch depth (AD) (mm): Three-dimensional perpendicular distance from the most occlusal contact point of the central teeth to the line that connects mesiobuccal cusp tips of first molars on both sides (Figure 3).[14]

Arch length (AL) (mm): Sum of the three-dimensional distances from the most occlusal contact point of the central teeth to mesial surfaces of the first molars (Figure 3).[14]

Occlusal angle (OA) (°): The angle formed by the lines connecting the mesiobuccal cusp tip of the left first permanent molar to the left canine cusp tip and the mesiobuccal cusp tip of the right first permanent molar to the right canine cusp tip (Figure 3).[18]

To assess measurement reliability, 25 patients were randomly selected from the total sample. All dental and cephalometric parameters for these patients were remeasured by the main examiner (G.Y) after a 4-week interval to assess intra-examiner reliability, and by a second independent examiner (E.A.Ö) to assess inter-examiner reliability.

Statistical Analysis

IBM SPSS Statistics version 25.0 (IBM Corp., NY, USA) was used to conduct statistical analyses. ICC was used to assess both intra- and inter-examiner measurement reliability. The Shapiro-Wilk test was used to determine whether the data were normally distributed. One-way analyses of variance (ANOVA) and the Kruskal-Wallis test were used to determine intergroup differences. Parametric variables are presented as mean ± standard deviation with 95% confidence intervals; while nonparametric variables as median with interquartile range. For post-hoc pairwise comparisons, Tukey's honestly significant difference test was applied. Spearman's correlation analysis was performed to examine relationships between sagittal, vertical, and dental measurements. Statistical significance was set at $p<0.05$.

RESULTS

The mean ages and the mean and median values of FMA, ANB, SNA, and SNB angles for the groups are presented in Table 1. No significant differences in age were observed among the groups. No significant difference was found in the SNA angle between the CI and CIII subgroups (Table 1, p=0.416, p=0.554, respectively). Significant differences were detected in SNB angle between CI subgroups CI-H and CI-L and between CIII subgroups CIII-H and CIII-L (Table 1; p=0.027 and p=0.025, respectively). Regarding incisor inclinations, no significant differences in UI-SN angle were observed among subgroups of either CI or CIII patients (Table 1, p=0.662, p=0.250, respectively). Similarly, no significant difference in IMPA was found among CI subgroups (Table 1, p=0.433). However, IMPA values differed significantly among CIII vertical subgroups (Table 1, p=0.002). Pairwise comparisons indicated that the CIII-H subgroup had significantly lower IMPA values than the CIII-N and CIII-L subgroups.

ICC analyses demonstrated high reliability for all skeletal and dental measurements. Intra-examiner reliability coefficients ranged from 0.947 to 0.975, indicating excellent reproducibility, and inter-examiner reliability coefficients ranged from 0.910 to 0.960, demonstrating excellent agreement between the two examiners.

In the Maxillary Dental Measurements

Statistically significant differences in IMW and IMA were found between groups (Table 2; p=0.004 and p=0.003, respectively). ICW, OA, AL, and AD parameters were not significant.

Table 1: Descriptive statistics of study sample

					FMA (°)		ANB (°)		SNA (°)			SNB (°)			UI-SN (°)			IMPA (°)		
	Age (years)	p	n	Gender	Mean±SD	Median	Mean±SD	Median	Mean±SD	Median	p	Mean±SD	Median	p	Mean±SD	Median	p	Mean±SD	Median	p
CI-H	18.75±2.43	0.554	20	f (100%)	32.4±2.89	32	2±1.41	2	79±2.38	80	0.416	76.95±2.74^{A}	77	0.027*	104.8±6.59	104.5	0.662	89.85±6.58	90	0.433
CI-N	16.85±2.47		20	f (100%)	25.15±2.28	25.5	1.85±1.31	2	80±2.83	81		78.5±2.47^{AB}	79		103.2±5.26	102		90.75±5.74	90	
CI-L	18.13±1.89		20	f (100%)	19.2±2.35	20	2±1.52	2	81.1±3.6	82		79.5±3.35^{B}	80		103.25±6.96	104		92.45±6.86	90	
CIII-H	20.12±2.17		20	f (100%)	32.85±3.67	32	-2.85±2.16	-2.5	80.25±4.77	80	0.554	82.5±4.27^{A}	82.5	0.025*	109.5±7.21	110	0.250	79±5.54^{A}	78.5	0.002*
CIII-N	20.75±1.19		20	f (100%)	26±1.97	26.5	-4.2±2.8	-4	81.3±3.56	80.5		85.5±3.56^{AB}	84		113.05±7.74	113		85.3±8.27^{CB}	86.5	
CIII-L	17.80±1.09		20	f (100%)	18.6±3.97	20.5	-4.3±3.2	-3.5	81.85±3.03	81.5		85.9±3.24^{B}	85.5		113.15±8.39	113		87.35±8.12^{BC}	87	

Values are presented as mean ± standard deviation. "f" indicates female. CI-H: Class I High Angle Vertical Pattern; CI-N: Class I Normal Angle Vertical Pattern; CI-L: Class I Low Angle Vertical Pattern; CIII-H: Class III High Angle Vertical Pattern; CIII-N: Class III Normal Angle Vertical Pattern; CIII-L: Class III Low Angle Vertical Pattern. FMA indicates the angle between the Frankfurt Horizontal plane and the mandibular plane. ANB indicates the angle between points A, N, and B; SNA indicates the angle between points S, N, and A. SNB indicates the angle between points S, N, and B. UI-SN indicates the angle between the upper incisor long axis and the Sella-Nasion plane. IMPA indicates the angle between the long axis of the lower incisor and the mandibular plane. A, B, C: The same letters indicate that there were no statistically significant differences between interaction groups. "p" values for one-way analyses of variance (ANOVA) test. *p<0.05.

Pairwise comparisons revealed a significant difference in IMW between CI-H (50.3±2.1 mm) and CIII-L (53.4±3.8 mm) groups (Table 2, p=0.004). IMA values also significantly differed between CI-N (23.1±12°) and CIII-N (35±10.9°), and between CI-L (22.7±8.9°), and CIII-N (35±10.9°) (Table 2, p=0.003). No significant differences in vertical patterns among CI subgroups were observed for any parameter. No significant differences were observed among the CIII vertical pattern subgroups for any of the parameters.

In the Mandibular Measurements

Statistically significant differences in IMW and OA were found between groups (Table 3, p=0.002 for both). ICW, IMA, AL, and AD parameters were not statistically significant.

Pairwise comparisons revealed a significant difference in IMW between the CI-H (43.3 mm) and CIII-L (47.4 mm) groups (Table 3, p=0.002). OA values also showed significant differences between CI-N (45.7°) and CIII-H (58.3°) and between CI-N (45.7°) and CIII-L (56.5°) (Table 3, p=0.002). There were no significant differences in vertical-patterns of CI subgroups in any of the parameters. There were also no significant differences in vertical patterns of CIII subgroups across any of the parameters.

Spearman's correlation analysis showed that none of the dental measurements were associated with the FMA angle. IMW had a weak negative correlation with the ANB angle at the maxilla and a moderate positive correlation with the ANB angle at the mandible (p=0.001, p<0.001, respectively, Table 4). IMA showed a moderate negative correlation with ANB in the maxilla and a weak negative correlation in the mandible (p<0.001 and p=0.037, respectively; Table 4). OA had a weak positive correlation with ANB at the maxilla and a weak negative correlation with it at the mandible (p=0.018, p=0.002, respectively; Table 4).

DISCUSSION

In the literature, studies of dental arch parameters have reported that dental width decreases with increasing vertical dimension.[3-5] Current research indicates that, when analyzing the relationship between dental arch characteristics and vertical patterns, researchers often overlook sagittal malocclusions or assess dental parameters solely within the same sagittal malocclusion classification, disregarding vertical discrepancies.[5,11-13] In the study by Ocak et al.[14] focused on Class II (CII) malocclusion cases, vertical categorization was applied, and it was revealed that both sagittal and vertical morphology significantly influenced dental arch characteristics. Similarly, Grippaudo et al.[19] divided CII individuals into three separate vertical-patterns and reported a connection between vertical-patterns and ICW. However, the effects of vertical facial patterns on dental characteristics of CIII patients have not been investigated previously. Therefore, this study aimed to examine the dental arch parameters of CIII patients with different vertical patterns and to compare their results with those of their CI counterparts. To accurately measure arch parameters and maintain group homogeneity, patients requiring skeletal expansion for maxillary hypoplasia were excluded from the study. To account for the impact of sex on dental parameters, only female patients were included in the study because previous reports have indicated that dental arch width is larger in males than in females.[5,6,20]

With the development of technology, digital modeling has replaced analog modeling. In this study, digital models obtained before treatment were used. Previous studies comparing digital and manual measurements concluded that there was no significant difference between the two methods, regardless of crowding.[21,22]

Statistical analyses revealed a significant difference in SNB angles between the low- and high-angle subgroups within each main group. Ghafari and Macari[23] reported that in patients exhibiting increased vertical growth, chin and B point shifted posteriorly due to the clockwise rotation of the mandible. This may explain the significant disparity in SNB angle between the low- and high-angle subgroups.

In the present study, no differences were observed between vertical patterns within the same sagittal malocclusion groups. As a result, vertical patterns did not significantly affect the dental parameters within each group with the same sagittal skeletal relationship. AL, AD, and ICW did not show any differences between groups and were unaffected by either

Table 2. Maxillary measurements

Maxillary measurements	Class I groups			Class III groups			
	CI-H	CI-N	CI-L	CIII-H	CIII-N	CIII-L	p
Intermolar width (IMW) (mm)	50.3±2.1^{B} (49.3-51.3)	50.5±3.1^{AB} (49.0-51.9)	51.2±3.1^{AB} (49.8-52.7)	52.8±3.1^{AB} (51.3-54.2)	53.2±4^{AB} (51.3-55.0)	53.4±3.8^{A} (51.6-55.1)	0.004**
Intercanine width (ICW) (mm)	33.7±2.8 (32.4-35.1)	33.5±3.4 (31.9-35.1)	34.3±2.3 (33.2-35.3)	33.9±2.4 (32.8-35.1)	35±2.6 (33.8-36.2)	34.6±3.2 (33.1-36.2)	0.541
Intermolar angle (IMA) (°)	24.5±13 ^{ABC} (18.5-30.6)	23.1±12 ^{A} (17.5-28.7)	22.7±8.9 ^{AC} (18.5-26.8)	29.1±12.1^{ABC} (23.5-34.8)	35±10.9^{B} (29.9-40.1)	31.7±11.6^{ABC} (26.3-37.1)	0.003**
Occlusal angle (OA) (°)	46.3±9.8 (41.7-50.9)	45.5±8.9 (41.3-49.6)	46.8±7.9 (43.2-50.5)	50.2±8 (46.4-53.9)	48.3±8.6 (44.2-52.3)	51.04±8.9 (47.3-55.6)	0.217
Arch length (AL) (mm)	68±2.8 (66.7-69.3)	68.5±3.9 (66.7-70.3)	68±3.3 (66.4-69.5)	68.6±2.8 (67.3 -69.9)	70±4.9 (67.8-72.3)	70.2±4.4 (68.1-72.2)	0.237
Arch depth (AD) (mm)	27.5±2 (26.6-28.5)	27.6±2.4 (26.5-28.7)	27±2.2 (25.9-28)	26.9±1.9 (26.0-27.8)	27.5±2.4 (26.4-28.6)	27.6±2.4 (26.5-28.7)	0.796

Values are presented as mean ± standard deviation (95% confidence interval). CI-H, Class I High-Angle Vertical Pattern; CI-N, Class I Normal-Angle Vertical Pattern; CI-L, Class I Low-Angle Vertical Pattern; CIII-H, Class III High-Angle Vertical Pattern; CIII-N, Class III Normal-Angle Vertical Pattern; CIII-L, Class III Low-Angle Vertical Pattern. A, B, C: The same letters indicate that there were no statistically significant difference between interaction groups. "p" values for one-way analyses of variance(ANOVA)test. * p<0.05, ** p<0.01.

Table 3. Mandibular measurements

Mandibular measurements	Class I Groups			Class III Groups			
	CI-H	CI-N	CI-L	CIII-H	CIII-N	CIII-L	p
Intermolar Width (IMW) (mm)	43.3 (40.8-44.0)^{A}	43.2 (40.7-45.8)^{AB}	43.1 (40.9-46.3)^{AB}	46.5 (43.6-48.1)^{AB}	45.9 (41.8-49.2)^{AB}	47.4 (43.2-49.1)^{B}	0.002**
Intercanine Width (ICW) (mm)	26.6 (24.4-27.4)	26.7 (25.5-27.9)	26 (23.9-26.9)	25.9 (25.0-27.8)	26.5 (25.3-29.6)	26.5 (25.7-28.3)	0.227
Intermolar Angle (IMA) (°)	41.2 (34.1-52.6)	42.3 (35.1-49.7)	45.5 (41.0-51.8)	48.6 (42.0-55.1)	42.7 (37.0-59.3)	47.5 (41.5-60.3)	0.169
Occlusal Angle (OA) (°)	49.2 (41.3-54.3)^{AB}	45.7 (40.4-51.3)^{A}	49.6 (45-61.1)^{AB}	58.3 (49.0-69.2)^{B}	52.1 (45.1-57.1)^{AB}	56.5 (51.2-64.9)^{B}	0.002**
Arch Length (AL) (mm)	57.9 (55.7-58.8)	58 (56.3-59.6)	57.5 (55.7-59.1)	57.4 (55.2-59.2)	58.6 (56.5-64.8)	59.3 (56.8-62.0)	0.167
Arch Depth (AD) (mm)	22.9 (21.5-23.7)	23.2 (22.1-23.7)	22.7 (21.2-23.7)	21.7 (20.1-23.1)	23.6 (22.0-25.2)	22.2 (20.7-24.2)	0.062

Values are presented as median (IQR, 25^{th}-75^{th} percentiles). CI-H indicates Class I High Angle Vertical Pattern; CI-N, Class I Normal Angle Vertical Pattern; CI-L, Class I Low Angle Vertical Pattern; CIII-H, Class III High Angle Vertical Pattern; CIII-N, Class III Normal Angle Vertical Pattern; CIII-L, Class III Low Angle Vertical Pattern. A, B, C: The same letters indicate that there were no statistically significant difference between interaction groups. "p" values for Kruskal-Wallis test. *p<0.05, **p<0.01.

sagittal or vertical patterns. IMA showed a significant difference in the maxilla (between CI-N and CIII-N, and between CI-L and CIII-N), whereas OA showed a significant difference in the mandible (between CI-N and CIII-H, and between CI-N and CIII-L). IMW was the parameter that most consistently showed significant differences between CI-H and CIII-L in both jaws. Studies have characterized the taper of the arches using measurements such as IMA and IMW.[18] In this study, maxillary IMA and mandibular OA were affected by different sagittal malocclusions and vertical patterns. From this perspective, CIII-N patients have a more tapered maxillary arch than CI-N patients due to differences in IMA. In the mandible, the most tapered subgroup was the CIII-L group when considering both OA and IMW. According to Grippaudo et al.,[19] the mandibular arch form is more V-shaped in individuals with low-angles and ovoid in those with high-angles, which partially supports our findings. In support of Grippaudo et al[19], when the mandibular OA and IMW values were taken into consideration in the CIII-L subgroup, it was found to be the group with the most tapered arches. However, examined in terms of maxillary IMA, our results showed that CIII-N sugbroups had more tapered arch characteristics than the CI-L subgroup, which was contrary to the results reported by Grippaudo et al.[19] In contrast, Ciavarella et al.[18] reported that a V-shaped arch was observed in patients with more high-angle individuals. However, unlike this study, the patients included in the study conducted by Ciavarella et al.[18] were not adults. Considering that IMA and OA can be affected by the buccolingual inclinations and rotations of the teeth, it may be safer to comment on arch taper based on IMW and ICW. While ICW did not show any differences in either the maxillary or the mandibular arch, IMW was increased in CIII-L. One may argue that, among CIII-L individuals, females have more tapered arch forms than other subgroups. However, this assumption contradicts the literature. Slaj et al.[24] stated that CIII individuals had more square-shaped arches, but in their study, vertical assessment was ignored. Kook et al.[25] examined arch forms according to ethnicity and malocclusion and stated that white CI groups had more tapered arches than others. Ethnic differences, sex differences, and differences in vertical values may underlie this conflict. This issue warrants clarification in future studies.

Uysal et al.[11] compared patients with CI and CIII malocclusions and found that maxillary and mandibular IMW were significantly different between these two malocclusions, similar to our results. While there was no significant difference in maxillary ICW in our study, they found a significant difference in mandibular ICW, which differs from our study. The fact that Uysal et al.[11] did not include vertical evaluations may be the reason for these differences. Braun et al.[26] reported that CIII individuals had greater dental arch widths than CI individuals, which was in accordance with this study. However, in their study, the vertical facial pattern was ignored.

Suk et al.[13] evaluated the mandibular dental and basal arch forms of patients with CI and CIII malocclusion using cone-beam computed tomography. They concluded that there was a difference in ICW but not in IMW. However, in their research, sex and vertical patterns were not considered. Koo et al.[12] examined dental casts and CT images to perform transverse evaluation of CI and CIII individuals with normal-vertical patterns and reported no significant difference in IMW and ICW between the groups for both arches, similar to the normal-angle subgroups of both CI and CIII individuals in this study. While their maxillary ICW in the CIII group was similar to that in this study, they found it to be 2.9 mm greater in the CI group.[12] However, they found that the maxillary IMW in the CI group was 4.8 mm greater and the maxillary IMW in the CIII group was 2.5 mm greater compared with our study.[12] Koo et al.[12] reported 1.5 mm and 1 mm greater mandibular ICW, 3.7 mm and 1.9 mm greater mandibular IMW respectively in the CI and CIII groups, compared to our study. The reason for these differences may be regional differences based on where the individuals in the samples were recruited, or the fact that there were only female individuals in this study, while sex was not taken into consideration in the Koo et al.'s[12] study.

Önçağ et al.[27] categorized skeletal CI, CII, and CIII patients based on their vertical-patterns and analyzed their arch widths, finding no significant differences among the categories. The difference in reported results, despite the study involving a similar population to ours, may be attributed to the inclusion of individuals aged 15-18, whose growth and development could still be in progress.

Table 4. Evaluation of the relationship between sagittal and vertical values and dental measurements

	Intermolar width (IMW) (mm)		Intercanine width (ICW) (mm)		Intermolar angle (IMA) (°)		Occlusal angle (OA) (°)		Arch length (AL) (mm)		Arch depth (AD) (mm)	
	Maxillary Arch											
	r	p	r	p	r	p	r	p	r	p	r	p
ANB (°)	-0.287	0.001**	-0.045	0.628	-0.360	<0.001***	0.216	0.018*	0.058	0.529	0.112	0.224
FMA (°)	-0.121	0.190	-0.091	.325	0.041	0.657	0.060	0.518	0.096	0.297	-0.036	0.699
	Mandibular Arch											
ANB (°)	0.344	<0.001***	-0.141	0.124	-0.191	0.037*	-0.284	0.002**	-0.134	0.146	0.096	0.298
FMA (°)	0.105	0.254	-0.080	0.386	-0.040	0.665	-0.062	0.501	-0.096	0.295	-0.031	0.738

FMA inditcates angle between Frankfurt Horizontal plane and mandibular plane. ANB indicates angle between A, N and B points, SNA indicates angle between S, N and A points. "p" values for Spearman correlation analysis.*p<0.05, **p<0.01, ***p<0.001

Dentoalveolar compensation is an important factor in maintaining interarch relationships, particularly with respect to the influence of CIII malocclusions on arch formation.[28] The compensatory mechanism helps maintain anterior tooth relationships through labial proclination of the maxillary incisors and lingual retroclination of the mandibular incisors, thereby compensating for the severity of the malocclusion. The literature suggests that the degree of dentoalveolar compensation may be related to vertical patterns in CIII cases.[28] In the present study, this relationship was demonstrated by the significantly lower IMPA values observed in the CIII-H subgroup, suggesting greater mandibular incisor retroclination as a compensatory mechanism in hyperdivergent patterns. The presence and degree of compensation are determinants of the decision to perform orthognathic surgery with camouflage treatment, especially in adult borderline CIII cases.[9] Therefore, when evaluating the effects of vertical patterns on arch dimensions, consideration of underlying dentoalveolar compensation mechanisms is crucial to individualize treatment planning.[28]

Based on the results of this study, the null hypothesis was partially rejected because some dental arch parameters differed significantly among subgroups. One of the limitations of the study was that it was conducted in a single-sex group, which restricts the applicability of the findings to mixed-sex populations. This modification to the sample selection was made to address issues related to sexual dimorphism arising from an insufficient initial sample size of males. This enhances internal validity by removing a potential confounder. However, further studies with larger samples that include both sexes are necessary to determine whether vertical patterns similarly influence male arch dimensions. The vertical pattern was characterized solely by the FMA; the inclusion of supplementary vertical indicators such as SN-MP or the Y-axis might have yielded a more thorough evaluation. The retrospective design introduced inherent selection bias, which may also limit the generalizability of the findings. Larger cohorts and different age groups would enhance generalizability. Consequently, it is recommended that future research incorporate both advanced morphometric analyses and 3-D radiographic imaging for a more thorough examination of dental and basal parameters. Clinically, these findings highlight that arch dimensions are not uniform across vertical patterns. Therefore, during treatment planning, archwire selection and individualized arch forms, considering the patient's vertical growth pattern, are essential to ensure stability and avoid iatrogenic expansion or relapse.

CONCLUSION

IMW is affected by sagittal and vertical patterns. The highest IMW value in both the maxilla and the mandible was found in the CIII-L group. It is recommended to consider this difference in diagnosis and treatment planning or to implement different restorative techniques, especially when choosing prefabricated wires for use in CIII-L individuals. ICW, AL, and AD are not affected by sagittal and vertical patterns. IMA at the maxillary arch and OA at the mandibular arch can be affected by sagittal and vertical-patterns. Since some dental arch measurements can be affected by vertical parameters, individualized arch forms should be applied based on the patient's initial intraoral condition and treatment objectives.

Ethics

Ethics Committee Approval: Ethical approval was obtained from the Faculty of Medicine, Marmara University (approval number: 09.2024.1183, date: 16.11.2024).

Informed Consent: Written informed consent was obtained from all participants, or from the legal guardians of those under 18 years of age.

Footnotes

Author Contributions:

Concept – G.Y., E.A.Ö., Y.B.A.; Design – G.Y., Y.B.A.; Data Collection and/or Processing – E.A.Ö.; Analysis and/or Interpretation – G.Y., E.A.Ö., Y.B.A.; Literature Search –E.A.Ö., Y.B.A.; Writing – G.Y., Y.B.A.

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Original Article

The 100 Most Cited Studies on Impacted Canines: A Bibliometric Analysis Study

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Main Points

- The most influential literature on impacted canines is predominantly composed of observational studies, highlighting a need for higher-level evidence such as randomized controlled trials and systematic reviews.
- Highly cited research primarily focuses on the etiology, radiographic assessment, and associated dental anomalies of impacted maxillary canines.
- Despite the large body of literature, key areas including mandibular canine impactions, periodontal outcomes, and long-term treatment effects remain underexplored.

ABSTRACT

Objective: To evaluate the scientific literature on impacted canines using bibliometric and altmetric analyses.

Methods: A systematic search of the Web of Science Core Collection was performed using keywords related to impacted canines. Three independent reviewers identified, screened, and evaluated the 100 most-cited articles. Citation data were cross-verified with Scopus and Google Scholar. Extracted information included citation counts, study design, publication year, authors, institutions, journals, and countries. Bibliometric mapping was conducted using VOSviewer, and altmetric indicators were obtained from dimensions. Statistical analysis was performed using Spearman's rank correlation, with significance set at $p<0.05$.

Results: The 100 most-cited articles received 10,429 citations in the Web of Science, and citation counts were strongly correlated across databases ($p<0.001$). Most studies were observational (69%), followed by narrative reviews (12%) and interventional studies (10%). Research topics primarily addressed the etiology, radiographic assessments, and associated anomalies. The most cited article in the Web of Science database was Ericson and Kurol's 1988 study on the interceptive extraction of primary canines. Publications were concentrated in orthodontic specialty journals, with the USA, Italy, and Israel being the leading countries.

Conclusion: Analysis of the 100 most-cited articles revealed that influential research on impacted canines is predominantly, focusing on etiology and diagnosis. Areas such as mandibular impactions, periodontal outcomes, and long-term treatment effects remain underexplored.

Keywords: Cuspid, impacted tooth, bibliometrics

INTRODUCTION

Tooth impaction is defined as the condition in which a fully formed tooth is obstructed from erupting into its intended functional position within the dental arch.[1] Maxillary canines are the second most commonly impacted teeth after third molars,[2] with a reported prevalence of 0.92% to 2.2% and a female-to-male ratio of approximately 2:1.[3,4] While maxillary impacted canines are more commonly located on the palatal side than the labial side,[5] mandibular canine impactions are less frequent, with a reported prevalence of 0.35%.[4]

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Although the etiology of impacted canines is complex and not fully understood, it is thought to arise from the interaction among genetic, systemic, and local factors.[6,7] Various local factors are believed to be critical, including discrepancies between tooth size and arch length,[6,8] prolonged retention, early loss or failure of the primary canine root to resorb, and ankylosis of the permanent canine.[7] Other contributing causes may include the presence of a cyst or neoplasm, or the absence of, or variation in, the size or root formation of the maxillary lateral incisor.[7] Insufficient arch length is considered the most common cause of labially impacted canines.[9] In contrast, the widely accepted "guidance theory" proposes that the eruption of maxillary canines is directed by the root of the adjacent lateral incisor. In cases where this incisor is absent or malformed, the canine lacks guidance and becomes palatally impacted.[10-14]

The proper positioning of the canine teeth in the dental arch is integral to the development of a stable functional occlusion and contributes significantly to both smile and facial aesthetics. Consequently, an unmanaged canine impaction presents considerable clinical challenges, with potential complications including malocclusion, aesthetic impairment, abnormal craniofacial growth, and root resorption of adjacent teeth.[15]

The diagnosis of impacted canines is often made incidentally during routine dental examinations. Early detection and timely intervention, typically involving a combination of surgical and orthodontic procedures, are essential for achieving functional and aesthetic outcomes. Successful management frequently requires a multidisciplinary approach, with collaboration among orthodontists, pediatric dentists, periodontists, oral surgeons, and general practitioners.[15] Consequently, the diagnosis and management of impacted canines have become a central topic in both clinical practice and academic research.

In recent years, bibliometric analysis has become an essential tool for navigating rapidly growing scientific literature. This quantitative approach uses statistical methods to analyze academic publications by revealing research trends, mapping the intellectual structure of a field, and highlighting areas for future investigation.[16] A fundamental aspect of this methodology is the use of citation count to measure scholarly impact. Consequently, citation metrics serve as key indicators of a publication's influence on both contemporary research and clinical applications.[17-19] As the volume of published research continues to increase, bibliometrics provides a structured means of evaluating the quantity, relevance, and interconnectedness of scholarly work within a given domain.[19,20]

Altmetric analysis complements traditional bibliometrics by assessing the online attention given to research articles.[16] It collects data from social media, news outlets, and reference managers to calculate the Altmetric Attention Score (AAS), where higher scores indicate greater visibility and engagement. Unlike citation-based metrics, altmetrics enable the rapid recognition of recent studies and provide insights into societal impacts through digital mentions and discussions.[21,22]

In recent years, there has been a notable increase in studies and reviews investigating the etiology and management of impacted canines. However, to the best of our knowledge, no bibliometric or mapping analyses have been conducted to systematically evaluate the structure, trends, and impact of the scientific literature on this topic. Therefore, the aim of this study was to perform a comprehensive bibliometric and altmetric analysis of publications related to impacted canines.

METHODS

This study adhered to the BIBLIO guidelines for reporting bibliometric research in the biomedical field.[23] Since this study did not involve human participants, animal subjects, or access to personal data, ethical approval was not required. A systematic literature search was conducted in the Web of Science Core Collection (WoS-CC) on August 26, 2025, to identify relevant studies. The studies included were selected based on the following search methodology: ALL=(""impacted canine*") OR ALL=("ectopic canine*") OR ALL=("unerupted canine*") OR ALL = ("displaced canine*") OR ALL = ("impacted cuspid*") OR ALL = ("ectopic cuspid*") OR ALL = ("unerupted cuspid*") OR ALL = ("impacted maxillary canine*") OR ALL = ("unerupted maxillary canine*") OR ALL = ("displaced maxillary canine*") OR ALL = ("canine impaction*") OR ALL = ("cuspid impaction*") OR ALL = ("impaction of canine") OR ALL = ("ectopic eruption of canine").

The articles were screened according to the predefined inclusion criteria. Studies exploring, describing, or relating to impacted canines in the context of orthodontics and their surgical management were included in this bibliometric analysis, with no restrictions on publication year or language. Publications unrelated to this relationship were excluded.

Articles selected from WoS-CC were sorted by citation count in descending order. The top 100 most-cited studies were reviewed and selected by three independent researchers (M.G.K., G.A.S., and C.S.) based on titles and abstracts and on full

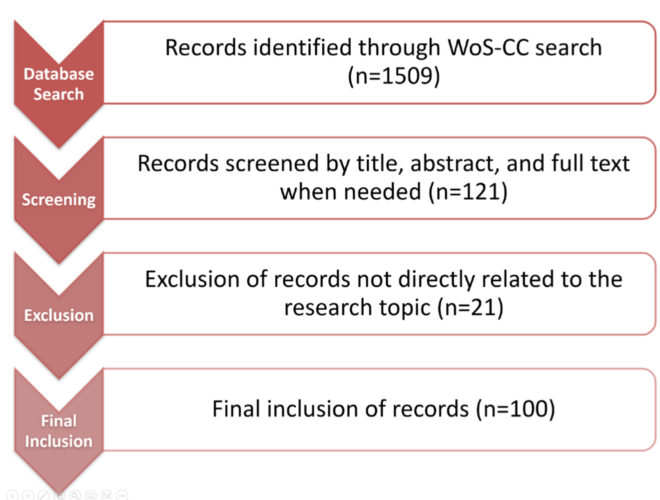

Figure 1. Flow chart of the study selection process.

texts when necessary (Figure 1).[16] Disagreements were resolved through discussion to achieve consensus, which served as the validation method for the screening and classification process. To ensure accuracy, citation counts were compared with data from Scopus and Google Scholar, as these databases differ in indexing, which could affect bibliometric results. For articles with the same number of citations, rankings were determined by dividing the number of citations by the number of years since publication.[24]

Information extracted from the selected articles included the title, language, number of authors and their names, and citation metrics (total citations and self-citations). Self-citations were defined as citations in which the citing document shared at least one author with the cited document, as identified using the Web of Science Citation Report tool.[25] Additionally, affiliated institutions, country of origin, publication year, journal name, 2024 journal impact factor (IF; as reported in Journal Citation Reports), keywords, study design, and topics were recorded. The study designs were categorized as systematic reviews, narrative/literature reviews, interventional studies, observational studies, case reports or case series, and preliminary research. Furthermore, the articles were grouped thematically into the following categories: etiology and prevalence, radiographic assessment and diagnosis, interceptive treatment, surgical-orthodontic management, treatment outcomes and clinical considerations, associated dental anomalies and dentoskeletal characteristics, and complications and risk factors.

Bibliometric networks were visualized using VOSviewer (version 1.6.20, the Netherlands). In the maps generated, the size of each node represents the frequency or strength of the data, whereas items of the same color and those clustered together indicate underlying correlations.

Altmetric indicators were obtained from the Dimensions platform (dimensions.ai) on August 26, 2025, the same day that data were extracted from the WoS-CC. The specific indicators analyzed included the AAS, mentions in news outlets, blogs, policy documents, social media (X/Twitter and Facebook), and reference-manager saves (Mendeley).

Statistical Analysis

Data normality was assessed using the Kolmogorov-Smirnov test, and the relationships between variables were analyzed using Spearman's rank correlation coefficient. All statistical analyses were performed using SPSS version 26.0 (IBM, Armonk, NY, USA), and statistical significance was set at $p<0.05$.

RESULTS

Of the 1,509 documents initially found in the WoS-CC database, 121 articles with the highest citation counts were reviewed for relevance by examining their titles, abstracts, and full texts. After screening, 21 articles were excluded because they were not directly related to the research topic. The final selection included the 100 most cited and relevant studies (Supplementary Table 1). Although no language restrictions were applied during screening, all included articles were published in English.

The 100 most-cited articles received 10,429 citations in the WoS-CC, with citation counts ranging from 48 to 402 and a median of 77.5. Among these, 581 were self-citations, accounting for 5.6% of the total. Approximately 36.0% of the articles had more than 100 citations, and 9.0% had 200 or more. By comparison, the same articles received 28,568 citations in Google Scholar (range: 59-1,353; median: 216.5) and 12,439 citations in Scopus (range: 55-470; median: 89.5). Citation counts across the three databases showed strong positive correlations between WoS-CC and Google Scholar ($\rho=0.878$, $p<0.001$), Google Scholar and Scopus ($\rho=0.900$, $p<0.001$), and WoS-CC and Scopus ($\rho=0.929$, $p<0.001$).

The most-cited article was "Early treatment of palatally erupting maxillary canines by extraction of the primary canines" by Ericson and Kurol (1988), published in the European Journal of Orthodontics; it received 402 citations in WoS-CC and 470 in Scopus. In contrast, the article with the highest citation count on Google Scholar was "Impacted maxillary canines: a review" by Bishara,[3] published in 1992 in the American Journal of Orthodontics and Dentofacial Orthopedics; it received a total of 1,353 citations.

Among the selected studies, the oldest article, "Diagnosis and prevention of maxillary cuspid impaction" by Williams (1981), was published in Angle Orthodontist and has received 51 citations. The most recent article, "Impaction of maxillary canines and its effect on the position of adjacent teeth and canine development: A cone-beam computed tomography study", by Dekel (2021) was published in the American Journal of Orthodontics and Dentofacial Orthopedics and received 57 citations.

The 100 most cited articles received the largest number of citations in 2001-2010 (4,089 citations, 39.2%), followed by 1991-2000 (2,635 citations, 25.3%), 2011-2021 (2,078 citations, 19.9%), and 1981-1990 (1,627 citations, 15.6%). There was a marked increase in publications after 2000, with 74.0% of the articles published during this period, accounting for 6,578

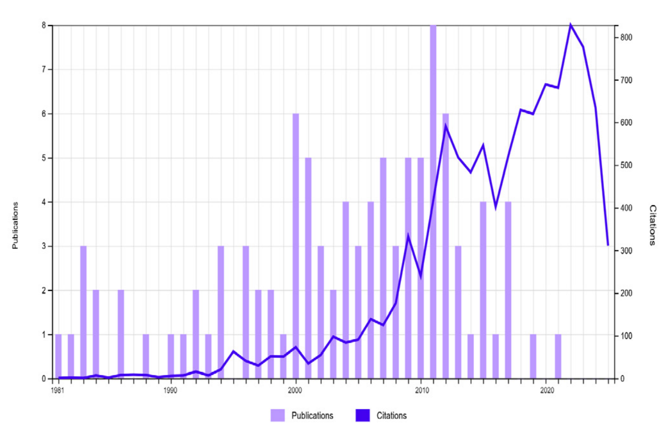

Figure 2. Distribution of publications and citations of the 100 most cited studies on impacted canines over time.

citations (63.1%) (Figure 2). Spearman's correlation showed a weak negative association between the number of citations in the WoS-CC and the year of publication (p=-0.325, p=0.001).

The American Journal of Orthodontics and Dentofacial Orthopedics was the most prominent journal in terms of the number of publications, with 39 articles (4,011 citations; 38.5%), followed by the European Journal of Orthodontics with 23 articles (2,678 citations; 25.7%) and Angle Orthodontist with 16 articles (1,704 citations; 16.3%). According to the 2024 Journal Citation Reports, the Journal of Dental Research had the highest IF and contributed two of the selected studies (IF 5.9, 223 citations, 2.1%), followed by Dentomaxillofacial Radiology with two of the selected studies (IF 4.1, 192 citations, 1.8%), and the Journal of the American Dental Association with three of the selected studies (IF 3.5, 378 citations, 3.6%) (Table 1).

Most included articles were observational studies (69 publications; 7,014 citations; 67.2%), followed by narrative or literature reviews (12 publications; 1,612 citations; 15.5%) and interventional studies (10 publications; 1,064 citations; 10.2%). Fewer studies were classified as systematic reviews (4 publications; 374 citations; 3.6%) or as case reports/series (3 publications; 231 citations; 2.2%). Additionally, one study used an *in vitro* design (66 citations, <1%), and another was a preliminary study (68 citations, <1%).

The majority of the selected articles focused on associated dental anomalies and dentoskeletal features (25 publications, 2,342 citations, 22.5%). This was followed by radiographic assessment and diagnosis (19 publications, 1,877 citations, 18.0%) and etiology and prevalence (17 publications, 2,296 citations, 22.0%). Studies investigating complications and risk factors accounted for 15 of the articles (1,536 citations, 14.7%), while surgical-orthodontic management was the main topic of 12 studies (1,200 citations, 11.5%). Fewer studies focused on interceptive treatment (9 publications; 991 citations; 9.5%), and only three addressed periodontal outcomes and clinical considerations (187 citations; 1.8%). Most studies focused on maxillary impacted canines, whereas only three specifically investigated mandibular impacted canines, highlighting the limited attention this topic has received in the literature.

A total of 277 authors contributed to the 100 most cited articles on impacted canines. Figure 3 illustrates the frequency of their appearances and their co-authorship relationships. Becker A was the author with the highest number of publications (15 publications; 1,209 citations; 11.6%), followed by Baccetti T (9 publications; 978 citations; 9.4%), and Chaushu S (9 publications; 688 citations; 6.6%) (Table 2).

Table 1. Top 10 journals with the most articles in the 100 most cited article list

Journal	Number of articles	Number of citations (WoS-CC)	Impact factor 2024
American Journal of Orthodontics and Dentofacial Orthopedics	39	4011	3.0
European Journal of Orthodontics	23	2678	2.7
Angle Orthodontist	16	1704	3.2
Journal of the American Dental Association	3	378	3.5
Journal of Dental Research	2	223	5.9
Dentomaxillofacial Radiology	2	192	4.1
Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontology	1	147	-
Community Dentistry and Oral Epidemiology	1	117	2.1
Clinical Oral Investigations	1	114	3.1
Medicina Oral Patologia Oral Y Cirugia Bucal	1	98	2.1

Table 2. Top 10 authors among the 100 most cited article list

Authors	Number of articles published on WoS-CC	Number of citations on WoS-CC
Becker A	15	1209
Baccetti T	9	978
Chaushu S	9	688
Peck S	6	859
Jacobs R	5	508
Alqerban A	4	416
Willems G	4	416
Zilberman Y	4	330
Kataja M	3	635
Peck L	3	635

A total of 33 countries were identified as contributors to publications on impacted canines, with the USA (30 publications, 3,250 citations, 31.2%), Italy (19 publications, 1,657 citations, 15.9%), Israel (16 publications, 1,269 citations, 12.2%), Sweden (6 publications, 1,003 citations, 9.6%), and Belgium (5 publications, 508 citations, 4.9%) constituting the top five countries.

A total of 130 institutions were affiliated with studies on impacted canines, with the top ten institutions presented in Table 3. The Hebrew University of Jerusalem (15 publications, 1,209 citations, 11.6%), Harvard University (8 publications, 980 citations, 9.4%), and University of Florence (8 publications, 686 citations, 6.6%) were the three most-cited institutions, respectively. A total of 276 co-authorship links were identified between institutions, reflecting the extent of collaborative research in this field.

A total of 238 different keywords were identified, with "teeth" (25 occurrences), "lateral incisors" (18 occurrences), "ectopic eruption" (15 occurrences), "localization" (13 occurrences), "resorption" (13 occurrences) being the five most frequent keywords in the included 100 studies. A total of 1,605 keyword co-occurrence links were identified, indicating a dense network of interrelated terms within studies on impacted canines (Figure 4).

Altmetric data were available for 44 of the selected studies on impacted canines. The article with the highest AAS was "Early treatment of palatally erupting maxillary canines by extraction of the primary canines" by Ericson and Kurol (1988), published in the European Journal of Orthodontics, which received an AAS of 18, 3 mentions in blogs, 1 in a policy document, and 171 saves on Mendeley (Supplementary Table 2).

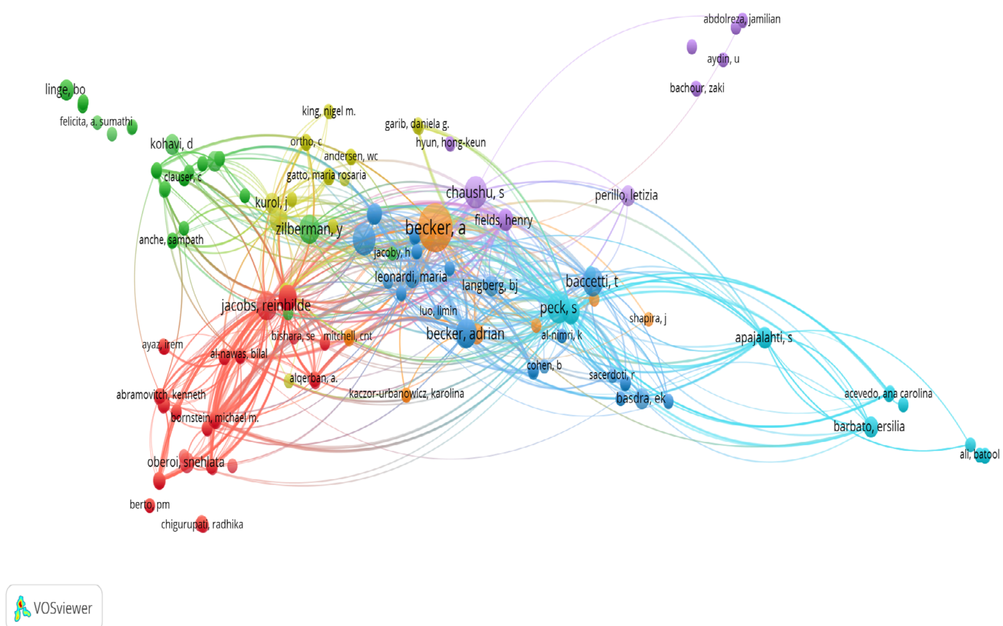

Figure 3. Author collaboration network generated with VOSviewer. Node size represents the number of publications per author, and links indicate co-authorship relationships among researchers.

Table 3. Top 10 institutions with the most articles in the 100 most cited article list

Institution	Country	Number of articles	Number of citations (WoS-CC)
Hebrew University of Jerusalem	Israel	15	1209
Harvard University	USA	8	980
University of Florence	Italy	8	686
Ku Leuven	Belgium	5	508
University of Michigan	USA	5	332
Finland National Institute for Health Welfare	Finland	3	635
Jonkoping University	Sweden	3	609
University of Washington	USA	3	279
University of California San Francisco	USA	3	268
University of Catania	Italy	3	267

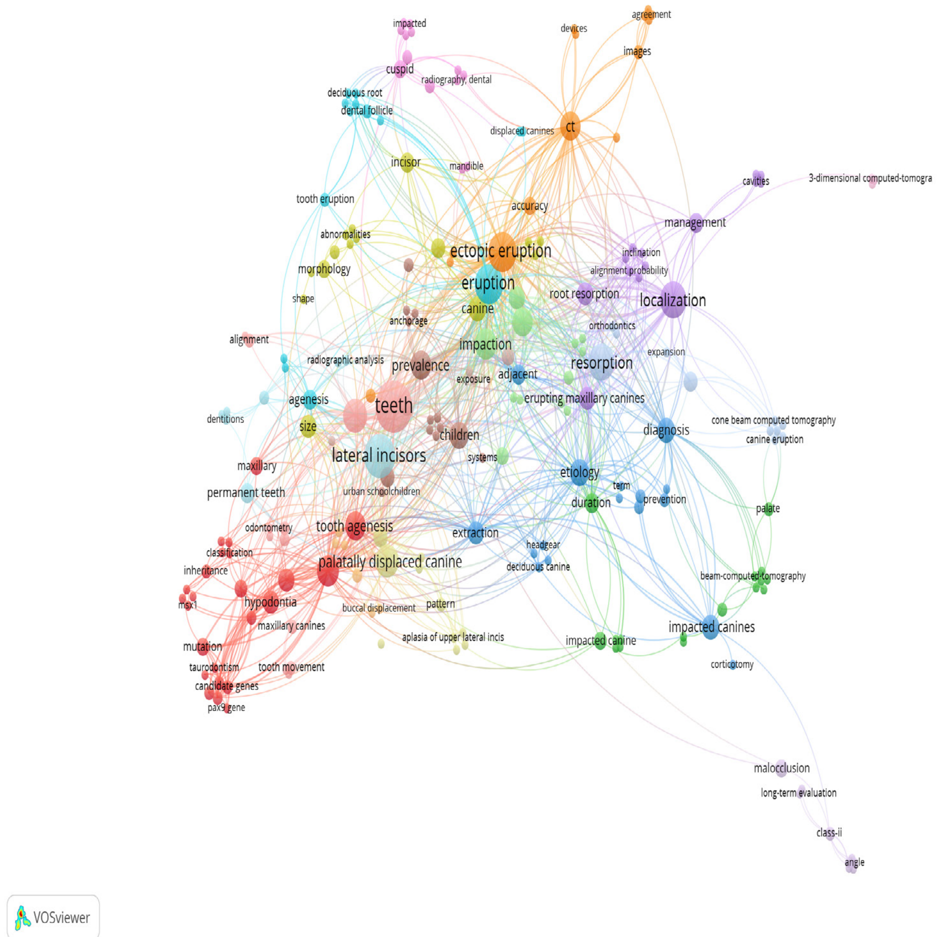

Figure 4. Keyword co-occurrence network of the 100 most cited studies on impacted canines. Node size indicates keyword frequency, and colours represent clusters of related terms, reflecting research trends and thematic relationships.

DISCUSSION

To the best of our knowledge, this is the first study to apply bibliometric and altmetric analyses to map the scientific literature on impacted canines quantitatively. This study, by analyzing the 100 most cited articles, identified key research trends, influential publications, leading contributors, and focus areas that have shaped the current understanding of this important clinical topic. The results highlight a well-established body of research, marked by a notable increase in publications since 2000, reflecting the sustained relevance of impacted canines in orthodontics and oral surgery.

This bibliometric analysis shows that research on impacted canines has primarily focused on etiology, prevalence, radiographic assessment, and associated dental anomalies, which are critical for accurate diagnosis and effective management. The frequent occurrence of keywords such as "lateral incisors," "resorption," and "localization" underscores the diagnostic challenges and clinical complications. Highly cited studies, such as those by Ericson and Kurol (1988) and Bishara,[3] remain influential to date, reflecting the lasting significance of early contributions to the development of interceptive treatment strategies and to comprehensive reviews.

The distribution of publications was concentrated in high-impact specialty journals, with the American Journal of Orthodontics and Dentofacial Orthopedics, European Journal of Orthodontics, and Angle Orthodontist collectively accounting for 78% of the most cited articles. This concentration underscores the prominence of impacted canines as a central topic within the orthodontic specialty, with leading authors such as Becker A. and institutions such as the Hebrew University of Jerusalem playing influential roles in this research field.

A critical finding of this study was the predominance of observational studies, which accounted for 69% of the 100 most cited articles, whereas interventional studies and systematic reviews represented a much smaller fraction (10% and 4%, respectively). Although observational studies are useful for identifying associations and understanding causes, the lack of stronger evidence from randomized controlled trials and systematic reviews may limit the formulation of definitive, evidence-based clinical guidelines. In addition, most of the included studies focused on maxillary canines, with only three of the top 100 most cited studies addressing mandibular impactions. Although this reflects the higher prevalence of maxillary impactions, it also reveals a significant disparity in research: the management of mandibular canines may rely on a more limited body of evidence.

There has been a recent rise in the number of bibliometric analyses in dentistry,[16,17,20,26-31] reflecting the need to objectively synthesize an increasingly large and complex body of literature. A recent bibliometric study of publications in three major orthodontic journals highlighted that bibliometrics enables a structured evaluation of research trends by examining authorship patterns, keywords, institutions, and citation networks and emphasized that bibliometric approaches are now widely applied across dentistry and its subfields.[30] This journal-level mapping further suggested that although overall publication output remained broadly stable across two decades, collaboration patterns intensified and cooperative networks became denser in the more recent decade, accompanied by broader international participation. Furthermore, the growing bibliometric literature increasingly focuses on research design. A contemporary bibliometric visualization of orthodontic randomized controlled trials identified keyword clusters, including periodontal health, and showed that themes such as root resorption and canine retraction have become more prominent in recent years.[32] However, this trend is only partially reflected in our findings, which indicate that highly cited research on impacted canines remains dominated by observational designs. Nevertheless, bibliometric evidence from interdisciplinary orthodontic-periodontal research highlights the rapid growth of the orthodontic-periodontal interface.[33] Given that impacted canine management frequently intersects with periodontal considerations, including surgical exposure approaches, long treatment durations, and mitigation of iatrogenic effects, these developments may help guide future research priorities.

The altmetric analysis, which provides a contemporary perspective on scholarly impact, revealed that fewer than half of the 100 most-cited articles had altmetric data, suggesting that the influence of this body of research is largely confined to academic and clinical communities. This may be due to the specialized nature of impacted canines, which likely limits their visibility on broader public-facing platforms such as social media and news outlets. Furthermore, a significant portion of the top 100 cited articles were published before the widespread adoption of social media and digital tracking tools; this likely contributed to the absence of Altmetric data for 56 of the included studies. However, the study by Ericson and Kurol (1988) had the highest AAS, consistent with the bibliometric analysis results. This may be because despite predating modern social metrics, this study remains a central topic of contemporary discussion, as it provides clinical guidelines for interceptive treatment of impacted canines by recommending extraction of the primary canine as the treatment of choice in young patients, particularly when panoramic radiographs show overlap between the impacted canine and the root of the lateral incisor.

Study Limitations

This study had several limitations that warrant consideration. The analysis was based solely on WoS-CC to identify the 100 most-cited articles. Although WoS is a comprehensive and widely accepted source for bibliometric analysis,[16,17,19,27] the inclusion of additional databases such as Scopus or PubMed may have yielded a different set of relevant articles. Furthermore, the analysis was limited to the 100 most cited studies, which may have introduced a bias toward older publications, potentially excluding more recent but influential works that have not yet accumulated high citation counts. Finally, although citation metrics are useful indicators of academic impact, they do not necessarily reflect the quality, methodological rigor, or clinical relevance of the studies.

CONCLUSION

This bibliometric study provides an in-depth analysis of the most frequently cited publications on impacted canines. Most of the included studies were observational and focused on etiology, diagnosis, and associated anomalies, with limited contributions from interventional studies or systematic reviews. Research was concentrated in high-impact orthodontic journals and driven by key institutions and authors. However, only a limited number of systematic reviews and interventional studies ranked among the top 100 most-cited articles, and areas such as mandibular impaction, periodontal outcomes, and long-term treatment effects remain underexplored.

Ethics

Ethics Committee Approval: Ethics committee approval was not required for this study, as it consisted of a bibliometric and altmetric analysis of previously published articles and did not involve human participants or animal subjects.

Informed Consent: Not applicable.

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Footnotes

Author Contributions: Surgical and Medical Practices - M.G.K., G.A.S.; Concept - M.G.K.; Design - M.G.K.; Data Collection and/or Processing - G.A.S.; Analysis and/or Interpretation - G.A.S.; Literature Search - M.G.K.; Writing - M.G.K.

Conflict of Interest: No conflict of interest was declared by the authors.

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Supplementary Tables 1-2: https://https://d2v96fxpocvxx.cloudfront.net/4615d177-864c-42ed-adf7-32226220a22b/content-images/58f67d26-98bb-4b7f-8f39-c9f52f87dceb.pdf

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Review

Orthodontic Treatment and External Apical Root Resorption: A Study on the Worldwide Prevalence - A Scoping Review

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Main Points

- Mild external apical root resorption (EARR) prevalence does not correlate with severe resorption diagnosis after orthodontic treatment, indicating that EARR may only be well classified when it is advanced.
- Although cone-beam computed tomography is a precise diagnostic tool, inconsistency exists among studies.
- There is a lack of consensus and standardization in identifying EARR, highlighting the need for unified diagnostic and classification methods.

ABSTRACT

External apical root resorption (EARR) is an important concern in orthodontic practice. Despite extensive research, the reported prevalence, occurrence, and grade distribution of EARR remain heterogeneous, ranging from 0% to 100%. This review aimed (i) to analyse the available scientific evidence worldwide to ascertain conclusions regarding EARR prevalence and (ii) to identify and evaluate the most appropriate radiographic technique and complete/comprehensive assessment method for EARR. This review followed the JBI and PRISMA guidelines and included studies of any orthodontic treatment. The studies were analysed based on diagnostic imaging methods, quantification, categorisation, and other variables. Of the 1209 records identified, 81 studies were included. The evidence originated from six continents, predominantly Europe (33 studies), Asia (23 studies), and the Americas (13 studies from North America and 16 from South America). Across the studies, marked variability was observed in both the reported prevalence and the severity of EARR. Studies utilising two-dimensional techniques mainly reported no or only mild resorption in most incisors. Similarly, studies employing three-dimensional techniques found that mild or no resorption was predominant. However, severe EARR was rare in all studies, consistently affecting fewer than 5% of cases. Notably, discrepancies in severity and mean EARR values among studies were largely attributable to variations in techniques and classification systems. This inconsistency emphasises the urgent need for standardised diagnostics and a unified classification. Resolving these issues will provide clearer insights into EARR.

INTRODUCTION

External apical root resorption (EARR) is a common iatrogenic consequence of orthodontic forces applied to teeth and can be identified radiologically in clinical practice.[1,2] It is described as a destructive pathological condition that permanently affects the cementum and/or dentine of the tooth root and frequently manifests during orthodontic treatment.[3] Despite extensive research on EARR, the specific factors influencing its onset, development, and severity remain unclear.[1,3] EARR is a multifactorial condition influenced by both environmental factors and individual variations in susceptibility.[3-5]

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Although EARR is a condition of serious concern for orthodontic professionals, its occurrence remains unclear. Accordingly, reported rates of EARR after orthodontic treatment vary widely, with some studies describing values as low as 0%[6] to 10%,[7] and others indicating that up to 45% of the patients present some degree of resorption.[8] This leads to considerable uncertainty regarding the proportion of orthodontic patients affected. Moreover, a substantial discrepancy exists in the EARR classification,[9,10] quantification methods, and severity estimation[11-13] among studies.[8]

Although EARR in orthodontics has been studied for over a century, an exponentially increasing body of scientific evidence has become available only recently. While previous meta-analyses and systematic reviews have addressed and quantified EARR, they have not specifically investigated its prevalence.[14,15] As a result, scientific evidence regarding the prevalence and average severity of EARR secondary to orthodontic therapy is still lacking.[16]

Therefore, this study primarily aimed to analyse the available scientific evidence worldwide to ascertain the prevalence of EARR in orthodontics. The secondary objective was to identify and critically evaluate the most appropriate radiographic technique and comprehensive assessment method for EARR.

METHODS

Protocols and Guidelines

This review followed the guidelines and protocols outlined in the JBI Manual for Evidence Synthesis and its template, and in the PRISMA extension for scoping reviews. No prior protocol registration was performed, which is consistent with the exploratory nature of scoping reviews and is acknowledged as a methodological limitation. However, the review adhered strictly to these methodological standards to ensure transparency and reproducibility.

Eligibility Criteria

The eligibility criteria for the studies included in this research are described below.

Participants: The studies must involve patients undergoing any orthodontic treatment for the first time (excluding retreatments).

Concept: The studies should include EARR measurements in at least one upper incisor and compare pre- and post-treatment scenarios using any radiographic diagnostic method.

Context: No specific context was required; it was considered open.

Type of sources: The year of publication and the study duration were not restricted by the eligibility criteria. The required study designs included case-control studies, case series, and prospective and retrospective longitudinal studies, whereas meta-analyses and systematic reviews were excluded.

Furthermore, studies were excluded if they included patients with syndromes, patients with prior treatment, patients with previous dental trauma, or patients with compromised periodontal status. In addition, all in vitro and animal studies, as well as studies focusing exclusively on impacted canines, were excluded.

No language restrictions were applied; non-English studies were screened using English abstracts, with full texts translated when necessary.

Search Strategy

A literature search was conducted using multiple sources, with PubMed and Scopus as the primary databases. Additionally, searches were performed using the Web of Science, SciELO, Google Scholar, and grey literature repositories. The search covered studies published from 1970 to July 2025, with the final search conducted on 30 July 2025. The complete search strategy and keywords used are provided in Supplementary File 1.

Study Selection

Screening was performed in the following phases: 1) search, 2) duplicate removal, 3) title screening, 4) abstract screening, and 5) full-text screening. All phases were independently reviewed by two reviewers.

In cases of disagreement at any stage of the screening process, the two reviewers reached consensus through discussion.

Data Extraction

Data were extracted by one reviewer and were later corroborated by a second reviewer. The predetermined variables of interest were documented as follows: author, year, country, study design, sample, ethnicity, diagnostic imaging method, quantification method, categorisation, mean EARR (mm/mm^3/%), prevalence, calculated prevalence, prevalence in categories, assessed teeth, orthodontic techniques, treatment duration, age at the beginning of treatment, sex, and covariables.

For articles with incomplete data, attempts were made to contact the authors and obtain the missing information for inclusion.

RESULTS

Search Results

Our search strategy identified 1209 records, including 81 duplicates. After removing duplicates, 393 articles were screened by title, and 182 were selected based on their abstracts. Subsequently, 159 articles were assessed at the full-text level. 81 studies were included in the final analysis (Figure 1). The reasons for exclusion have been summarised in Figure 1. The specific reason for the exclusion of each article is detailed in Supplementary File 2.

Description of the Included Studies

The characteristics of the included studies are summarised in Supplementary Table 1. Detailed methodological and demographic characteristics are provided in Supplementary Table 1 and Supplementary File 3 to improve readability. To assess the prevalence of resorption, four groups were established to classify its severity: no EARR, mild EARR, moderate EARR, and severe EARR, as shown in Figure 2. The mild EARR classification included root resorption lesions of Malmgren grades 1 and 2[17] (Figure 2).

Findings

The results are organised based on the radiographic diagnostic technique (2D or 3D), the treatment type (fixed or removable appliances), and the presence of additional quantitative data in the studies. Across all included studies, no or mild EARR predominated regardless of imaging modality or appliance type, while severe EARR was uncommon (Table 1).

Two-Dimensional (2D) Radiographic Assessment of EARR

EARR after orthodontic treatment with fixed appliances

In almost all studies using 2D imaging after fixed appliances, mild or no EARR was reported in the majority of cases (Figure 2). When the four upper incisors were analysed collectively, most patients exhibited no or only mild EARR. Nevertheless, four studies showed moderate or severe resorption in over 50% of the examined upper incisors.[12,16,18,19]

When studies were scrutinised by tooth group (central vs. lateral upper incisors), a similar trend was observed. Only one study reported moderate or severe resorption in more than 50% of the central incisors.[20] Studies differentiating between only two categories (moderate/severe resorption vs. no/mild resorption) indicated a higher prevalence of moderate or severe resorption[21-23] with some reporting that up to 70% of the patients experienced severe or moderate resorption during orthodontic treatment.[21] This finding appears to be influenced by the classification itself rather than reflecting a true increase in severe EARR.

Focusing on studies that specifically analysed each incisor individually, most[24-29] reported that approximately 70% of teeth had no or mild resorption during orthodontic fixed appliances. Mild resorption represented the most frequent outcome across these studies[30-32] (Figure 2), reinforcing the predominance of low-severity EARR in 2D assessments.

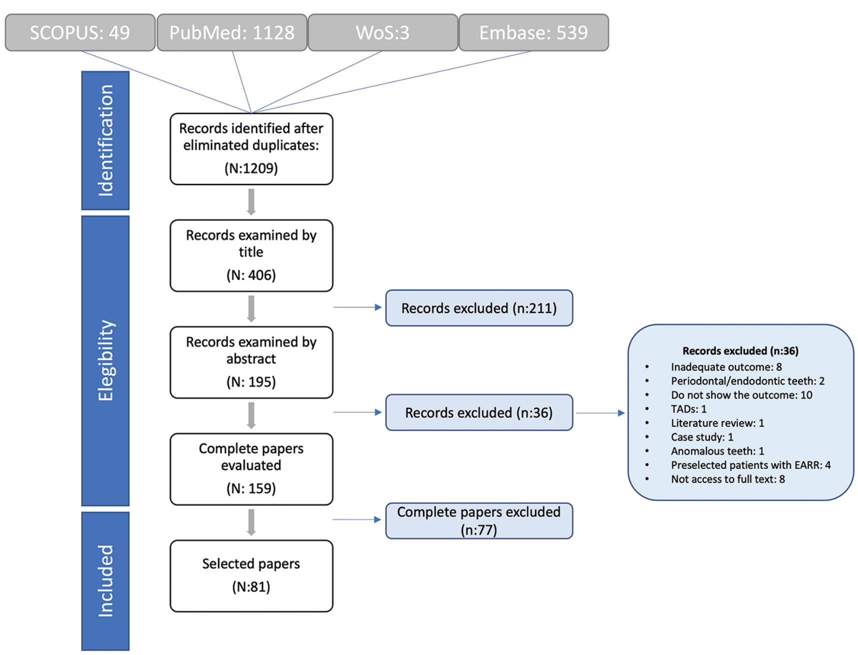

Figure 1. Flowchart of article retrieval.

Table 1. Summary of EARR prevalence according to imaging modality and appliance type

Imaging modality	Appliance type	Predominant EARR severity	Severe EARR prevalence
2D	Fixed	No or mild	<10% in most studies
2D	Removable	No or mild	Rare
3D	Fixed	No or mild	<5%
3D	Removable	No or mild	Rare or absent

EARR, external apical root resorption.

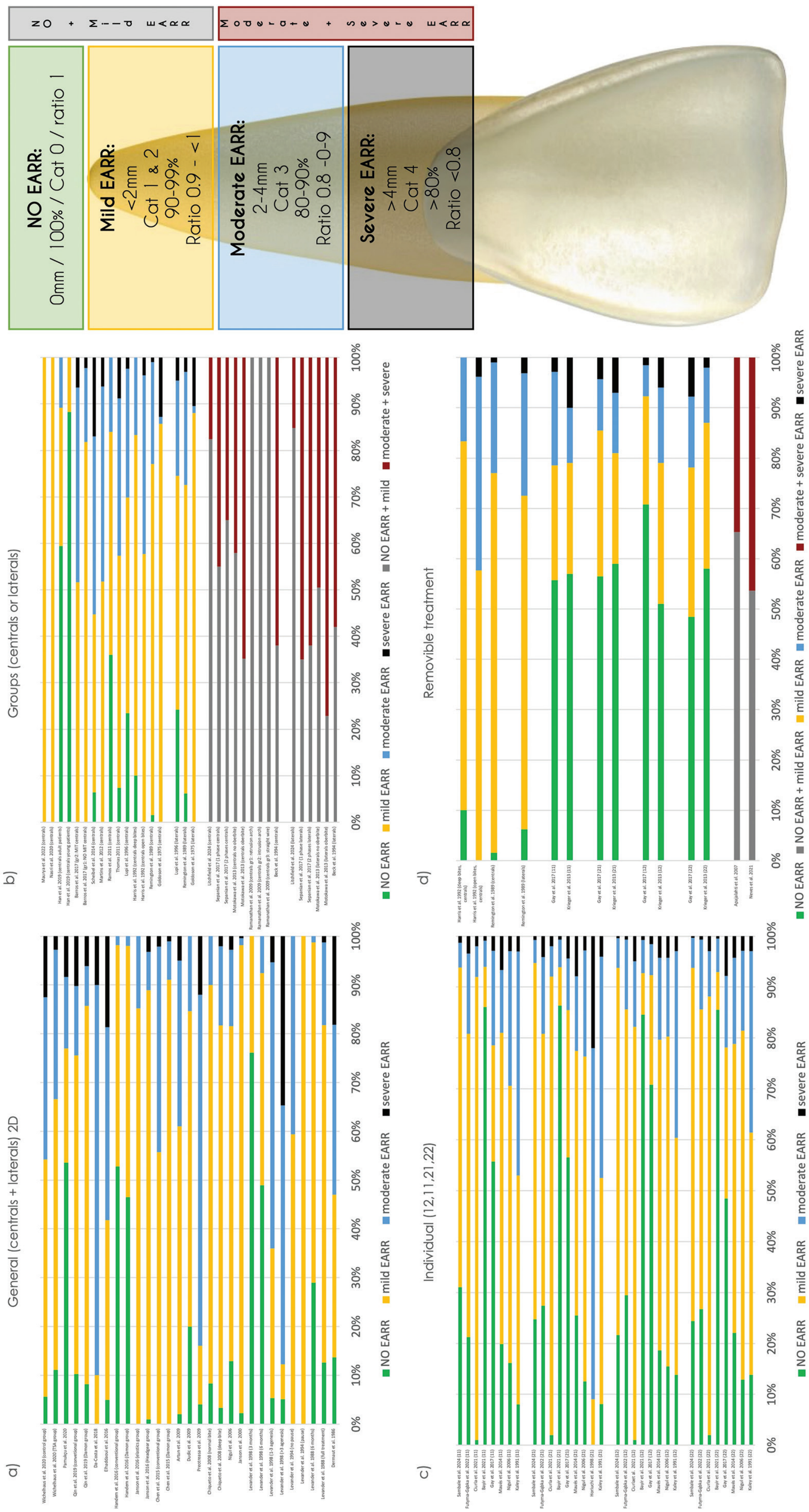

Figure 2. EARR prevalence diagnosed using two-dimensional methods.

EARR after orthodontic treatment with removable appliances

Studies analysing removable appliances have consistently reported a low prevalence of moderate-to-severe resorption. In studies using the four-group classification, fewer than 30% of patients had moderate or severe EARR (Figure 2), except for patients treated for open bite, who had a higher prevalence.[33]

Considering studies that grouped moderate and severe resorption together, the majority still exhibited no or mild resorption. With the exception of the study by Linhartova et al.,[11] more than 50% of the sample presented mild or no resorption (Supplementary File 4). Overall, removable appliances assessed using 2D imaging were associated with mild or absent EARR.

Three-Dimensional (3D) Radiographic Assessment ef EARR

EARR after orthodontic treatment with fixed appliances

Studies using 3D radiographic measurements and fixed appliances consistently reported a high prevalence of no or only mild resorption. In studies which classified EARR into four groups (none, mild, moderate, or severe EARR),[6,34] approximately 70-90% of incisors exhibited no or mild EARR. Severe resorption was uncommon across all studies and classifications that used 3D diagnostic methods (Figure 2). Studies with a simpler two-category classification (no/mild vs moderate/severe EARR), reported lower proportions of no or mild resorption, with approximately 30% of incisors in this category.[35-38] These differences were associated with the classification approach used across studies.

Notably, one of the included studies reported EARR only in the lateral incisors.[6] Another study examined EARR using cone-beam computed tomography (CBCT) and panoramic radiography to improve the detection of severe EARR, reinforcing the higher diagnostic sensitivity of 3D imaging[39] (Supplementary File 5). Overall, studies employing 3D imaging demonstrated a consistently low prevalence of moderate and severe EARR following treatment with fixed appliances.

EARR after orthodontic treatment with removable appliances

In studies of removable appliances that analysed root resorption using 3D radiographic, linear, and volumetric assessment methods, severe resorption was consistently rare and was reported in less than 5% of cases. In fact, two of these studies reported neither moderate nor severe resorption[40,41] (Supplementary File 6).

Additional Analysis of Incisors Resorption (Quantitative Data)

Across all included studies, mean root resorption values remained low, with an apical root loss generally not exceeding 2 mm (Figure 3). In studies where measurements were reported for individual teeth, the mean EARR rarely exceeded 1.5 mm. All measurements remained below 5 mm.

The samples analysed in this study originated from various locations worldwide. Most of the studies were conducted in Europe (33 studies), followed by Asia (23 studies) and the Americas (13 studies from North America and 16 studies from South America). The worldwide distribution is shown in Figure 4. However, no specific distribution based on their origin could be established due to substantial heterogeneity in the results.

DISCUSSION

This scoping review aimed to identify and map the prevalence of EARR after orthodontic treatment. Although the prevalence of EARR has been described in many studies, only a limited number of systematic reviews have estimated the actual

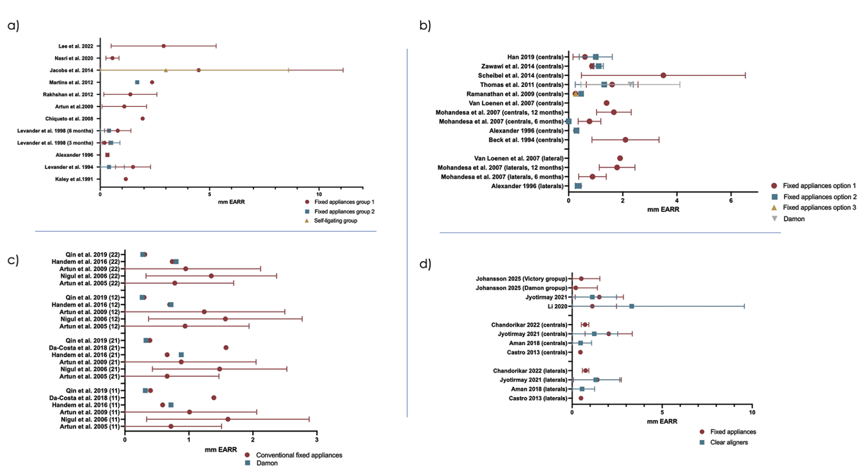

Figure 3. Overview of reported EARR values (in mm) in the included literature.
a) General (centrals + laterals) with 2D: Studies measuring EARR on all upper incisors in patients treated with fixed orthodontic treatment, b) Groups (central or lateral) with 2D: Studies measuring EARR on central and/or lateral incisors in patients treated with fixed orthodontic treatment, c) Individual (12,11,21,22) with 2D: Studies measuring EARR on incisor independently in patients treated with fixed orthodontic treatment, d) Fixed vs. clear appliances with 3D: Studies measuring the EARR using CBCT.
EARR, external apical root resorption; CBCT, cone-beam computed tomography

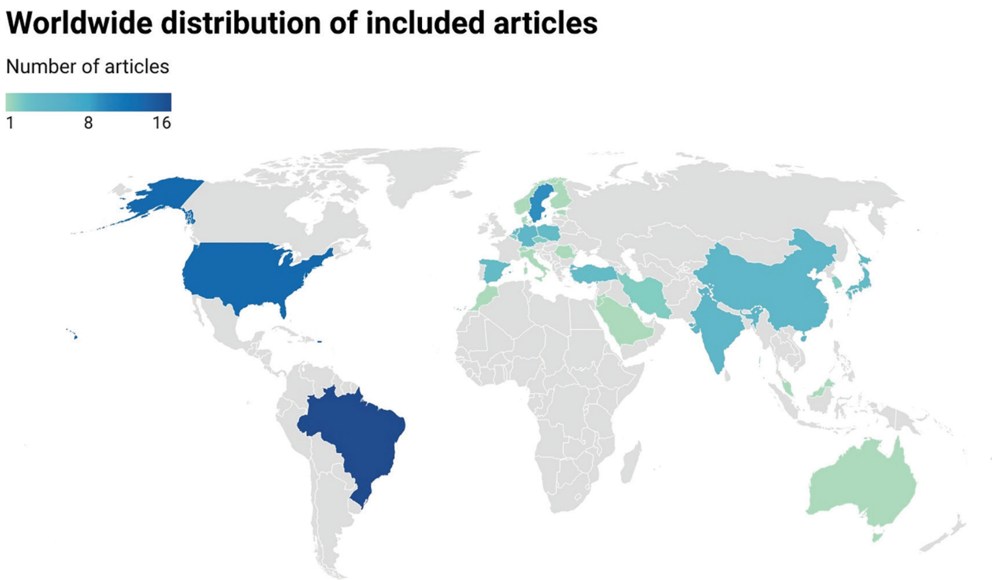

Figure 4. Worldwide distribution of the included articles.

occurrence of EARR across orthodontic treatment modalities. Our review, by analysing studies conducted worldwide, provides a broader picture of the expected prevalence of EARR in clinical practice.

Despite the wide geographic distribution of the included studies, spanning six continents and diverse populations, consistent global patterns of EARR prevalence were observed. Across studies conducted in Europe, Asia, North and South America, and other regions, the predominant finding was no or only mild EARR, regardless of geographic origin, population, or orthodontic technique. Severe EARR was consistently uncommon worldwide, particularly in studies using 3D-imaging, where it generally affected fewer than 5% of cases. This low prevalence of severe EARR represents an infrequent outcome of orthodontic treatment on a global scale. Although reported prevalence values varied substantially between studies, this variability appeared to be method-driven rather than region-specific, largely reflecting differences in radiographic techniques, quantification methods, and classification systems, and not true geographic or population-based differences. Consequently, no consistent regional pattern could be identified.

A significant challenge in comparing studies on EARR is the substantial heterogeneity of diagnostic procedures and measurement methods. While some authors relied on 2D techniques (panoramic radiography,[16,30,39] periapical radiography,[27,42] occlusal radiography,[4] or lateral radiography,[11,16,33]), others used 3D approaches, such as CBCT.[6,35,36,39] The choice of imaging method directly affects the quantification of EARR: conventional radiographs are widely available and involve lower radiation exposure but may overestimate resorption, whereas CBCTs provide more detailed and accurate measurements yet are less commonly used in clinical practice because of cost and higher radiation dose. This variability complicates cross-study comparison and likely contributes to the wide variability in EARR prevalence.[9]

Beyond diagnostic imaging, studies have used different approaches to quantify EARR, even when similar radiographic techniques were applied. For example, regarding panoramic and periapical radiography, some authors have used a visual scoring systems, as described by whereas others have used quantitative measurements in millimetres or percentages.[40,43] The heterogeneity becomes even greater when comparing 2D and 3D methods: panoramic or periapical radiographs allow only linear measurements, whereas CBCTs enable volumetric analysis, providing data that cannot be captured with conventional radiographs.[4,30,33,44]

Studies have used different criteria to classify EARR severity. Some adopt visual scoring systems, such as Levander et al.,[19] later modified by Levander and Malmgren,[17] while many others apply quantitative thresholds based on root shortening in ratios,[12] millimetres of EARR,[45,46] percentage (%) of root loss,[7,47] or volume (mm^3) of EARR. This may partly explain the wide variability in reported prevalence and severity. To address this issue, this scoping review harmonised all data into a four-category system (none, mild, moderate, severe), allowing comparison among studies with different classification systems.

Upper incisors (central and lateral) are most commonly affected by EARR.[2] Furthermore, these teeth are easily available to researchers, and they typically undergo the greatest movement during treatment. Therefore, upper incisors are considered the most representative for assessing resorption in both arches.[19]

An additional consideration in interpreting EARR prevalence is how root changes are conceptually defined. Some researchers consider any detectable alteration of root surface as EARR,[41] whereas others maintain that the EARR should not be considered until it extends up to 2 mm of root shortening.[44] This conceptual distinction influences how severity is interpreted and reported.[17]

In studies employing 2D diagnostic systems, severe EARR was reported in fewer than 10% of incisors in almost all cases. This likely reflects that severe EARR is readily apparent and can be diagnosed long before the end of orthodontic treatment, as observed on control radiographs. Only a few studies reported severe EARR above 10% of the incisors, and these exceptions were generally associated with specific clinical conditions when the incisors were analysed. Five studies analysed the incisors as a group,[7,10,16,18,48] two studies divided them into groups of incisors,[20,49] and only one analysed each incisor separately.[29] Among these, the study by Wichelhaus et al.[10] reported severe EARR in one of the two groups analysed (i.e., the control group), but not in the torque-segmented archwire group. Dermaut and De Munck[50] analysed incisors subjected to real intrusion over time, and the other three studies[16,18,19] presented special considerations that may be associated with a high risk of resorption during orthodontic treatment. Regarding studies analysing individual incisors, the only study reporting severe EARR in more than 10% of cases was conducted by Horiuchi et al.,[29] who specifically assessed the left central incisor; this finding may be limited by its focus on a single tooth.

Overall, the evidence from 2D studies indicates that severe EARR is rare, whereas most patients experience no or only mild resorption. This scenario changes significantly when studies employing 3D diagnostic methods are considered; the prevalence of EARR is consistently lower than in 2D analyses. Across both fixed and removable appliances, severe EARR represents less than 5% of all cases. Indeed, with clear aligners, severe EARR was practically non-existent; studies by Jyotirmay et al.[41] and Li et al.[9] did not identify any severe cases.

Some studies employed only a two-group classification (none/mild vs. moderate/severe), such as those by Castro et al.[35] and de Freitas et al.[36] In these cases, the larger second group appeared to consist mainly of moderate EARR, with relatively few severe cases. This pattern is consistent with the trend observed in studies employing the four-category classification, in which moderate EARR is more frequent than severe EARR.[35,36]

However, there was no clear consensus among studies regarding the distribution of the EARR across the three categories. By contrast, agreement was greater for severe EARR, which was consistently reported at very low levels. This likely reflects that, until resorption becomes noteworthy and distinct, classification is not straightforward. As a result, it may not be possible to establish the extent of resorption precisely until it becomes evident and severe.

Across the included studies, the vast majority of cases exhibited mild resorption. This suggests that some degree of EARR is almost inevitable in most cases during orthodontic treatment. However, resorption is mild in most cases and falls within the realm of acceptable risks during treatment.

From a clinical perspective, these findings indicate that although some degree of EARR may be expected during and after orthodontic treatment, it is predominantly mild and of limited clinical relevance. Nevertheless, the consistent occurrence of EARR underscores the importance of appropriate radiographic monitoring, particularly in prolonged treatments or complex tooth movement. Individual patient risk assessment remains essential, taking into account treatment-related factors, force magnitude, and biomechanics. Early identification of EARR may allow timely modification of treatment mechanics, thereby reducing the risk of progression to clinically significant resorption.

Although most EARR cases remain mild, certain patient- and treatment- related factors appear to increase the risk of more severe EARR. Specific factors include a history of dental trauma and, potentially, genetic variables related to bone and root metabolism. With respect to treatment mechanics, prolonged treatment duration, application of heavy forces, and specific types of tooth movement (intrusion, torque, and extraction space closure) have been linked to greater resorption. This consideration highlights the importance of individual risk assessment and the need for careful biomechanical assessment before initiating orthodontic treatment.

Mean EARR values across almost all studies were low, reflecting what clinicians are likely to encounter in orthodontic practice. Cases outside this range are rarely reported. Notably, studies that unified measurements across different incisors reported values that were generally greater than those obtained in studies presenting individualised measurements for each incisor.

When EARR was measured individually for each tooth using radiographs, the mean values remained below 2 mm. Studies reporting separate means for the central and lateral upper incisors showed results closer to 2 mm, particularly with conventional fixed appliances. In contrast, studies that collectively analysed all four incisors tended to report higher mean values.[47] Using 3D systems, mean EARR values were consistently lower, reflecting the greater measurement accuracy of CBCT, as demonstrated in previous research.[15]

This review has certain limitations that should be considered. As a scoping review, it synthesises evidence from studies with diverse methodological approaches, which limit quantitative comparisons. Evidence regarding removable appliances remains scarce despite their increasing use in contemporary orthodontic practice.

Future research should prioritise standardised diagnostic and classification systems, prospective multicentre studies with adequate follow-up, and the inclusion of diverse treatment modalities, particularly clear aligners, to obtain more robust and comparable estimates of EARR prevalence worldwide.

The primary aim of this review was to provide orthodontic professionals with an overview of the expected EARR associated with treatment. In addition, this study highlights the need to establish a unified, standardized diagnostic method for this pathology and to consolidate the classification system. Such standardisation would greatly facilitate comparisons across studies and improve the interpretation and applicability of future research.

CONCLUSION

The prevalence of mild EARR does not correlate with a diagnosis of severe EARR following orthodontic treatment. In most studies, a similar percentage of severe EARR was observed, whereas diagnoses in other categories varied considerably. This suggests that the diagnosis and classification of EARR may be limited until the resorption becomes notably severe. Despite the use of CBCT as a precise diagnostic method, the included studies lack consensus regarding the assessment method. The disparity in the reported mean EARR measurements secondary to orthodontic treatment with fixed appliances ranged from 0.13±0.47 mm to 3.53±3.03 mm.

This scoping review revealed a lack of consensus and uniformity among the studies analysed regarding the identification and classification of EARR following orthodontic treatment. This review highlights the urgent need for standardised diagnostic methods and a unified classification system for EARR after orthodontic treatment. Standardisation would improve the comparability between studies and the interpretation of results, and provide orthodontic professionals with clear expectations regarding the occurrence of root resorption after orthodontic treatment. The extensive range of diagnostic radiographic techniques, from 2D methods to 3D CBCT, and the diverse classification systems employed complicate comprehensive understanding of the prevalence and severity of EARR.

Footnotes

Author Contributions: Concept – R.S-C., A.I-L.; Design – R.S-C., P.I-D., A.I-L.; Data Collection and/or Processing – R.S-C., Y.C.; Analysis and/or Interpretation – R.S-C., P.I-D., Y.C., A.I-L.; Literature Search – R.S-C., Y.C.; Writing – R.S-C., P.I-D., A.I-L.

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Supplementary Link: https://d2v96fxpocvxx.cloudfront.net/bda9171a-fae8-4995-8276-2138323f1e16/content-images/de648a28-b932-4dd3-b7a1-eee9caf3972b.pdf

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