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TURKISH JOURNAL OF ORTHODONTICS

Original Article

Effects of Emotional States on Reproducibilities of Rest Position, Social and Spontaneous Smiles, and Speech

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Main Points

- The reproducibility of functions varies according to emotional states.
- Social and spontaneous smiles vary depending on the emotional state.
- The rest position was found to have the most reliable reproducibility compared with social and spontaneous smiles and speech.
- The reproducibility of functions is important in multidisciplinary treatment planning.

ABSTRACT

Objective: To evaluate the effect of emotional states on reproducibilities of rest position, social and spontaneous smiles, and speech.

Methods: A total of 30 individuals aged 18-22 years were included (mean age; 19.03 years ±1.03). Three emotional states were determined: amusing, sadness, and neutral. The participants watched three different videos in 3 sessions on the same day. After each video, the participants completed a questionnaire to assess their mood. The rest position, social and spontaneous smiles, and speech recordings were gathered from the participants using videographic method. Measurements were made for each function. The Friedman test, One-Way ANOVA, Kruskal-Wallis test was performed for statistical evaluations, and intra-observer correlation coefficients and Bland-Altman Limits of Agreement were calculated.

Results: In spontaneous smiles, there were significant differences between amusing and sadness in the smile height (p=0.020); amusing and sadness in the lower lip thickness (p=0.029). In social smiles there was a significant difference between amusing and sadness in the maxillary incisor display (p=0.006). There were no statistically significant differences in the rest position, but clinically significant differences were observed in some participants. In speech, a significant difference was found between amusing and sadness in the distance between the upper lip and subnasal (p=0.035).

Conclusion: The reproducibility of social and spontaneous smiles was influenced by various emotional states. However, the rest position exhibits higher reproducibility than social and spontaneous smiles in all emotional states.

Keywords: Rest position, smile, speech, reproducibility, emotional state

INTRODUCTION

In the modern orthodontic perspective, the examination of overall facial esthetics has become more important in diagnosis and treatment planning, because of the development of the soft tissue paradigm.[1] In this regard, the

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number of studies evaluating soft tissue esthetics have recently been increasing. These studies are based on both objective data and subjective individual perceptions. Enhancing smile esthetics is an important factor for motivating patients to undergo orthodontic treatment. However, it is also believed that it is not always related to orthodontic diagnosis and treatment but is also associated with an individual's emotional state.[2]

Clinicians use diagnostic materials, including intraoral and extraoral images, to ensure the success of treatment planning or mechanics during the orthodontic treatment process. Because these records are taken at specific intervals within a particular time point during the treatment, the reproducibility of rest position, social and spontaneous smiles, and speech can play an important role in achieving esthetic treatment goals. During orthodontic treatment, clinicians need a reference point that can be considered constant. However, if the rest position, social and spontaneous smiles, and speech are affected by emotional states, identifying a dependable reference point becomes challenging In this case, differences not attributable to the treatment may be observed upon analysis of the records.[3] Sarver and Ackerman[4] used a social smile as a guide during the planning of hard and soft tissue facial treatment. They pointed out that the reproducibility of smile showed variability, and that the rest position had the highest reproducibility.[5,6] Ekman[7] suggested that social smile could be affected by a person's social abilities and emotional background, leading to a smile that may be unnatural or asymmetrical. Zachrisson[8] emphasized that a photograph taken directly from the frontal view while the patient is in the rest position provided one of the most important parts of information for planning, diagnosis, and treatment. Ackerman et al.[5] reported that the reproducibility of smiles in children is uncertain. They noted that it was likely for adolescents to develop a maturation sequence in a reproducible smile.[5] Burstone[9] stated that the rest position has the highest reproducibility and that the appearance of maxillary incisors in the rest position would guide orthodontic treatment planning. Van der Geld et al.[10] stated that a spontaneous smile can serve as a guide for evaluating the relationship between the lips and teeth.

If the emotional state of the patient affects the reproducibility of the above-mentioned functions, clinicians may find it challenging to determine the realization of the esthetic goals they have devised during recurring appointments, leading to potential unnecessary alterations in treatment objectives and, consequently, in treatment modalities. In such situations, clinicians can administer questionnaires to assess the patients' current emotional state and, if necessary, guide patients toward their desired emotional state before taking the records or conducting clinical examinations. While many studies have examined the reproducibilities of rest position, social and spontaneous smiles, and speech; no studies have addressed the relationship between reproducibility and the individual's emotional state. The aim of this study was to evaluate the effect of emotional states on the reproducibilities of rest position, social and spontaneous smiles, and speech. The study hypothesis was that the emotional state of the patient affected the reproducibility of rest position, social and spontaneous smiles, and speech.

METHODS

The study was approved by the Medical Research Ethics Committee of Ege University (approval no.: 22-4T/1, date: 12.04.2022). Participants were asked to fill out a signed consent form at the beginning of the study. The surveys of the study have been used in research conducted in the Clinical Psychology Department at Ege University and are highly validated.[11]

As a result of the power analysis performed with the software program G*Power 3.1.9.2 (Franz Faul, UniversitätKiel, Germany), more than 80% power was obtained with an effect size of 0.8 and a significance level of α=0.05 with a sample size of 30 people.[12] A total of 30 volunteers were included in the study, consisting of 15 females (mean age; 18.93 years ±1.03) and 15 males (mean age; 19.13 years ±1.06). The participants' ages ranged from 18 to 22 years, with a mean age of 19.03 years ±1.03. The inclusion criteria were determined as; no active orthodontic treatment, no prominent scars in the head and neck region, no illness that would impair speech and smiling, and no prosthetic restorations within the smiling area.

Upon the participants' initial arrival, a survey designed to assess their levels of positivity and excitement was administered at the start of the day. The survey was handed out to the participants in person. There were two questions in the survey. They were asked to score the questions, "Over the past few weeks, how negative or positive have you been feeling emotionally?" and "Over the past few weeks, how calm or excited have you been feeling emotionally?" on a scale from 1 to 9. The purpose of this survey was to determine the participants' positivity and excitement levels at the beginning of the day.[11] In terms of positivity, a score of (1-4) indicates negativity, and a score of (6-9) indicates positivity. In terms of excitement, a score of (1-4) indicates calmness, and a score of (6-9) indicates excited. A score of 5 is neutral.

Participants were informed about the process of video recording. No detailed information related to the purpose of the study was provided. Each participant was given three appointments in one day. During three different parts of the day-morning, noon, and afternoon-participants were shown videos in three varied themes: sadness, neutral, and amusing in an empty 8 m^2 room with daylight, containing only one chair and a tripod in different order. Participants sat in a chair and watched approximately three-minute-long colored videos from a laptop provided to them, with the sound level set to conversational volume level. Video recordings of the participants were recorded immediately after they watched the videos.

The videos used in this study were taken from a stimulus set development study conducted by Amado et al.[11] to evaluate the emotion induction levels of videos in the study group. One video from each category of amusing, sadness, and neutral emotions pertaining to the mentioned study was selected to be used in this study. When selecting the positive and negative videos, similarity criteria considered, which is included the absolute distances of the valence scores related to excitement levels, effectiveness in inducing the target emotions (such as amusing or sadness), and consistency in video durations. The neutral video was selected due to its duration being similar to that of the positive and negative videos.

Participants were recorded in rest position, during social and spontaneous smiles, and during speech under the same conditions. They were instructed to stand 15 cm away from the camera with a natural head position, to stand in a way that they felt comfortable, and to look at the camera with calibration glasses. The recordings were recorded using a digital camera. In the first step, they were asked to say word "Emma"[8,13] to capture the rest position. Then, a social smile was elicited with the command, "I want a big smile where I can see all your teeth". This process was followed by the speech recordings, where the Turkish version of a sentence containing specific phonetics, which was determined in the literature,[12] was utilized. To elicit spontaneous smiles, the participants were instructed to repeat their funny phrases immediately after a period of formal interaction, such as recording the rest position. This procedure was reported to be particularly effective for eliciting spontaneous smiles when funny sentences were made unexpectedly.[12]

After recording the videos, participants were administered a survey in which they rated various emotions they were feeling at that moment on a scale of 1-9. This survey comprises 27 questions. Their positivity, excitement, and 20 different emotions were scored.[11] The emotional levels recorded in these surveys after watching each emotional state video were compared.

The videos were uploaded to a MacOS-supported computer. Two hundred images were captured from each functional state in each video. From these 200 images, five that best reflect each function and have the optimal head position, image clarity, and distance to the camera were identified by three researchers. Subsequently, the image that best represented each function was selected by the consensus of two orthodontists with different levels of experience (14 years and 2 years). As a result, a total of four images were obtained after each emotional state: rest position, social and spontaneous smiles, and speech, making a total of 12 images per participant. During the measurements, a calibration eyeglass, which was worn by the participants during the video recording, was utilized. The length of the ruler was proportional to the parameters to be measured. Parameters measured in the rest position (Figure 1), social smile (Figure 2), spontaneous smile (Figure 3), and speech (Figure 4) are shown in the images. The parameter explanations are presented in Table 1.

Statistical Analysis

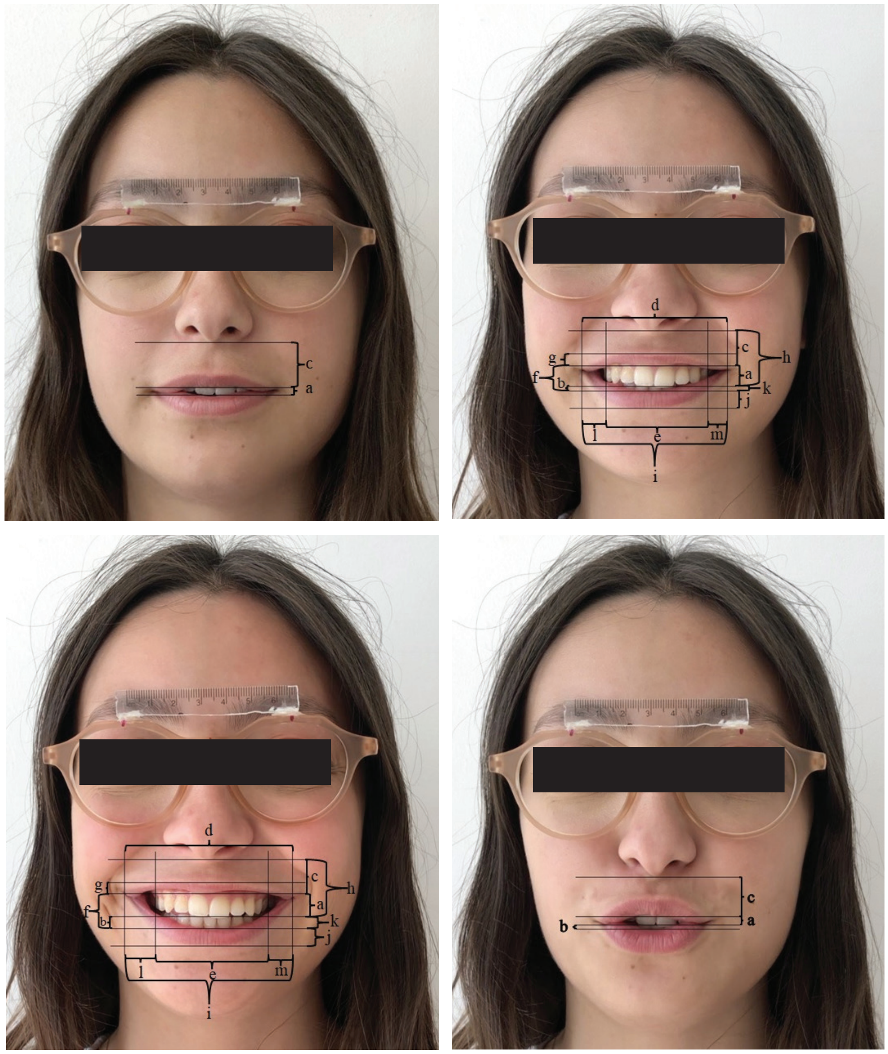
The statistical analysis was conducted using the SPSS V.22 software (IBM SPSS Statistics; Armonk, NY, USA). The descriptive statistics of the data were calculated. The normality of the data was evaluated with Shapiro-Wilk test. The level of each emotional states after each video session were compared with Kruskall-Wallis test with Dunn post-hoc test for non-normally distributed data and One-Way ANOVA with Tukey post-hoc test for normally distributed data. Each parameter measured on the images was compared among the emotional states using Friedman's two-way analysis of variance, and intraclass correlation coefficient (ICC) values were calculated using Spearman's Correlation Analysis. Bland-Altman plots of upper and lower agreement levels were determined. Twenty images were randomly selected after one month from the first measurement, and all measurements were made again to evaluate the intra-observer reliability using the ICC. The level of significance was set as $p<0.05$.

RESULTS

The intraobserver reliability of the measurements was between 0.897 and 0.975. The mean positivity level of all participants in the experiment day just before the experiment was 5.6±1.82, while the mean excitement level was 5.83±1.7. The emotional states of the participants on the experiment day were determined to be neutral.

The descriptive statistics of the emotional state survey scores obtained from the participants after each video are presented in Table 2. After the amusing video, the scores for the positivity, happiness, and amusing conditions were significantly higher compared to the other video groups ($p<0.001$). Similarly, after the sadness video, the participants' scores for unhappiness, anxiety, and sadness were significantly higher compared to other emotions ($p<0.001$).

For the rest position, all differences between various emotional states were not statistically significant for all parameters, and mean differences were less than 1 mm. The highest difference was between sadness and neutral states for the distance between upper lip and subnasal. The correlation values between the measurements were 0.598 and 0.913. The highest correlation was in the distance between upper lip and subnasal parameters of amusing and sadness, while the lowest correlation was observed in the mandibular incisor display. According to Bland Altman plot, the agreement limits exceeded 2 mm for all parameters in some cases, and particularly for the distance between the upper lip and subnasal, the limits increased for the difference between amusing and sadness videos compared to neutral videos (Table 3).



Figures 1, 2, 3, 4. a: Maxillary incisor display, **b:** mandibular incisor display, **c:** distance between upper lip and subnasal, **d:** smile width, **e:** visible dentition width, **f:** smile height, **(d/f):** smile index, **g:** upper lip thickness, **h:** distance between subnasal and incisal edge of maxillary central incisor, **i:** intercommissural width, **j:** lower lip thickness, **k:** lower lip to maxillary incisor distance, **l:** buccal corridor right, **m:** buccal corridor left, **(l+m):** buccal corridor total. (It was considered 0 mm when it was not visible.)

In social smiles, a statistically significant difference was found between amusing and sadness (p=0.006) in maxillary incisor display. A significant difference was found in the visible dentition width between sadness and neutral (p=0.017). For the distance between the subnasal and incisal edges of the maxillary central incisor, a significant difference was found between sadness and neutral. Significant differences were found in the intercommissural width between the amusing and sadness states. The correlation of measurements was found to be between 0.512 and 0.922. The highest correlation was in the smile height between sadness and neutral, while the lowest correlation was observed in the lower lip thickness. The upper and lower agreement limits of the Bland-Altman plots increased, especially in the visible dentition width and the intercommissural width (Table 4).

In the spontaneous smile, a significant difference was found between amusing and neutral (p=0.007) in the mandibular incisor display. A significant difference in smile height was found between amusing and sadness (p=0.020). In the smile index, a significant difference was found between sadness and neutral states (p=0.009). In the distance between the subnasal and incisal edges of the maxillary central incisor, a significant difference was found between sadness and neutral. In the lower lip thickness, a significant difference was found between amusing and sadness. In spontaneous smiles under different emotional states, although significant differences were not found in other parameters, the upper and lower agreement limits of Bland-Altman plots were high in smile width, visible dentition width, and intercommissural width. The correlation of measurements ranged from 0.639 to 0.937. The highest correlation was observed in the parameter of the maxillary incisor display between amusing and neutral, while the lowest correlation was observed in the smile index parameter between amusing and sadness (Table 5).

Table 1. Measurement definitions	
Measurements	**Description**
Maxillary incisor display	Volume of vertical display of the maxillary central incisors
Mandibular incisor display	Vertical display of the mandibular central incisors
Distance between the upper lip and subnasal layer	Distance from the subnasal to inferior border of the upper lip
Smile width	Intercommissure width as measured by distance between left cheilion to right cheilion during smiling
Visible dentition width	Distance from the most lateral aspect of the most visible maxillary posterior tooth on the right and left sides
Smile height	Interlabial gap as measured by the distance from the upper to lower stomion during smiling
Smile index	Smile width divided by smile height
Upper lip thickness	Vertical distance from the deepest midline portion of the superior margin to the most inferior portion of the upper lip
Distance between the subnasal and incisal edges of the maxillary central incisor	Distance from the subnasal to incisal edge of the maxillary central incisor
Intercommissural width	Horizontal distance between the right and left inner commissures
Lower lip thickness	Vertical distance from the deepest midline portion of the superior margin to the most inferior portion of the lower lip
Lower lip to the maxillary incisor distance	Vertical distance from the incisal edge of the maxillary right central incisor to the deepest midline point on the superior margin of the lower lip.
The buccal corridor right	Horizontal distance from the most lateral aspect of the posterior most visible tooth to the right inner commissure
The buccal corridor left	Horizontal distance from the most lateral aspect of the left posterior visible tooth to the left inner commissure
Buccal corridor total	The right and left buccal corridor sums
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Table 2. Descriptive statistics of the emotional state survey scores after each video					
Emotional State	**Video Type**	**Video Type**	**Mean Difference**	**Standard Error**	**p-value***
Positivity	Amusing	Sadness	4.2	0.364	p<0.001
	Amusing	Neutral	2.8	0.364	p<0.001
	Sadness	Neutral	-1.4	0.364	p<0,001
Happiness	Amusing	Sadness	5.7	0.467	p<0.001
	Amusing	Neutral	3.9	0.467	p<0.001
	Sadness	Neutral	-1.8	0.467	0.001
Unhappiness	Amusing	Sadness	-5.1	0.511	p<0.001
	Amusing	Neutral	-2.6	0.511	p<0.001
	Sadness	Neutral	2.5	0.511	p<0.001
Anxiety	Amusing	Sadness	-4.6	0.642	p<0.001
	Amusing	Neutral	-2.4	0.642	0.001
	Sadness	Neutral	2.2	0.642	0.003
Sadness	Amusing	Sadness	-6.0	0.465	p<0.001
	Amusing	Neutral	-2.3	0.465	p<0.001
	Sadness	Neutral	3.7	0.465	p<0.001
Amusing	Amusing	Sadness	5.9	0.313	p<0.001
	Amusing	Neutral	5.5	0.313	p<0.001
	Sadness	Neutral	-0.4	0.313	0.412

*Kruskall-Wallis test with Dunn post-hoc and One-Way ANOVA with Tukey post-hoc
The statistical significance level was p<0.05

Table 3. Statistical comparison of rest position parameters between different emotional states

						Agreement Limits of Bland-Altman Plots		
	p-value*		Mean difference	95% Confidence interval	p-value*	Upper limit (95% CI)	Lower limit (95% CI)	ICC values^
Maxillary incisor display	0.134	Amusing-Sadness	0.26	(-0.15; 0.67)	NS	2.42 (1.71; 3.14)	-1.90 (-2.62; -1.19)	0.867
		Amusing-Neutral	0.31	(-0.04; 0.67)	NS	2.19 (1.57; 2.81)	-1.57 (-2.19; -0.95)	0.856
		Sadness-Neutral	0.05	(-0.32; 0.43)	NS	2.05 (1.39; 2.70)	-1.94 (-2.6; -1.28)	0.836
Mandibular incisor display	0.122	Amusing-Sadness	-0.32	(-0.67; 0.02)	NS	1.51 (0.90; 2.11)	-2.16 (-2.76; -1.55)	0.598
		Amusing-Neutral	-0.15	(-0.52; 0.22)	NS	1.83 (1.18; 2.48)	-2.13 (-2.78; -1.48)	0.667
		Sadness-Neutral	0.17	(-0.11; 0.46)	NS	1.67 (1.18; 2.17)	-1.33 (-1.82; -0.83)	0.748
Distance between the upper lip and subnasal	0.146	Amusing-Sadness	0.40	(-0.08; 0.88)	NS	2.92 (2.09; 3.76)	-2.12 (-2.96; -1.29)	0.913
		Amusing-Neutral	-0.30	(-1.01; 0.40)	NS	3.40 (2.18; 4.62)	-4.01 (-5.23; -2.79)	0.802
		Sadness-Neutral	-0.70	(-1.26; 0.14)	NS	2.22 (1.26; 3.19)	-3.63 (-4.60; -2.67)	0.877

*Friedman's Two Way Analysis of Variance; Bland Altman Plots of Agreement; ^Spearman Correlation Analysis. The statistical significance level was p<0.05
CI, confidence interval; NS, non-significant

Table 4. Statistical comparison of social smile parameters between different emotional states

						Agreement Limits of Bland-Altman Plots		
	p-value*		Mean difference	95% Confidence interval	p-value*	Upper limit (95% CI)	Lower limit (95% CI)	ICC values^
Maxillary incisor display	0.006	Amusing-Sadness	0.51	(0.11; 0.90)	0.006	2.57 (1.89; 3.25)	-1.55 (-2.23; -0.87)	0.888
		Amusing-Neutral	0.22	(-0.20; 0.65)	0.060	2.46 (1.72; 3.2)	-2.01 (-2.74; -1.27)	0.909
		Sadness-Neutral	-0.28	(-1.70; 1.13)	1	3.52 (1.62; 5.42)	-8.02 (-10.93; -6,12)	0.883
Visible dentition width	0.012	Amusing-Sadness	1.75	(0.48; 3.01)	0.072	8.38 (6.20; 10.56)	-4.88 (-7.06; -2.69)	0.771
		Amusing-Neutral	0.50	(-0.71; 1.72)	1	6.89 (4.79; 9,00)	-5.88 (-7.98; -3.78)	0.786
		Sadness-Neutral	-1.24	(-2.2; -0.28)	0.017	3.79 (2.13; 5.45)	-6.28 (-7.94; -4.62)	0.834
Smile height	0.048	Amusing-Sadness	0.93	(0.25; 1.6)	0.117	4.46 (3.30; 5.63)	-2.60 (-3.77; -1.44)	0.719
		Amusing-Neutral	0.37	(-0.32; 1.08)	1	4.06 (2.85; 5.28)	-3.30 (-4.52; -2.09)	0.766
		Sadness-Neutral	-0.55	(-0.94; -0.15)	0.085	1.50 (0.82; 2.18)	-2.61 (-3.28; -1.93)	0.922
Distance between the subnasal and incisal edges of the maxillary central incisor	0.020	Amusing-Sadness	0.55	(-0.07; 1.18)	0.158	3.86 (2.77; 4.95)	-2.76 (-3.85; -1.67)	0.832
		Amusing-Neutral	-0.24	(-0.73; 0.24)	1	2.34 (1.49; 3.19)	-2.83 (-3.68; -1.98)	0.870
		Sadness-Neutral	-0.79	(-1.33; -0.26)	0.020	1.99 (1.07; 2.91)	-3.59 (-4.51; -2.67)	0.894
Intercommissural width	0.007	Amusing-Sadness	1.30	(0.23; 2.37)	0.043	6.93 (5.08; 8.78)	-4.32 (-6.17; -2.47)	0.845
		Amusing-Neutral	-0.05	(-1.19; 1.08)	1	5.93 (3.96; 7.90)	-6.04 (-8.01; -4.06)	0.867
		Sadness-Neutral	-1.35	(-2.24; -0.47)	0.009	3.26 (1.74; 4.79)	-5.98 (-7.51; -4.46)	0.880
Mandibular incisor display	0.920	Amusing-Sadness	0.06	(-0.32; 0.46)	NS	2.15 (1.47; 2.84)	-2.01 (-2.70; -1.33)	0.811
		Amusing-Neutral	0	(-0.46; 0.46)	NS	2.44 (1.64; 3.25)	-2.45 (-3.25; -1.64)	0.607
		Sadness-Neutral	-0.07	(-0.41; 0.27)	NS	1.75 (1.15; 2.35)	-1.89 (-2.49; -1.29)	0.732

Table 4. Continued

						Agreement Limits of Bland-Altman Plots"		
	p-value*		Mean difference	95% Confidence interval	p-value*	Upper limit (95% CI)	Lower limit (95% CI)	ICC values^
Distance between the upper lip and subnasal	0.356	Amusing-Sadness	-0.04	(-0.58; 0.48)	NS	2.74 (1.82; 3.67)	-2.84 (-3.76; -1.92)	0.857
		Amusing-Neutral	-0.45	(-1.00; 0.08)	NS	2.39 (1.45; 3.33)	-3.31 (-4.25; -2.37)	0.892
		Sadness-Neutral	-0.40	(-0.93; 0.11)	NS	2.33 (1.43; 3.23)	-3.15 (-4.05; -2.24)	0.871
Smile width	0.079	Amusing-Sadness	1.31	(0.26; 2.36)	NS	6.83 (5.01; 8.65)	-4.19 (-6.01; -2.38)	0.860
		Amusing-Neutral	0.17	(-0.92; 1.27)	NS	5.95 (4.05; 7.85)	-5.59 (-7.5; -3.69)	0.886
		Sadness-Neutral	-1.14	(-1.93; -0.34)	NS	3.04 (1.66; 4.41)	-5.32 (-6.69; -3.94)	0.894
Smile index	0.072	Amusing-Sadness	-0.58	(-1.09; -0.06)	NS	2.13 (1.23; 3.02)	-3.29 (-4.19; -2.40)	0.761
		Amusing-Neutral	-0.36	(-0.95; 0.23)	NS	2.74 (1.72; 3.77)	-3.46 (-4.49; -2.44)	0.749
		Sadness-Neutral	0.22	(-0.24; 0.68)	NS	2.66 (1.86; 3.47)	-2.22 (-3.02; -1.41)	0.902
Upper lip thickness	0.393	Amusing-Sadness	-0.006	(-0.43; 0.42)	NS	2.26 (1.51; 3.01)	-2.27 (-3.02; -1.53)	0.825
		Amusing-Neutral	-0.13	(-0.50; 0.23)	NS	1.82 (1.18; 2.47)	-2.09 (-2.74; -1.45)	0.823
		Sadness-Neutral	-0.12	(-0.44; 0.18)	NS	1.50 (0.96; 2.04)	-1.76 (-2.3; -1.22)	0.857
Lower lip thickness	0.648	Amusing-Sadness	1.58	(-2.02; 5.19)	NS	2.51 (1.27; 2.74)	-1.34 (-2.57; -1.10)	0.512
		Amusing-Neutral	1.52	(-2.05; 5.10)	NS	2.31 (1.12; 2.49)	-1.26 (-2.45; -1.08)	0.557
		Sadness-Neutral	-0.06	(-0.38; 0.25)	NS	1.61 (1.06; 2.17)	-1.74 (-2.30; -1.19)	0.822
Lower lip to the maxillary incisor distance	0.873	Amusing-Sadness	0.24	(-0.23; 0.71)	NS	2.75 (1.92; 3.58)	-2.27 (-3.09; -1.44)	0.743
		Amusing-Neutral	0.17	(-0.34; 0.69)	NS	2.92 (2.01; 3.82)	-2.57 (-3.47; -1.66)	0.648
		Sadness-Neutral	-0.06	(-0.39; 0.26)	NS	1.66 (1.09; 2.23)	-1.79 (-2.37; -1.22)	0.827
The buccal corridor right	0.239	Amusing-Sadness	0.02	(-0.36; 0.41)	NS	2.06 (1.39; 2.73)	-2.01 (-2.68; -1.34)	0.789
		Amusing-Neutral	-0.37	(-0.8; 0.06)	NS	1.90 (1.15; 2.65)	-2.65 (-3.4; -1.90)	0.671
		Sadness-Neutral	-0.40	(-1.52; 0.72)	NS	1.48 (0.86; 2.10)	-2.28 (-2.90; -1.66)	0.856
The buccal corridor left	0.648	Amusing-Sadness	-0.04	(-0.59; 0.49)	NS	2.78 (1.85; 3.72)	-2.88 (-3.82; -1.95)	0.758
		Amusing-Neutral	0.19	(-0.28; 0.66)	NS	2.68 (1.86; 3.51)	-2.30 (-3.13; -1.48)	0.824
		Sadness-Neutral	0.23	(-0.24; 0.72)	NS	2.77 (1.93; 3.60)	-2.29 (-3.12; -1.45)	0.799
Buccal corridor total	0.943	Amusing-Sadness	-0.01	(-0.75; 0.72)	NS	3.86 (2.59; 5.14)	-3.89 (-5.17; -2.61)	0.815
		Amusing-Neutral	-0.18	(-0.90; 0.53)	NS	3.59 (2.35; 4.84)	-3.96 (-5.20; -2.71)	0.836
		Sadness-Neutral	-0.17	(-0.81; 0.47)	NS	3.22 (2.10; 4.33)	-3.56 (-4.68; -2.44)	0.864

*Friedman's Two Way Analysis of Variance; Bland Altman Plots of Agreement; ^Spearman Correlation Analysis. The statistical significance level was p<0.05
CI, confidence interval; NS, non-significant

In the speech, a significant difference was found between amusing and sadness states regarding the distance between the upper lip and subnasal (p=0.035). The correlation among the measurements was between 0.573 and 0.887. The lowest correlation was observed in the parameter of the mandibular incisor display among amusing and sadness, while the highest correlation was observed in the parameter of the distance between the upper lip and subnasal among amusing and neutral (Table 6).

The correlations were moderate or high for all parameters in all functions, ranging from 0.512 for social smiles to 0.937 for spontaneous smiles (Tables 3-6).

DISCUSSION

In this study, the potential effects of emotional states on the reproducibilities of rest position, social and spontaneous smiles, and speech were assessed. Quantitative evaluations of hard and soft tissue relationships during rest position, social and spontaneous smiles, and speech have critical importance for success in orthodontic planning and treatment.[4] Orthodontists set specific esthetic goals in planning, and minimal changes make a significant difference in reaching these goals. Patient expectations are also important when planning treatment. For instance, the patient may have specific concerns such as insufficient incisor appearance during speech or irregularities in the lower incisor teeth during speech. Achieving the initial treatment goals with these minimal changes and being able to make the right decision at each appointment requires that the photographs and/or video recordings taken should be reproducible for the function being considered.

Table 5. The statistical comparison of spontaneous smile parameters between different emotional states

						Agreement Limits of Bland-Altman Plots"		
	p-value*		Mean difference	95% Confidence interval	p-value*	Upper limit (95% CI)	Lower limit (95% CI)	ICC values^
Mandibular incisor display	0.004	Amusing-Sadness	0.65	(0.05; 1.25)	0.051	3.78 (2.75; 4.81)	-2.47 (-3.50; -1.44)	0.799
		Amusing-Neutral	-0.05	(-0.57; 0.46)	0.007	2.66 (1.76; 3.56)	-2.77 (-3.66; -1.87)	0.845
		Sadness-Neutral	-0.70	(-1.20; -0.21)	1	1.89 (1.03; 2.75)	-3.31 (-4.16; -2.45)	0.803
Smile height	0.014	Amusing-Sadness	1.22	(0.21; 2.22)	0.020	6.49 (4.75; 8.22)	-4.04 (-5.78; -2.31)	0.703
		Amusing-Neutral	0.25	(-0.70; 1.20)	1	5.26 (3.61; 6.91)	-4.76 (-6.41; -3.11)	0.767
		Sadness-Neutral	-0.97	(-1.68; -0.26)	0.060	2.76 (1.53; 3.99)	-4.70 (-5.93; -3.47)	0.817
Smile index	0.007	Amusing-Sadness	-0.66	(-1.21; -0.12)	0.043	2.21 (1.26; 3.15)	-3.54 (-4.49; -2.6)	0.639
		Amusing-Neutral	-0.04	(-0.64; 0.55)	1	3.11 (2.07; 4.15)	-3.20 (-4.23; -2.16)	0.696
		Sadness-Neutral	0.62	(0.12; 1.13)	0.009	3.27 (2.40; 4.14)	-2.02 (-2.89; -1.14)	0.746
Distance between the subnasal and incisal edges of the maxillary central incisor	0.039	Amusing-Sadness	0.60	(-0.09; 1.30)	0.212	4.28 (3.07; 5.49)	-3.07 (-4.28; -1.86)	0.843
		Amusing-Neutral	-0.16	(-0.61; 0.27)	1	2.16 (1.39; 2.92)	-2.49 (-3.26; -1.72)	0.905
		Sadness-Neutral	-0.77	(-1.56; 0.01)	0.043	3.38 (2.01; 4.75)	-4.93 (-6.30; -3.56)	0.792
Lower lip thickness	0.032	Amusing-Sadness	-0.35	(-0.76; 0.04)	0.029	1.76 (1.06; 2.47)	-2.48 (-3.18; -1.78)	0.738
		Amusing-Neutral	-0.25	(-0.54; 0.04)	1	1.29 (0.78; 1.8)	-1.79 (-2.30; -1.28)	0.811
		Sadness-Neutral	0.10	(-0.32; 0.54)	0.280	2.38 (1.63; 3.13)	-2.17 (-2.92; -1.40)	0.687
Maxillary incisor display	0.151	Amusing-Sadness	0.47	(0.07; 0.88)	NS	2.60 (1.90; 3.30)	-1.64 (-2.35; -0.94)	0.911
		Amusing-Neutral	0.15	(-1.06; 1.36)	NS	1.61 (1.06; 2.17)	-1.55 (-3.35; 0.23)	0.937
		Sadness-Neutral	-0.32	(-0.63; -0.01)	NS	1.3 (0.76; 1.83)	-1.95 (-2.49; -1.42)	0.881
Distance between the upper lip and subnasal	0.967	Amusing-Sadness	0.10	(-0.36; 0.56)	NS	2.54 (1.73; 3.34)	-2.33 (-3.13; -1.53)	0.926
		Amusing-Neutral	-0.11	(-0.61; 0.38)	NS	2.50 (1.64; 3.37)	-2.74 (-3.61; -1.88)	0.903
		Sadness-Neutral	-0.22	(-0.66; 0.22)	NS	2.09 (1.33; 2.86)	-2.54 (-3.30; -1.77)	0.884
Smile width	0.107	Amusing-Sadness	1.30	(0.28; 2.32)	NS	6.64 (4.88; 8.39)	-4.03 (-5.79; -2.27)	0.917
		Amusing-Neutral	0.75	(-0.3; 1.81)	NS	6.33 (4.49; 8.16)	-4.81 (-6.65; -2.98)	0.875
		Sadness-Neutral	-0.54	(-1.5; 0.41)	NS	4.49 (2.83; 6.15)	-5.59 (-7.25; -3.92)	0.785

Table 5. Continued

						Agreement Limits of Bland-Altman Plots"		
	p-value*		Mean difference	95% Confidence interval	p-value*	Upper limit (95% CI)	Lower limit (95% CI)	ICC values^
Visible dentition width	0.195	Amusing-Sadness	1.29	(0.13; 2.45)	NS	7.40 (5.39; 9.41)	-4.81; (-6.82; -2.80)	0.888
		Amusing-Neutral	0.69	(-0.31; 1.7)	NS	5.99 (4.25; 7.74)	-4.60 (-6.34; -2.85)	0.936
		Sadness-Neutral	-0.59	(-1.4; 0.21)	NS	3.65 (2.25; 5.05)	-4.85 (-6.25; -3.45)	0.829
Upper lip thickness	0.239	Amusing-Sadness	-0.22	(-0.66; 0.22)	NS	2.09 (1.33; 2.86)	-2.53 (-3.30; -1.77)	0.819
		Amusing-Neutral	-0.18	(-0.55; 0.18)	NS	1.76 (1.12; 2.40)	-2.12 (-2.77; -1.48)	0.827
		Sadness-Neutral	0.03	(-0.33; 0.40)	NS	1.99 (1.34; 2.63)	-1.91 (-2.56; -1.27)	0.834
Intercommissural width	0.792	Amusing-Sadness	0.85	(-0.06; 1.76)	NS	5.66 (4.07; 7.24)	-3.96 (-5.54; -2.37)	0.928
		Amusing-Neutral	0.57	(-0.47; 1.61)	NS	6.05 (4.24; 7.86)	-4.91 (-6.72; -3.1)	0.910
		Sadness-Neutral	-0.28	(-1.25; 0.68)	NS	4.81 (3.13; 6.48)	-5.37 (-7.04; -3.69)	0.818
Lower lip to the maxillary incisor distance	0.066	Amusing-Sadness	0.85	(0.15; 1.56)	NS	4.56 (3.34; 5.78)	-2.84 (-4.06; -1.62)	0.794
		Amusing-Neutral	0.01	(-0.51; 0.54)	NS	2.79 (1.88; 3.71)	-2.76 (-3.67; -1.84)	0.912
		Sadness-Neutral	-0.84	(-1.41; -0.26)	NS	2.18 (1.18; 3.17)	-3.86 (-4.85; -2.86	0.775
The buccal corridor right	0.107	Amusing-Sadness	0.11	(-0.27; 0.49)	NS	2.11 (1.45; 2.77)	-1.89 (-2.55; -1.23)	0.865
		Amusing-Neutral	0.39	(0.06; 0.72)	NS	2.14 (1.56; 2.71)	-1.35 (-1.93; -0.77)	0.894
		Sadness-Neutral	0.28	(-0.12; 0.69)	NS	2.42 (1.72; 3.13)	-1.86 (-2.56; -1.15)	0.832
The buccal corridor left	0.967	Amusing-Sadness	0.01	(-0.56; 0.59)	NS	3.05 (2.05; 4.05)	-3.02 (-4.02; -2.01)	0.747
		Amusing-Neutral	-0.03	(-0.54; 0.40)	NS	2.63 (1.75; 3.51)	-2.71 (-3.59; -1.83)	0.818
		Sadness-Neutral	-0.05	(-0.43; 0.31)	NS	1.9 (1.25; 2.55)	-2.02 (-2.66; -1.37)	0.895
Buccal corridor total	0.648	Amusing-Sadness	0.17	(-0.53; 0.89)	NS	3.93 (2.69; 5.16)	-3.57 (-4.81; -2.34)	0.824
		Amusing-Neutral	0.28	(-0.46; 1.03)	NS	4.20 (2.91; 5.49)	-3.63 (-4.92; -2.34)	0.824
		Sadness-Neutral	0.10	(-0.49; 0.71)	NS	3.29 (2.24; 4.34)	-3.07 (-4.12; -2.02)	0.834

*Friedman's Two Way Analysis of Variance; "Bland Altman Plots of Agreement; ^Spearman Correlation Analysis. The statistical significance level was p<0.05
CI, confidence interval; NS, non-significant; ICC, intraclass correlation coefficient

Multidisciplinary treatments have become common in recent years. The common language of communication between physicians during treatment is of great importance. In treatments requiring multidisciplinary approaches, differences arising from the recorded data can complicate interdepartmental agreements and associated planning. According to the outcomes of this study, physicians working together on a case can, through a standard recording procedure, bring the patient's emotional state close to the same condition, even if not precisely the same, and obtain more accurate records, leading to more accurate outcomes.

Table 6. Statistical comparison of speech parameters between different emotional states

						Agreement Limits of Bland-Altman Plots"		
	p-value*		Mean difference	95% Confidence interval	p-value*	Upper limit (95% CI)	Lower limit (95% CI)	ICC values^
Distance between the upper lip and subnasal	0.039	Amusing-Sadness	0.76	(0.13; 1.40)	0.035	4.09 (2.99; 5.18)	-2.56 (-3.65; -1.46)	0.733
		Amusing-Neutral	0.14	(-0.37; 0.66)	0.999	2.85 (1.96; 3.75)	-2.57 (-3.46; -1.67)	0.887
		Sadness-Neutral	-0.62	(-1.11; -0.12)	0.364	1.97 (1.12; 2.83)	-3.22 (-4.08; -2.36)	0.773
Maxillary incisor display	0.670	Amusing-Sadness	0.05	(-0.42; 0.53)	NS	2.59 (1.75; 3.42)	-2.48 (-3.31; -1.64)	0.820
		Amusing-Neutral	-0.20	(-0.68; 0.27)	NS	2.3 (1.47; 3.13)	-2.71 (-3.54; -1.88)	0.810
		Sadness-Neutral	-0.26	(-0.77; 0.25)	NS	2.43 (1.54; 3.32)	-2.95 (-3.84; -2.06)	0.767
Mandibular incisor display	0.991	Amusing-Sadness	0.27	(-0.2; 0.74)	NS	2.74 (1.93; 3.56)	-2.20 (-3.02; -1.39)	0.573
		Amusing-Neutral	0.06	(-0.38; 0.50)	NS	2.38 (1.61; 3.14)	-2.26 (-3.02; -1.49)	0.596
		Sadness-Neutral	-0.21	(-0.61; 0.19)	NS	1.89 (1.20; 2.59)	-2.31 (-3.01; -1.62)	0.668

*Friedman's Two Way Analysis of Variance; "Bland Altman Plots of Agreement; ^Spearman Correlation Analysis. The statistical significance level was p<0.05
CI, confidence interval; NS, non-significant; ICC, intraclass correlation coefficient

Studies have shown that there is significantly more cheek movement in happy expressions than in sad or angry expressions.[14,15] Furthermore, in another study related to the activity of facial muscles while watching avatar faces,[15] it was found that the activity in the zygomaticus major muscle in the cheek was higher in happy faces than in neutral, sad, and angry faces. Neuroimaging studies have provided compelling evidence for overlapping brain regions involved in the production and observation of emotional expressions, including the pre-motor, somatosensory, and gustatory cortices.[16,17] One functional magnetic resonance study demonstrated how video clip facial expressions, such as joy, anger, and disgust, are associated with distinct neural signatures in the somatomotor system using a statistical Bayesian pattern recognition technique.[18] According to these studies, the emotional state has a pronounced effect on neuromuscular mechanisms and muscular activity. The reproducibilities of rest position, social and spontaneous smiles, and speech changes under different emotional states remain a subject for investigation.

The participants were between the ages of 18 and 22, with an average age of 19.6. With the widespread use of social media, the patient group in orthodontics has shifted from children to young adults. This range was chosen due to the increase in the number of patients in this age group who seek dental care because of rising esthetic concerns.

In the study, three videos were shown to the subjects to manipulate their emotional states. The videos used in the study were taken from a stimulus set development study conducted in a sample by Amado et al.[11] for evaluating the emotion-inducing levels of the videos. After the recordings were taken, a validated and proven reliable survey was administered to the participants, asking them to score various emotions they felt at that moment on a scale of 1 to 9.

Rest position, social and spontaneous smiles, and speech were obtained from the participants under the same commands. These records were captured using a video camera. The choice of videographic method may be subject to discussion. Wander et al.[19] stated that videography in dental records provides diagnostic information that cannot be obtained from photographs alone and that video images are preferred over static images by professionals. Tarantili et al.[20] described a progression of a smile using digital video, consisting of an initial attack period, a sustaining period, and a fade-out or decay period. If a clinical photograph is taken during the attack or fade-out phase, the resulting smile may not be a reliable reference. Therefore, video may have a distinct advantage over clinical photographs in accurately capturing a true representation of a smile.[4,20] In our study, images corresponding to that function were obtained over a specific period using videography. From these recordings, the image best representing that function was selected for the analysis. During photography, it was considered that the patient may have consciously directed the function based on their emotional state or increased awareness during the study process. From another perspective, since the video recording was taken immediately after participants were shown a sadness-inducing video, they may have become aware of being directed and thus adopted a more negative mood, fulfilling the commands in that manner. However, the videographic method may still be considered advantageous in capturing an ideal smile, regardless of the participant's emotional state. However, muscle-nerve studies detailed above brought to the forefront the possibility of differences even in the most naturally obtained images of a person. The fundamental aim of this study is to investigate the possibility of differentiation regarding the supposed ideal images of the patient in this emotional state. Measurements were taken from the image in which the function evaluated in the video was best captured. Ackerman et al.[2] stated that a spontaneous smile is an enjoyment smile, occurring involuntarily, emerging with laughter, developing with an instant explosion, and being unsustainable. In our study, the evaluation of spontaneous smiles was also made possible by the videographic method.

There are two different smiles: the social smile and the spontaneous smile. The literature suggests that there are morphologic differences between these smiles. Van der Geld et al.[10] analyzed differences in tooth display, lip-line height, and smile width between social and spontaneous (Duchenne) smiles and showed that these two types are different. As Duchenne de Boulogne observed in 1862, posed (social) and spontaneous smile exhibit physiognomic differences.[21] In addition to the zygomaticus major muscle, contracting the corners of the mouth, the spontaneous "Duchenne" smile involves the orbicularis oculi pars lateralis muscle. Dindaroğlu et al.[12] also examined this difference in their study and obtained similar results.

The primary aim of this study was not to examine the morphological differences between social and spontaneous smiles but to evaluate the reproducibility of these two different smiles under different emotional states. This study revealed that an individual's emotional state affects certain parameters. In social smiles, these include maxillary incisor display, visible dentition width, smile height, distance between the subnasal and incisal edges of the maxillary central incisor, and intercommissural width. In spontaneous smiles, the affected parameters are the mandibular incisor display, smile height, smile index, distance between the subnasal and incisal edges of the maxillary central incisor, and lower lip thickness. During speech, the affected parameter is the distance between the upper lip and subnasal.

Both Ackerman et al.[5] and Frey et al.[6] indicated that smile reproducibility is variable and that the rest position has the highest reproducibility. Similar results were obtained in our study, reinforcing the notion that the rest position is an important record that must be obtained for long-term follow-up of patients. Walder et al.[19] stated that when a social smile is objectively measured, it can be reliably reproduced. Sarver and Ackerman[4] considered a social smile to be reproducible and utilized it as a guide when planning soft tissue facial treatment. The conclusions of these two articles differ from our study. In this study, we found that social smiles may vary depending on the individual's emotional state. In accordance with our study, Ekman et al.[7] stated that a social smile could be influenced by an individual's emotional background, supporting the idea that a person's emotional background can direct measurements. There were no significant differences in the parameters measured in the rest position under different emotional states. Both speech and the rest position were found to be more reproducible than smiles. Burstone et al.[9] asserted that the rest position has the highest reproducibility. Even if significant differences are not found in certain parameters, the fact that the upper and lower agreement limits are high indicates that they may be clinically important at the individual level.

Study Limitations

Future studies could incorporate 3D imaging and recordings. In this way, measurements can be made more clearly and accurately using artificial intelligence, minimizing human intervention. One limitation of this study is the subjectivity of emotional state questionnaires, as participants self-report their feelings. More effective results could be obtained by employing objective methods to assess emotional states.

CONCLUSION

Social and spontaneous smiles may vary depending on the individual's emotional state.

The rest position exhibits higher reproducibility than social and spontaneous smiles in all emotional states.

Speech reproducibility varies based on emotional states.

Ethics

Ethics Committee Approval: The study was approved by the Medical Research Ethics Committee of Ege University (approval no.: 22-4T/1, date: 12.04.2022).

Informed Consent: Participants were asked to fill out a signed consent form at the beginning of the study.

Footnotes

Author Contributions: Concept - I.B., İ.Ş., F.D.; Design - I.B., İ.Ş., F.D.; Data Collection and/or Processing - I.B., F.D.; Analysis and/or Interpretation - I.B., İ.Ş., F.D.; Literature Search - I.B., F.D.; Writing - I.B., F.D.

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Timing of Therapeutic Extractions Can Affect En Masse Anterior Retraction: A Split Mouth Randomized Clinical Trial

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Main Points

- The rate of space closure at the recent extraction site was faster than the healed site.
- There was no significant difference in the mesial movement of anchorage molars or rotation of canines into the extraction site between the two sides.
- Orthodontic retraction should be initiated immediately following therapeutic extractions; this would be a practical and non-invasive way of hastening tooth movement.

ABSTRACT

Objective: To investigate the effect of deferred timing of therapeutic extraction on the rate of space closure during en masse anterior retraction.

Methods: Twenty-six patients (aged 16-24 years) with bimaxillary protrusion, crowding <3 mm, requiring bilateral extraction of four first premolars were recruited. Permuted block randomization was done. Allocations were concealed in opaque envelopes which were numbered and sealed. Each patient's right and left quadrant was randomly assigned for premolar extraction. The extraction of the contralateral side was deferred until the commencement of retraction. The primary outcome was the rate of space closure, and the secondary outcomes were anchorage loss and canine rotation. Blinding was applied only during the outcome assessment. The independent t-test and Intraclass correlation tests were used for statistical evaluation.

Results: Twenty-four patients completed the study. The mean rate of space closure over a period of 4 months was found to be significantly higher for the recently extracted site (0.818±0.208) when compared with healed site(0.426±0.184)($p<0.001$). The tipping of the canine was also significantly higher for the former (6.042°±1.398°) than the latter (5.125°±1.035°) ($p<0.05$). However, the amounts of anchorage loss and canine rotation were insignificant. No adverse effects were noted.

Conclusion: The rate of space closure at the recent extraction site was faster than that at the healed site. There was no significant difference in the mesial movement of anchorage molars or rotation of canines into the extraction site. The tipping of canines was significantly greater in the recent extracted quadrant. The results of this trial indicate a clinical recommendation to initiate orthodontic retraction immediately following therapeutic extractions and offer a practical, non-invasive, safe procedure for increasing the rate of tooth movement.

Keywords: Accelerated tooth movement, regional acceleratory phenomenon, rate of space closure, recently extracted site, healed site

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INTRODUCTION

The long-time span required for orthodontic treatment is a significant concern for both patients and orthodontists. The average duration of treatment is reported to range from 19.4 and 27.9 months and 18.1-24.5 months for extraction and non-extraction therapies, respectively.[1] Prolonged treatment times can lead to increased risks of dental caries, periodontal problems, and root resorption.[2,3] It can also adversely affect patient compliance and satisfaction.

Literature reveals an impetus to accelerate tooth movement by various means in the last decade.[4-10] These include surgical and non-surgical interventions (mechanical vibration, low-level laser therapy, low intensity pulsed ultrasound). Surgical approaches range from highly invasive procedures like corticotomy-facilitated orthodontics,[4] Periodontally Accelerated Osteogenic Orthodontics,[5] and dentoalveolar distraction[6,7] to minimally invasive procedures such as corticision,[8] piezocision,[9] and micro-osteo perforations (MOPs).[10] All invasive modalities were performed to take advantage of the "Regional Acceleratory Phenomenon" (RAP)[11] which is reported to induce transient functional osteopenia and decreased mineral density, thereby accelerating bone turnover and facilitating tooth movement through remodeling. RAP begins within a few days of injury, peaks at 1-2 months and lasts typically for approximately 4 months.[5,12]

The above procedures, whether invasive or minimally invasive, are all performed as additional interventions. It is possible that routine orthodontic extractions could also trigger the RAP phenomenon and thereby accelerate tooth movement. Hence, the timing of therapeutic extractions is important.

The literature regarding tooth movement into recent and healed extraction sites is controversial. While an animal study by Murphey[13] reported greater movement on the healed side, other animal studies have reported faster tooth movement at recent extraction sites.[14,15] Hasler[16] in his study involving 22 patients reported faster canine distalization on the recent extraction side. One trial comparing retraction of canine into healed versus recent extraction sites reported significantly faster movement in the latter.[17] However, data in this trial were analyzed after only one month of retraction, and no information was provided regarding anchorage loss, canine angulation, or rotation.

The decision to extract the first premolar is often included in the treatment plan for the correction of bimaxillary protrusion to achieve the desired outcomes. Both en masse and two-step retraction are effective methods of space closure through which incisors and canines can be retracted to correct proclination and crowding. Sliding mechanics using the MBT prescription are widely used for en masse retraction. After leveling and aligning using sequential heat-activated nickel-titanium (HANT) wires, en masse anterior retraction is performed using 0.019x0.025 stainless steel working wires. This leads to a time delay of around 4-5 months by which time the extraction sites can heal. There was no delay in treatment timing in this study, as retraction began as soon as the 19x25 stainless steel wires were inserted and sliding was effectivelyinitiated, as in a typical case. If extraction is performed after the completion of leveling and alignment, immediately before the start of en masse retraction, it is possible that tooth movement may be accelerated.

Although studies have compared canine retraction into healed and recently extracted sites, no studies have investigated en masse anterior retraction under similar conditions. En masse anterior retraction may not necessarily produce the same response as individual canine retraction. Hence, this study was conducted as a randomized clinical trial comparing en masse anterior retraction into healed and recently extracted sites, with monitoring over a period of at least 4 months. According to the literature, RAP begins within a few days following any surgical intervention, peaks at 1-2 months, and subsides by 4-6 months. Hence, we chose a 4-month observation period.[5,12] Furthermore, variables such as the amount of mesial movement of molars, rotation, and angulation changes in the canine etc. have not yet been evaluated, highlighting the need for further investigation.

Specific Objectives and Hypotheses

Assessment of rate of space closure into recently extracted and healed extraction sites was the primary objective. Evaluation of anchorage loss, canine rotation, and canine tipping were included as secondary objectives. The null hypothesis generated was that "there may be no difference in terms of the above outcomes between healed and recently extracted sites during en masse anterior retraction using MBT mechanics".

METHODS

Trial Design and Any Changes After Trial Commencement

This study was a single-center, split-mouth, randomized clinical trial with an allocation ratio of 1:1 between the right and left maxillary quadrants. The methodology remained unchanged after trial commencement.

Participants: Eligibility Criteria and Study Setting

This study is part of a postgraduate dissertation that was approved by the Institutional Research Board and Institutional Ethics Committee of Government Dental College, Kozhikode (approval no.: 162/2019/DCC, date: 14.11.2019) and registered under the Clinical Trials Registry (CTRI no.: CTRI/2020/05/025436). Participants were recruited from patients registered for orthodontic treatment at the postgraduate clinic of the Government Dental College, Calicut, Kerala, India. The inclusion criteria were as follows: Angle's Class I malocclusion with bimaxillary protrusion[18] necessitating bilateral extraction of premolars, presence of all permanent teeth (excluding third molars), age between 16-24 years, well-aligned arches with crowding of ≤3 mm, absence of transverse discrepancies, and maxillo-mandibular plane angle ranging between 23° and 31°.[19]

Exclusion criteria included poor oral hygiene, periodontal problems, alveolar bone loss, medications or medical conditions affecting bone biology, active systemic problems, smoking, presence of severe rotation of anterior and posterior teeth, any developmental anomalies of crown and root, deleterious oral habits, and those who were not willing to participate in the study were later excluded. Withdrawal criteria included missing routine appointments, appliance breakage, and failure to maintain proper oral hygiene. Both male and female participants were recruited. Informed consent was obtained from all participants or their legal guardians after providing all explanations and clarifications regarding the trial.

Sample Size

The nMaster software (Biostatistics Research & Training Centre, Christian Medical College, Vellore-2, India) was used for calculating the sample size. Based on the results from a previous study, for change in the anteroposterior movement of canine (T1-T3)[16] with a pooled standard deviation of 1.14, if the true difference between the means is 1.1, a sample size of 24 subjects per group was required to reject the null hypothesis. This calculation achieved a power of 0.9, with a Type I error probability of 0.05. It was decided to include more patients so as to increase the power of the study and compensate for possible dropouts during the study period. Thus, 26 patients were recruited.

Randomization

Random number generation, allocation concealment, and blinding

A splitmouth, paired design was used in which each participant had one "healed extraction side" and a recent contralateral extraction side. Extraction of first premolars were randomly allocated to the right or left sides at an allocation ratio of 1:1. Randomization was performed using random number tables occurring in permuted blocks of 2 patients, so that once all 26 patients were recruited, there would be equal numbers on either side. Random sequences were concealed in opaque, envelopes that were numbered and sealed. Ultimately, 50% of patients had the right premolar extracted, while the remaining 50%, had the left premolar extracted. Baseline information for each participant was stored by the investigator responsible for opening the next envelope in sequence and implementing the randomization process.

Blinding

This study did not allow the clinician or patients to be blinded. However, the co-investigator was blinded during the measurement and statistical analysis stages.

Intervention

A single investigator treated all the patients, using the pre-adjusted edgewise appliance (MBT prescription, 0.022×0.028" slot, 3M Unitek, Monrovia, CA, USA). As stated earlier, the upper and lower premolars on one side, be it left or right, was extracted at the beginning of treatment, based on randomization. This was considered the "healed extraction site". Only the upper arch was included in the investigation. The anterior segment was levelled and aligned using the following sequence of 0.014, 0.017x0.025, 0.019x0.025 HANT wires, with each archwire in place for 4 weeks. All six anteriors were consolidated (to prevent drifting of canine into extraction site) by tying them together using a single 0.010" ligature wire. This was followed by placement of the working wires, (0.019 x 0.025 posted stainless steel wires) in both the upper and lower arches for a period of 4 weeks, after which the contralateral first bicuspids were extracted, just before starting retraction. This was considered the "recent extraction site". Retraction was commenced simultaneously in both arches. Only the upper arch was included in the investigation. En masse retraction was initiated from the third day after the second extraction using closed coil Nitinol springs from the archwire hooks to the molar hooks, (3M Unitek; 9 mm), applied simultaneously on both sides of the arch. Activations were performed monthly. Upper molars were stabilized by placing a transpalatal arch at the first visit. Care was taken to maintain the retraction forces in the range of 150-200 g per side by delivering equal amounts of activation as measured by the force gauge every month ("Correx", Dentaurum, Germany). Patients were advised not to take anti-inflammatory NSAIDs as it may affect tooth movement. A positive overjet was maintained during the full treatment period. Impressions were taken using alginate, and casts prepared with die stone immediately before starting retraction, and also after the second and fourth months following retraction. The patients name, date and number were marked on all the casts before storage

Outcomes (Primary and Secondary) and Any Changes After Trial Commencement

The primary outcome was the rate of space closure at healed and recently extracted sites. The secondary outcomes were the rotational tendency of the canines, canine tipping, and changes in the first molar position. Outcomes were evaluated cephalometrically and using model analysis at two and four months. There were no changes after trial initiation.

Model Analysis

The midpalate raphe (MPR) served as the reference plane[20] and the medial aspects of the third rugae (RR-*rugae right*, RL-*rugae left*) as reference points for assessing anteroposterior changes in tooth position.[21] After identifying and marking the relevant landmarks on the pre- and post-retraction maxillary dental casts, they were scanned using an Epson perfection V700 scanner (maximum resolution-12,800 dpi). Perpendiculars were drawn on to the MPR reference plane from the mesiobuccal cusp tips of the maxillary permanent first molars (ML-molar left, MR-molar right) and the cusp tips of the maxillary permanent canines (CL- canine left, CR- canine right) (Figure 1). For determining rate of canine retraction, high accuracy digital calipers (Mitutoya, Kawasaki, Japan) with readings nearest to 0.1mm were used. After performing the measurements twice, the mean of the two measurements was recorded. The difference in the linear distance between the CL (tip of left canine) and CR (tip of right canine) from pre-retraction to post-retraction was measured. After determining the extent of change in position, the duration of canine retraction was recorded as time intervals, with corresponding periods: first 2 months (T_{1-2}), second 2 months (T_{2-4}), and first 4 months (T_{1-4}). The rate of canine retraction was calculated by dividing the amount of retraction in millimeters by the time interval. This yielded the rate of canine retraction for each period (Table 1).

The anchorage loss in terms of mesial movement of first molars, as measured by the difference in the linear distance of their mesiobuccal cusp tips (ML, MR - molar left and molar right) before and after retraction was assessed (Figure 1). Rotation of the canine during retraction was assessed by drawing the rotation angle which is formed between a reference line parallel to the mid-palatine raphe and another line passing through the mesial-distal contact points of the concerned canine. Change in values between pre and post treatment rotation angles gives the rotation of that canine (Figure 2).

Cephalometric Analysis

Change in the long axis of the canine (tipping of canine) was assessed cephalometrically before and after retraction with the help of two differently shaped (by giving a bend toward mesial on right and distal on left) radiopaque markers made of 0.021 ″stainless steel (SS) wire, ligated to canine brackets (Figure 3).[22] The change in marker angulation with respect to the palatal plane in pre- and post- treatment cephalograms depicted the amount of tipping undergone by the canine.[22] The direction of the bend helped to differentiate right and left canines. All measurements were performed to the nearest 0.5° with a protractor.

After two weeks, randomly selected models/radiographs of twelve patients were taken and all the above procedures repeated to assess the intraexaminer reliability.[22] There were no changes after trial initiation.

Statistical Analysis

All statistical analyses were performed using the SPSS statistical package (version 16.0, SPSS Inc., Chicago, Illinois, USA). The mean and standard deviation were calculated. The independent t-test was used to compare the amount of canine retraction between healed and recent extraction sites. A value of $p \leq 0.05$ was considered statistically significant. The intraclass correlation test was used to analyze intraexaminer variability.

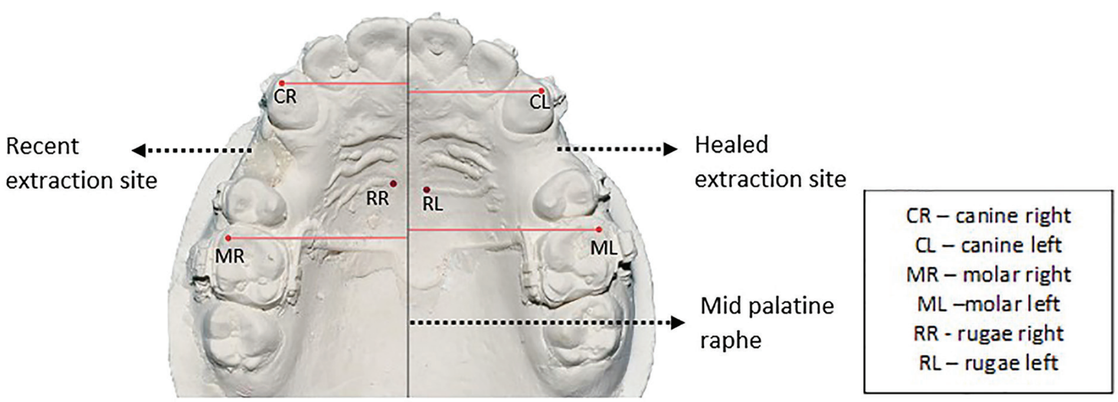

Figure 1. Landmarks on the maxillary cast showing recent and healed extraction sites

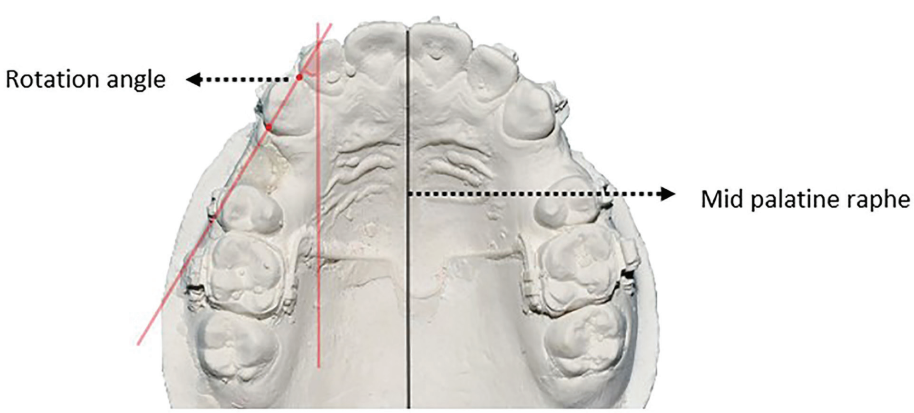

Figure 2. Determination of canine rotation

RESULTS

Participant Flow

Initially, 32 patients who presented to the Department of Orthodontics between July 2020 and December 2020 were assessed for eligibility by two clinicians not involved in the study. Six of the 32 patients not meeting the inclusion criteria were excluded from the study. Finally, 26 patients wereselected. The right and left quadrants were randomly allocated to either "healed"or "recent" extraction site in a 1:1 ratio. However, one patient was lost during follow-up. Another patient also had to be excluded due to breakage of the appliance. Information regarding each patient was stored in sealed envelopes to ensure confidentiality. Twenty-four patients finally completed the study and were analyzed (Figures 4 and 5).

Baseline Data

Of the 24 participants, 11 were male and 13 were female. The cephalometric variables included SNA (82.5º±3.7º), SNB (79.5º±4.6º), ANB (3.25º±2º), and maxillary incisor inclination to the palatal plane (120.5º±4.5º).

Numbers analyzed for outcome estimation and precision; subgroup analysis

Primary outcome: The mean rate of space closure (with standard deviation) for both healed and recent extraction

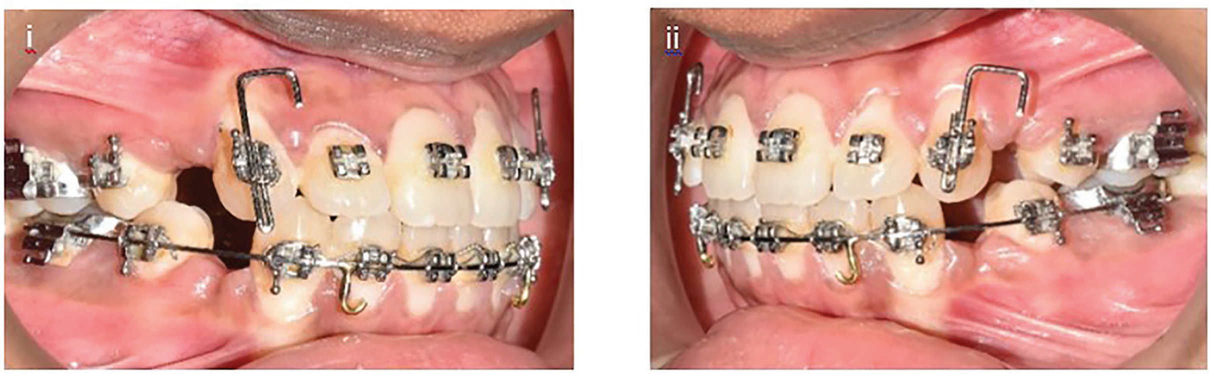

Figure 3. SS markers on right (i) and left (ii) canine
SS, stainless steel

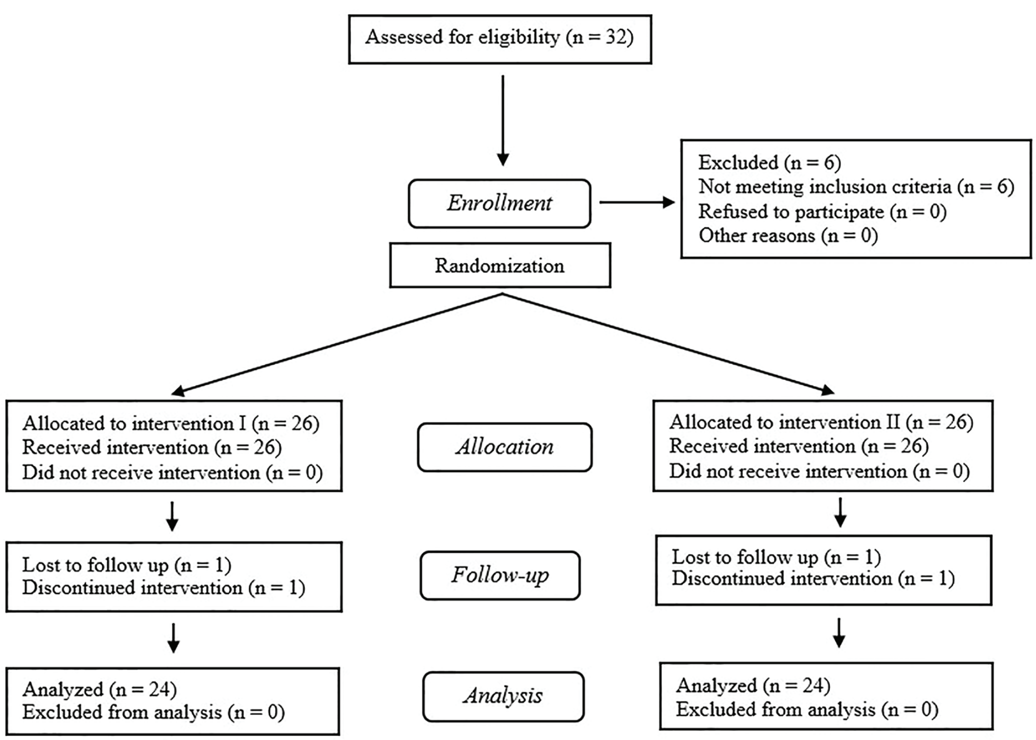

Figure 4. CONSORT diagram showing the flow of patients through the trial

sites is given in Table 1. The mean rate of space closure for a period of 4 months on the healed extraction site was found to be 0.426±0.184 mm/month, while for the recent extraction site it was 0.818±0.208 mm/month. This is highly significant (p<0.000). The rate of space closure during the first two months was higher than that during the second to fourth months for the recently extracted site.

Secondary outcomes (Table 1): Tipping of the canine into recent extraction side was 6.042° (±1.398°), which is significantly more than 5.125° (±1.035°) on the healed side (p<0.05). No statistically significant differences were observed in canine rotation and anchorage loss between the two sites. The intraclass correlation coefficient to test intra-examiner reliability is presented in Table 2, which demonstrates excellent agreement.

Harms

There were no harms or negative outcomes reported by any participant during the trial.

DISCUSSION

The rate of space closure on the side of recent extraction showed a 1.9-fold increase, as compared to the earlier healed side. This is relevant from a clinical standpoint as well. This can be explained by the "Regional accelerated phenomenon (RAP)", which is characterized by "transient functional osteopenia followed by accelerated bone turnover over time". In humans, RAP "begins within a few days following any form of surgical intervention, peaks at 1-2 months, and subsides by 4-6 months".[5,12] With respect to orthodontic tooth movement, RAP can be seen as a "tissue response to mechanical cyclical

Table 1. Comparison of mean rates of space closure, canine rotation, tipping, and anchorage loss between healed and recent extraction sites

	Healed extraction site		The recent extraction site		p-value
	Mean	SD	Mean	SD	
Rate of space closure (mm)					
R_{1-4}	0.426	0.184	0.818	0.208	
R_{1-2}	0.470	0.243	1.006	0.266	0.000***
R_{2-4}	0.356	0.115	0.639	0.239	
Canine rotation (CR) (degree)	1.125	0.797	1.541	0.658	0.055
Canine tipping (CT) (degree)	5.125	1.035	6.042	1.398	0.013*
Anchorage loss (AL) (mm)	0.708	0.765	1.062	0.727	0.107

Independent t-test, *p<0.05, ***p<0.001
SD, standard deviation

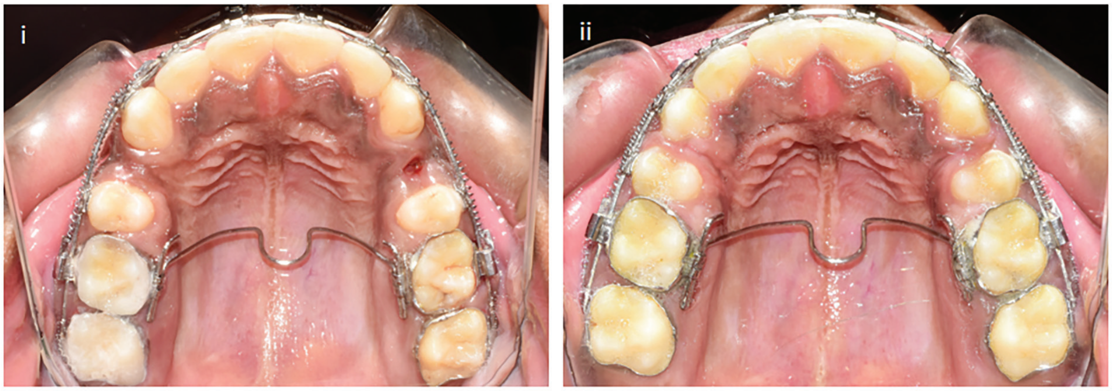

Figure 5. i) Pre-start of retraction, ii) 4 months post-retraction

Table 2. ICCs showing the level of agreement

Parameter	ICC
Retraction	0.991
Rotation	0.967
Anchorage loss	0.925
Tipping	0.936

ICC, intraclass correlation coefficient

perturbations" that induce microdamage which has to be removed to avoid their accumulation.[23] The adaptation to the "new orthodontically induced mechanical environment" is ensured by increased activation of the bone multicellular unit (BMU), which returns to normal levels after a few months. It is reported that the decreased mineral density allows easier orthodontic tooth movement during remodeling and healing.[23]

Previous research on the effects of timing of therapeutic extractions have all focused on individual canine retractions; hence, comparison of our findings with previous research was not possible. However, a recent study on the effects of micro-osteoperforations on en masse retraction reported a retraction rate ranging from 0.43±20 to 0.44±17 mm/month during the first 4 months for the control group, which is similar to the healed extraction side in this study.[24] They also reported a significant increase in the rate of retraction (0.71019 mm/month for the first month) in the group that underwent MOP. A recent publication by Zubair et al.,[17] has reported a rate of 1.17±0.27 mm/month for individual canine retraction into recent extraction site, (as compared to the healed site) during the first month. However, their study did not include evaluation beyond the first month. Alikhani et al.[10] hypothesized that "trauma amplifies the expression of inflammatory markers that are normally expressed during orthodontic treatment, and this response accelerates both bone resorption and tooth movement". High cytokine and chemokine levels help to convert osteoclast precursor cells into mature osteoclasts, thereby enhancing alveolar bone resorption at a faster rate.

Another important observation of this study is that the rate of tooth movement was considerably faster during the first two months (1.006 mm/month) for the recently extracted side, followed by a significant decline (0.639 mm/month). Observations by Raghav et al.[24] have also reported a similar decline in the rate of tooth movement after the first month in patients who underwent MOP. One possible explanation for the decline in the rate of tooth movement during 3rd and 4th month compared with the first 2 months could be the transient nature of RAP.

Although there are few clinical studies in this area, a histological explanation has been proposed by Diedrich and Wehrbein.[15] Their experiments on foxhounds reported that recent extraction sites were characterized by higher bone density with less maturity and broader alveolar processes, whereas older (12 weeks old) extraction sites had more mature lamellar bone, pronounced horizontal atrophy, and periosteal bone apposition in the direction of tooth movement. This makes orthodontic tooth movement challenging at older healed extraction sites. They opined that, according to histological finding, orthodontic retraction into extraction sites should be initiated at an early stage.

The contribution of the RAP phenomenon might explain the accelerated tooth movement rather than the existing histological differences in bone density. There is a reported difference in bone densities between healed and recently extracted sites (more denser in former than latter). In recently extracted sites, inflammatory markers are also reported to be amplified (than what is expressed during normal orthodontic treatment) due to the RAP phenomenon, which is induced without any additional surgical procedures. This response may be responsible for the difference in bone densities and for accelerating both bone resorption and tooth movement. The advantage of immediate retraction into the extraction site can definitely bring about rapid tooth movement, thereby decreasing the overall treatment time as well as the possible untoward effects on the periodontal tissues. Clinically, this information is applicable to cases with bimaxillary protrusion and minimal crowding. The clinical relevance of this approach is that it would be beneficial to delay extractions in such patients.

The results of our investigation revealed insignificant anchor loss and rotation of the canine on both sides. Although anchor loss was observed to be greater on the recent extraction side, it was not significant, probably due to reinforcement of anchorage with the transpalatal arch. A previous investigation of canine movement into healed and recently extracted sites reported similar findings.[16] However, their study involved sectional mechanics using Gjessing springs on either side for individual canine retraction. The tipping of the canine in our investigation was more toward the recent extraction site, with a difference of only 0.917°. Hasler[16] also reported significant tipping of canines in the quadrant that underwent a recent extraction. The angulation reported by them was 15.75° in recent and 14.25° in old extraction side, which is much higher than that obtained by us (mean 6.04° on recent extraction side and 5.13° on healed side). This is probably due to the fact that friction mechanics on continuous archwire (as advocated by MBT philosophy) were used in our investigation, which involved both tipping and uprighting during the course of retraction. The method of evaluation of canine angulation was also different in the two investigations.

Study Limitations

A limitation of our study is that evaluation was performed for only four months, and the complete closure of the extraction spaces was not considered. This is because RAP begins within a few days following any form of surgical intervention, peaks at 1-2 months, and subsides by 4-6 months. Treatment was continued thereafter, and all cases were debonded following the completion of space closure in all four quadrants. Moreover, no histological examination was performed to distinguish the bone qualities of both the experimental and control sides.

This clinical trial included patients with mild crowding and protrusion requiring extraction. Therefore, the findings are expected to be generalizable only to patients requiring extraction for orthodontic treatment.

CONCLUSION

The null hypothesis was rejected, as the results of the study showed that the rate of space closure was higher for the recently extracted site than for the healed site. The results of this randomized clinical trial show that:

• The rate of space closure at the recent extraction site was faster than at the healed site.

• There was no significant difference in the mesial movement of anchorage molars or rotation of canines into the extraction site between the two sides.

• Tipping of canines into the extraction site was significantly greater in the quadrant with recently extracted premolars.

The results of this trial support a clinical recommendation to initiate orthodontic retraction immediately following therapeutic extractions and offer a practical, non-invasive, safe procedure to enhance the rate of tooth movement.

Ethics

Ethics Committee Approval: Ethical permission was obtained from the Institutional Research Board and Institutional Ethics Committee of Government Dental College, Kozhikode (approval no.: 162/2019/DCC, date: 14.11.2019).

Informed Consent: Informed consent was obtained from all participants or their legal guardians after providing all explanations and clarifications regarding the trial.

Footnotes

Author Contributions: Concept - S.S.; Design- S.S.; Data Collection and/or Processing - D.P., N.M., Sr.S.; Analysis and/orInterpretation -Sr.S., D.P., B.J.; Literature Search - M.S., N.M., B.J.; Writing- M.S., D.P., S.S.

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

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Original Article

Skeletal, Dental, and Soft Tissue Changes after Slow Maxillary Expansion in Early Mixed Dentition

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Main Points

- Nickel titanium memory leaf expanders provide an effective and comfortable approach for maxillary expansion in mixed dentition cases.
- Treatment with leaf expansion appliances during mixed dentition results in both skeletal and dental effects.
- Significant improvements in transverse width and area measurements are observed in patients treated with the leaf expander.

ABSTRACT

Objective: This study aimed to evaluate the skeletal, dental, and soft tissue effects of the nickel titanium memory Leaf Expander in a growing sample of patients with unilateral posterior crossbite compared with a control group using digital models and lateral cephalometric radiographs.

Methods: The research included a total of 24 patients, 12 of whom were treated and 12 untreated. The Leaf Expander group consisted of 4 males and 8 females (mean age= 8.6±10.7 years), and the control group consisted of 5 males and 7 females (mean age: 9.2±0.8 years). Changes during the observation period in both groups were evaluated using the Wilcoxon signed-rank test. We used the Mann-Whitney U test to compare the data between the groups.

Results: There was a significant increase in the values indicating the vertical position of the maxilla and mandible in the treatment group. The palatal surface area increased significantly in both groups, but the increase was significantly higher in the treatment group than in the control group. In addition, intermolar width and arch perimeter measurements were significantly higher in the treatment group than in the control group.

Conclusion: With the advantage that this device does not require parent compliance, the possibility of incorrect activation was eliminated, and effective expansion using the Leaf Expander was achieved in patients with unilateral crossbite.

Keywords: Leaf expander, posterior crossbite, mixed dentition, slow maxillary expansion

INTRODUCTION

Transverse discrepancy due to reduced maxillary width, which is usually accompanied by crowding and posterior crossbite, is one of the most common skeletal deformities in orthodontics.[1] The prevalence of posterior crossbite ranges from 8% to 22% in patients with deciduous/mixed dentition.[2] Because posterior crossbite can cause problems, such as insufficient maxillary arch width and crowding, this type of crossbite should be treated early.[3] Anchorage from permanent teeth may show negative results, such as root resorption, bone loss, and white spot lesions in permanent dentition. To prevent these complications, it is recommended to obtain anchorage from

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deciduous teeth in the mixed dentition period.[4] Since 1970, several authors have continued to report the advantages of slow maxillary expansion (SME) in opening the midpalatal suture at an early stage and minimizing pain and discomfort by allowing regeneration of the suture site.[1,3,5]

Recently, nickel titanium (NiTi) alloy has been used in some appliances to induce maxillary expansion. These NiTi-containing appliances have the advantage of the shape-memory characteristics of this alloy and exert a constant and continuous force, allowing for dentoskeletal effects.[6] Initially, Arndt[7] eliminated the need for patient compliance with SME appliances containing a NiTi alloy in 1993. Corbett[8] introduced a second example of a NiTi-containing expansion appliance called a Nitanium Palatal Expander 2 in 1997. The Memory Palatal Split Screw (MPSS), an expansion device, was introduced in 2004. This appliance contains super-elastic NiTi open coil springs that reduce the high expansion forces.[9]

In 2013, the Leaf Expander was first constructed in Florence, Italy.[10] The active elements in this appliance are represented by leaf-shaped NiTi springs that return to their original form upon deactivation, resulting in predictable expansion of the maxillary arch. The Leaf Expander is now available in two lengths (6 and 9 mm) and two forces generated by the NiTi springs (450 and 900 g). The 6 mm screw contains two leaf springs and can be activated up to 30 times. The 9 mm screw contains three leaf springs and can be activated up to 45 times. In both appliances, each turn produces a 0.1 mm expansion.[11]

The present study aimed to evaluate the skeletal, dental, and soft tissue effects of SME using the Leaf Expander in a sample of patients in their growth stages with unilateral posterior crossbite using digital models and lateral cephalometric radiographs. In addition, it was intended to confirm whether the maxillary width of treated crossbite patients could reach the same width as that of normal controls in this study.

METHODS

The study included 12 patients who underwent orthodontic treatment with the Leaf Expander and 12 control subjects who had not undergone orthodontic treatment at Karadeniz Technical University Faculty of Dentistry. The patients were treated according to the ethical guidelines for human experiments described by the Scientific Research Ethics Committee of the Faculty of Medicine at Karadeniz Technical University, and written informed consent forms were completed by all parents. The ethics committee approval was also obtained from the Karadeniz Technical University Faculty of Medicine of Scientific Research Ethics Committee (approval no.: 6, date: 28.06.2021) for the research. The Leaf Expander group consisted of four males and eight females (group 1; mean age: 8.6±0.7 years), and the control group consisted of five males and seven females (group 2; mean age: 9.2±0.8 years). The SME protocol with Leaf Expander was used in 12 patients with maxillary transverse deficiency in group 1. Group 2 included 12 untreated patients without maxillary transverse deficiency.

Inclusion and Exclusion Criteria

The inclusion criteria for the treatment group included several parameters: (1) early mixed dentition period, (2) mild transverse deficiency, (3) presence of upper deciduous second molars, (4) no history of orthodontic treatment, (5) good oral hygiene, and (6) no systemic or syndromic disorder. Patients without upper deciduous canine, molar, permanent first molar, or severe maxillary transverse deficiency were excluded from the study.

The control group consisted of growing individuals who were matched to the treatment group according to sex and maturation stage. All control subjects had normal overjet and overbite, no posterior crossbite, and normal sagittal and vertical skeletal configurations.

Leaf Expander Protocol

The expansion screw was pre-activated in the laboratory to produce 3 mm of expansion. The Leaf Expander was bonded to deciduous second molars, and the ligatures were cut to allow expansion (Figure 1A). The Leaf screw (6 mm) delivers 900 g of force during deactivation. Patients visited the clinic every four weeks for Leaf Expander activation. The screw was activated by 10 quarter-turns until a normal transverse relationship was achieved, with no overcorrection. After the completion of active expansion (three months), as shown in Figure 1B, the appliance was kept in place for 4.5 more months for retention. Therefore, the total treatment duration, including retention was 7.5 months.

In group 1, lateral cephalometric radiographs and digital models were obtained before treatment (T1) and after retention (T2). Records from the control group were obtained at intervals similar to those from the treatment group.

All lateral cephalometric radiographs were obtained using a Kodak 9000 Extraoral Imaging System (Carestream Health, Inc. Rochester, NY, USA). All measurements of the lateral cephalometric films were performed using Nemoceph Version 6.0 (Nemotec, Madrid, Spain) and ImageJ version 1.3 (National Institutes of Health, Bethesda, Md).

Dental models of all patients were scanned using a 3shape R700 series (3Shape, Copenhagen, Denmark) scanning device. 3Shape Ortho Analyzer (Copenhagen, Denmark) was used for linear and angular measurements, and ImageJ version 1.3 (National Institutes of Health, Bethesda, Md) for surface area measurements (Figures 2-5). Table 1 lists the measurements used in the digital model analysis.

To detect skeletal and dental effects in the radiographs, measurements were obtained using reference planes. Accordingly, seven degrees to the sella nasion plane (SN) through sella point was taken as the horizontal reference plane (Hor) and perpendicular to Hor through S point was taken as the vertical reference plane (Ver), as shown in Figure 6.

All definitions of lateral cephalometric measurements are presented in Table 2.

Statistical Analysis

The sample size was calculated using the G*Power software (version 3.1.9.2). Based on a study by Lanteri et al.[12], it was concluded that 10 subjects would be sufficient at α error=0.05, β error=0.20, effect size=0.9, and standard deviation=0.72. However, considering possible data losses (20% loss), approximately 12 patients per group (24 patients in total) were included in the study. The data obtained in this study were analyzed using SPSS 17.0 (Statistical Package for Social Sciences). Conformity of the data to normal distribution was evaluated using the Shapiro-Wilk test. The Wilcoxon signed-rank test was used to evaluate differences between the model and the cephalometric measurements during the treatment period. Finally, the Mann-Whitney U test was used to compare data between the groups.

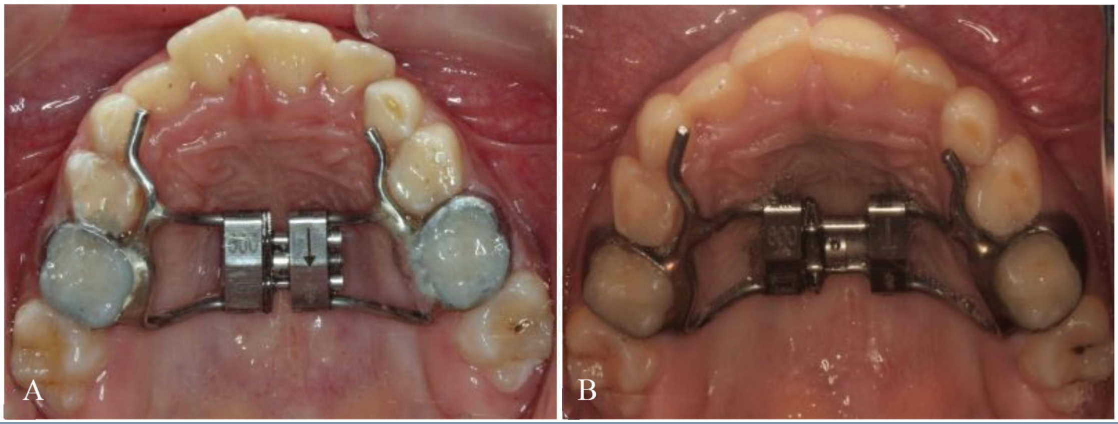

Figure 1. Leaf Expander in place (A) and completion of expansion (B)

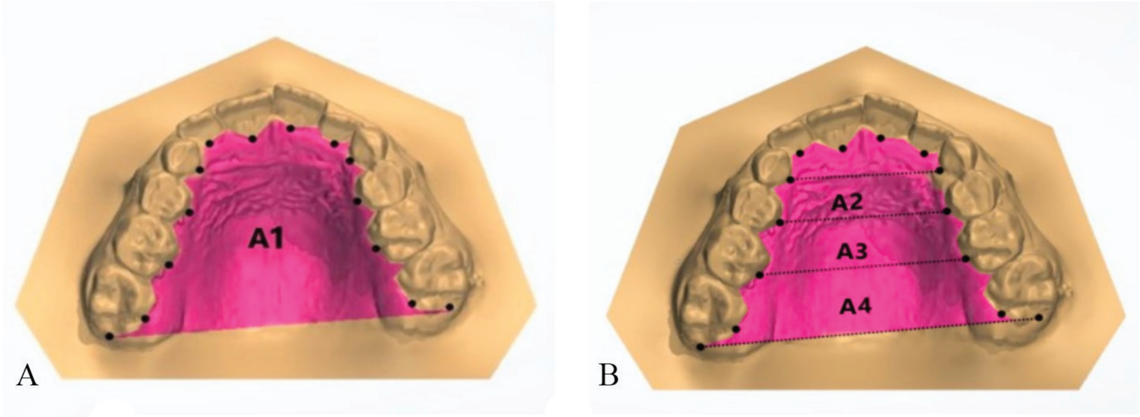

Figure 2. Area 1 measurements (A) and Areas 2, 3, and 4 measurements (B)

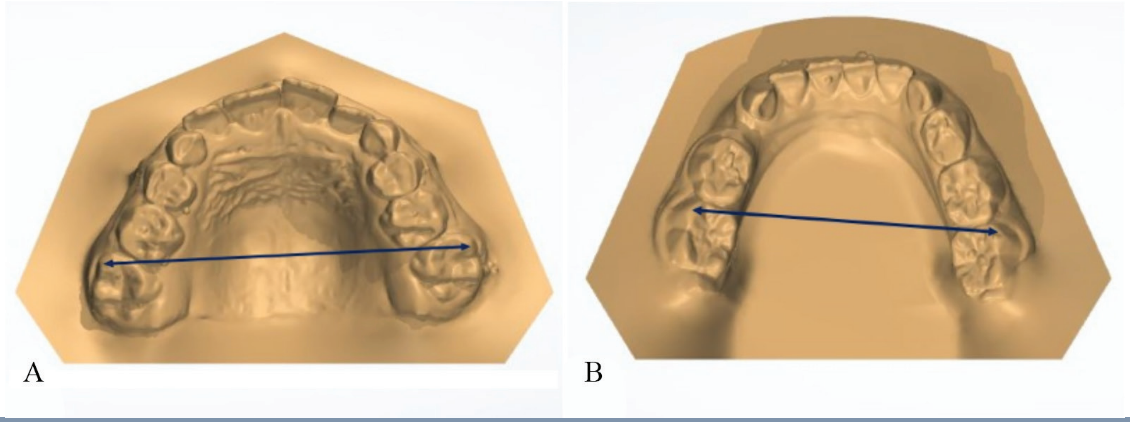

Figure 3. Upper (A) and lower (B) intermolar widths

RESULTS

A comparison of changes in cephalometric measurements and maxillary dental arch measurements on digital models in the post- and pre-observation (T2 and T1, respectively) periods for group 1 is presented in Table 3. In group 1, significant increases in A-Hor (0.98±0.56 mm; $p<0.01$), ANS-Hor (0.63±0.93 mm; $p<0.05$), and PNS-Hor (0.61±0.76 mm; $p<0.05$) distances from T1 to T2 (Table 4). Comparison of T2-T1 differences between the groups are presented in Table 5. Although the difference in A-Hor (0.97 mm; $p<0.001$) and PNS-Hor (0.79 mm; $p<0.01$) distances between the groups were significant, the difference in ANS-Hor distance was not significant ($p<0.05$), as shown in Table 5. For the mandibular skeletal measurements, a significant increase was observed in the B-Hor distance from T1 to T2 in group 1 (0.56±1.20 mm; $p<0.05$), as shown in Table 3. The differences between the groups were significant (0.40 mm; $p<0.05$), as shown in Table 5. Changes in B-Hor and overjet values were significant between the groups ($p<0.05$).

Significant increases were observed in group 1 in all area measurements from T1 to T2 ($p<0.01$), and this increase was

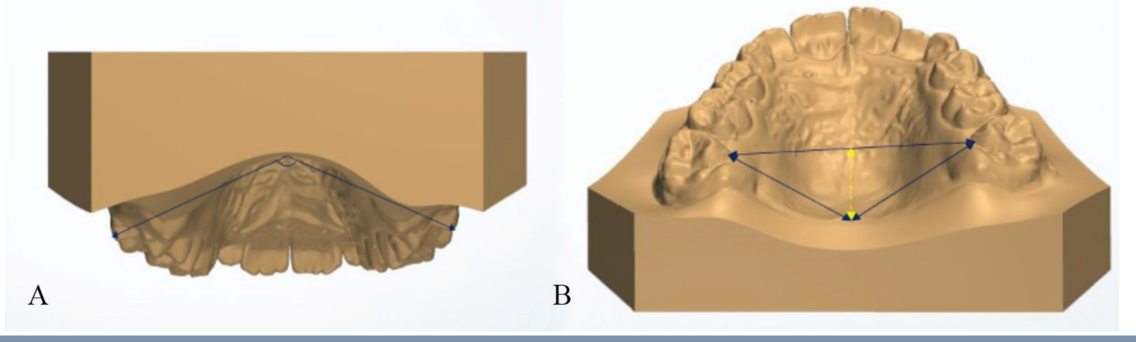

Figure 4. Molar angulation (A) and palatal depth (B) measurements

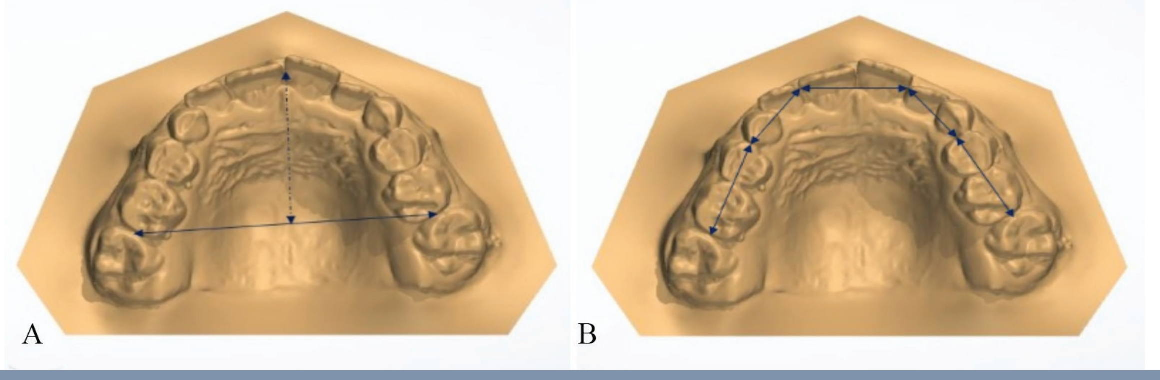

Figure 5. Arch length (A) and perimeter (B) measurements

Table 1. Measurements used in the digital model analysis

Area 1	The palatal area from the deepest points of the dentogingival junction of all teeth to the distal point of the permanent first molars.
Area 2	The palatal area between the deepest points of the dentogingival junction of the deciduous canines and first molars.
Area 3	The palatal area between the deepest points of the dentogingival junction of the primary and second molars.
Area 4	The palatal area between the deepest points of the dentogingival junction of the primary second molars and the distal end of the permanent first molars.
Upper intermolar width	Distance between the mesiobuccal cusps of the upper first permanent molars.
Lower intermolar width	Distance between the mesiobuccal cusps of the lower first permanent molars.
Molar angulation	Angle between the planes tangent to the buccal surfaces of the upper permanent first molars.
Palatal depth	The distance from a line passing through the gingiva of the permanent first molars to the deepest point in the palate.
Arch length	The distance from the midpoint of the upper central incisors to the plane passing through the mesiobuccal cups of the permanent first molars.
Arch perimeter	Perimeter between the mesial aspect of the first molars, over the contact points of the posterior teeth, and the incisal edge of the anteriors.

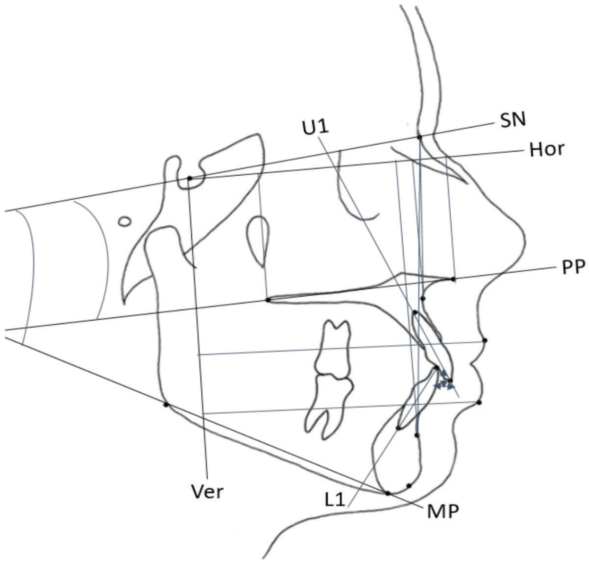

Figure 6. Lateral cephalometric measurements

significantly higher in Area 1 in particular (131.72±66.14 mm^2; p<0.01), as shown in Table 3. In addition, only slight increases observed in area measurements were found to be significant (p<0.01, p<0.05) in group 2, as shown in Table 4. Significant increases were observed in all area measurements in group 1 compared with group 2 (Area 1, 117.25 mm^2, area 2, 27.78 mm^2, area 3, 33.67 mm^2, and area 4, 53.28 mm^2; p<0.001), as shown in Table 5.

The upper and lower intermolar widths and arch perimeter measurements increased significantly from T1 to T2 in group 1 (p<0.01) (Table 3). When these changes were compared between the groups, group 1 showed greater changes in the upper (2.86 mm; p<0.001) and lower intermolar widths (1.26 mm; p<0.01) and arch perimeter (3.31 mm; p<0.001), as shown in Table 5. A significant increase from T1 to T2 in the molar angulation measurement in group 1 (1.97°; p<0.05) was observed, as shown in Table 3. A significant difference was found in the molar angulation measurement between group 1 and group 2 (2.06°; p<0.05), as shown in Table 5.

Table 2. The lateral cephalometric measurements

SNA	Angle between the Sella-Nasion and NA lines
A-Hor (mm)	The perpendicular distance between points A and the horizontal reference plane
ANS-Hor (mm)	The perpendicular distance between the point ANS and the horizontal reference plane
PNS-Hor (mm)	The perpendicular distance between the point PNS and the horizontal reference plane
SN/PP	Angle between the Sella-Nasion and palatal planes
SNB	The angle between the SN and NB lines
B-Hor (mm)	The perpendicular distance between points B and the horizontal reference plane
SN/MP	Angle between the mandibular plane (Gonion-Gnathion) and the SN
ANB	The angle between the NA and NB lines
Overjet	Horizontal distance between the incisor points of the maxillary and mandibular central incisors
Overbite	Horizontal distance between the incisor points of the maxillary and mandibular central incisors
U1/SN	Angle between the axis of the maxillary anterior incisor and the Sella sinus
U1/PP	Angle between the axis of the maxillary anterior incisor and the palatal plane
IMPA	Angle between the mandibular plane and the axis of the mandibular central incisor
UL-Ver (mm)	The perpendicular distance between the most anterior dot and the convexity of the upper lip to the vertikal reference plane
UL-Ver (mm)	The perpendicular distance between the most anterior dot and the convexity of the lower lip to the vertikal reference plane

Table 3. Analysis of skeletal and dental changes (Wilcoxon signed-rank test) observed in the T1-T2 time interval in the treatment group

	T1	T2	t	p
Maxillary skeletal measurements				
SNA	78.50±2.50	78.58±2.53	0.08	
A-Hor (mm)	30.06±1.55	31.04±1.48	0.98	**
ANS-Hor (mm)	26.39±2.22	27.02±1.48	0.63	*
PNS-Hor (mm)	26.49±1.32	27.10±1.29	0.61	*
SN/PP	7.08±2.71	7±2.62	-0.08	
Mandibular skeletal measurements				
SNB	77.83±2.75	78±2.73	0.16	
B-Hor (mm)	56.99±2.55	57.55±2.13	0.56	*
SN/MP	34.50±5.17	34.75±5.34	0.25	

Table 3. Continued

	T1	T2	t	p
Maxillomandibular measurements				
ANB	0.66±1.66	0.58±1.31	-0.08	
Dentoalveolar measurements				
Overjet	1.03±1.52	1.02±1.49	-0.01	
Overbite	0.20±2.22	0.35±2.08	0.15	
U1/SN	104.52±4.28	104.41±4.18	-0.10	
U1/PP	111.75±4.59	111.58±4.60	-0.16	
IMPA	92.08±7.95	92.08±7.92	0	
Soft tissue measurements				
UL-Ver (mm)	53.92±3.30	55±3.23	1.08	
LL-Ver (mm)	53.33±3.71	53.30±3.70	-0.03	
Digital model measurements				
Area 1	904.10±116.59	1035.83±87.07	131.72	**
Area 2	165.16±18.98	194.39±15.92	29.23	**
Area 3	229.10±29.39	265.16±30.70	36.06	**
Area 4	390.91±68.66	452.62±61.21	61.71	**
Upper intermolar width	49.61±4.29	52.62±4.46	3.01	**
Lower intermolar width	45.81±2.55	47.19±2.57	1.37	**
Molar angulation	120.09±9.29	122.07±9.34	1.97	*
Palatal depth	12.52±1.20	12.60±1.08	0.08	
Arch length	27.22±1.54	27.22±1.59	0	
Arch perimeter	73.01±2.83	76.39±3.20	3.37	**

*p<0.05, **p<0.01
T1, preobservation; T2, postobservation; t, difference

Table 4. Analysis of skeletal and dental changes (Wilcoxon signed-rank test) observed in the T1-T2 time interval in the control group

	T1	T2	t	p
Maxillary skeletal measures				
SNA	79.08±1.72	79.33±1.66	0.25	
A-Hor (mm)	31.06±2.76	31.06±2.66	0.01	
ANS-Hor (mm)	27.84 ±2.45	28.02±2.30	0.18	
PNS-Hor (mm)	27.63±2.26	27.45±2.15	-0.18	
SN/PP	9±2.29	9.08±2.53	0.08	
Mandibular skeletal measures				
SNB	76.75±2.80	76.66±3.17	-0.08	
B-Hor (mm)	56.27±3.71	56.43±3.46	0.16	
SN/MP	34.66±5.59	34.83±5.71	0.16	
Maxillomandibular measures				
ANB	2.33±2.14	2.66±2.67	0.33	
Dentoalveolar measures				
Overjet	2.25±1.50	2.15±1.58	-0.1	
Overbite	1.30±1.35	1.46±1.27	0.15	
U1/SN	104.35±5.50	104.24±5.65	-0.10	
U1/PP	114.66±7.11	114.50±6.93	-0.16	
IMPA	95.33±6.51	95.25±6.01	-0.08	

Table 4. Continued

	T1	T2	t	p
Soft tissue measurements				
UL-Ver (mm)	57.13±4.38	57.19±4.24	0.05	
LL-Ver (mm)	55.74±4.55	55.89±4.61	0.15	
Digital model measures				
Area 1	935.83±115.87	950.31±112.74	14.47	**
Area 2	173.04±27.39	174.49±27.60	1.45	*
Area 3	237.24±36.07	239.63±36.21	2.39	**
Area 4	422.67±47.39	431.10±46.49	8.43	**
Upper intermolar width	52.10±4.03	52.26±3.31	0.15	
Lower intermolar width	45.80±3.27	45.92±2.57	0.11	
Molar angulation	126.08±4.79	125.99±4.49	-0.09	
Palatal depth	13.16±2.41	13.26±2.28	0.09	
Arch length	26.62±2.74	26.59±2.73	-0.02	
Arch perimeter	74.63±5.86	74.70±6.04	0.06	

T1, pretreatment; T2, posttreatment; t, difference; *p<0.05, **p<0.01

Table 5. Analysis of comparisons (Mann-Whitney U test, p<0.05) of T1-T2 changes in the treated group vs. T1-T2 changes in the control group

	Treatment group		Control group		TG-CG T1-T2	
	Mean±SD		Mean±SD		Net difference	p
Maxillary skeletal measurements						
SNA	0.08±0.51		0.25±0.45		-0.17	
A-Hor (mm)	0.98±0.56		0.01±0.19		0.97	***
ANS-Hor (mm)	0.63±0.93		0.18±0.39		0.45	
PNS-Hor (mm)	0.61±0.76		-0.18±0.40		0.79	**
SN/PP	-0.08±0.28		0.08±0.66		-0.16	
Mandibular skeletal measurements						
SNB	0.16±0.57		-0.08±0.90		0.24	
B-Hor (mm)	0.56±1.20		0.16±0.47		0.40	*
SN/MP	0.25±0.45		0.16±0.57		0.09	
Maxillomandibular measurements						
ANB	-0.08±0.66		0.33±0.98		-0.41	
Dentoalveolar measurements						
Overjet	-0.01	0.06	-0.1	0.15	0.99	*
Overbite	0.15	0.25	0.15	0.35	0	
U1/SN	-0.10	0.22	-0.10	0.55	0	
U1/PP	-0.16	0.57	-0.16	1.19	0	
IMPA	0	0.85	-0.08	0.79	0.08	
Soft tissue measurements						
UL-Ver (mm)	1.08	1.44	0.05	0.47	1.03	
LL-Ver (mm)	-0.03	0.12	0.15	0.41	-0.18	
Digital model measurements						
Area 1	131.72	66.14	14.47	10.27	117.25	***
Area 2	29.23	11.01	1.45	1.34	27.78	***
Area 3	36.06	14.50	2.39	2.59	33.67	***
Area 4	61.71	27.97	8.43	6.56	53.28	***
Upper intermolar width	3.01	1.09	0.15	0.31	2.86	***

Table 5. Continued

	Treatment group		Control group		TG-CG T1-T2	
	Mean±SD		Mean±SD		Net difference	p
Lower intermolar width	1.37	0.85	0.11	0.23	1.26	**
Molar angulation	1.97	2.44	-0.09	0.80	2.06	*
Palatal depth	0.08	0.53	0.09	0.39	-0.01	
Arch length	0	0.25	-0.02	0.15	0.02	
Arch perimeter	3.37	1.54	0.06	0.75	3.31	***

*p<0.05, **p<0.01, ***p<0.001
T1, pretreatment; T2, posttreatment

DISCUSSION

This study aimed to confirm the effectiveness of Leaf Expander in patients who were in the early mixed dentition period and to compare the results with those of the control group. There is a lack of information in the literature in terms of the detailed evaluation of linear and areal measurements on digital models after maxillary expansion with Leaf Expanders in the control group.

Maxillary expansion in mixed dentition provides advantages in terms of tooth and skeletal changes and allows space for permanent teeth.[5,6,11] Various expansion protocols are available. The first protocol is the rapid palatal expansion (RPE) protocol, characterized by high intermittent forces applied over short periods of time, and the second protocol is the SME protocol, in which continuous lighter forces are applied over long periods of time. Therefore, SME using fixed expanders may be advantageous in terms of both lower force and cooperation in the mixed dentition period.[5,12,13]

The Leaf Expander is typically anchored by deciduous teeth, with the upper first permanent molars left to expand spontaneously.[1] Conventional fixed expansion screws are usually anchored to permanent teeth, a process that has some drawbacks, such as buccal tipping, alveolar bone resorption, root resorption, and periodontal damage to the anchorage teeth.[10-15] In addition, the Leaf Expander has the advantage of applying a constant light force as a result of NiTi sheets over conventional expansion appliances; thus, this method is easier for patients to tolerate. Patients report experiencing significantly less pain and discomfort with this appliance.[16] Parents often have difficulty turning a screw in the activation of expansion appliances. This problem can also be eliminated with Leaf Expanders. However, we aimed to observe the skeletal, dental, and soft tissue effects of expansion using the Leaf Expander and compare it with the control group. To compare the expansion efficiency of the appliance with the growth effect, a control group was included in the study. For ethical reasons, the control group included normal subjects, as treatment was indicated only indications for treatment immediately after the diagnosis of maxillary discrepancy in individuals during the mixed dentition period existed.

Commonly used reference planes in cephalometric evaluation are the Sella-Nasion and Frankfort horizontal planes. Both of these approaches have certain shortcomings, which make their use a reference plane questionable.[17-19] Several authors have concluded that the natural head position (NHP) has clinically acceptable reproducibility, and it has also been documented that the horizontal reference planes (Hor) derived from the NHP registration represent a more valid craniofacial reference system.[20-22] In light of this information, we preferred to use the Hor in this study, as in previous studies.[23-25]

In this study, the position of the maxilla in the sagittal direction did not significantly change. The results for this group are similar to those of Lanteri et al.[12] The A-Hor and ANS-Hor distances, which indicate the vertical position of the maxilla, increased significantly among treated patients. At the end of the study, the change in the A-Hor distance was significantly higher in the treatment group than in the untreated group, but the changes in the ANS-Hor distance did not differ significantly.

Considering these values, we observed a significant vertical downward displacement after the treatment. In addition, the PNS point of our treated patients was significantly displaced downward (0.61 mm), similar to the ANS point. Moreover, the change in the PNS-Hor distance was significantly higher in the treatment group than in the control group (T2-T1). The absence of a significant change in the SN/PP angle in the treatment group could be associated with a similar downward displacement of the PNS and ANS points (+0.61 and +0.63 mm, respectively). This finding can be explained by the fact that the palatal plane descends almost parallel after expansion and does not exhibit any rotational changes. Similar to the study of Lanteri et al.,[12] increases in SNB, ANB, and SN/MP angles were not significant in the current study, and no difference was found compared with the control group. The B-Hor distance, which shows the vertical position of the mandible, was significantly increased after treatment. In addition, the change in the B-Hor distance of the treatment group was found to be significantly higher than that of the control group. This finding suggests that the downward movement of the maxilla after SME in the early period and the cusp relationships of the maxillary posterior teeth cause vertical size increases in the mandible.

There were no significant changes in the dentoalveolar values of either group in the measurements on the lateral cephalometric radiographs. When the changes in dentoalveolar measurements were compared between the groups, the reduction in overjet was significantly greater in the control group than in the treatment group. Contrary to the findings of the current study, Akkaya et al.[26] found a significant increase in the amount of overjet in patients who underwent SME. However, the authors detected no significant change in overbite levels, which is similar to the findings of the present study. Because patients are in the early mixed dentition period, a slight increase in the amount of overbite can be expected as the incisors continue to erupt. However, we hypothesize that the increase in overbite levels is compensated by the buccal tipping of posterior teeth. Contrary to a study[12] that showed significant retroclination of the upper incisors after expansion with the Leaf Expander, no change was observed in the inclination of the upper incisors in the current study. Küçükkeleş and Ceylanoğlu[27] reported that the pressure of the upper lip on the buccal side of the upper incisors significantly increased after maxillary expansion. Conversely, tongue pressure on the lingual side of the upper incisor significantly decreased following palatal expansion. This finding agrees with findings from a study by Proffit[28] who reported the theory of equilibrium, which demonstrates the natural alignment and retraction of the maxillary incisors. Moreover, Grob[29] reported retroclination of the upper incisors during diastema closure resulting from RPE. In this study, it was estimated that the inclination values of the upper incisors did not change due to the predominance of the dental expansion effect of the Leaf Expander.

In previous studies, significant increases in the total palatal area were observed in the treatment group after SME in the early period, similar to the current study's findings.[30,31] Although no increase was observed in the total palatal area in the control group in the study by Bukhari et al.[30], the increase in all area measurements was found to be significant in this study. Primožic et al.[31] Explained the increase in the total palatal area due to the increase in transversal dimensions with the opening of the midpalatal suture after expansion. In the treatment group, Area 4 showed a greater increase than Areas 2 and 3. This finding can be explained by the fact that the increase occurred as a result of anchoring the deciduous second molars with the Leaf Expander. Likewise, the greater increase in Area 4 relative to the other areas in the control group could be explained by the fact that the transverse dimension increases less anteriorly and more posteriorly in patients during the growth period due to sutural growth. The increase in all area measurements was significantly higher in the treatment group than in the control group. Aside from the opening of the midpalatal suture, the movements in the teeth during expansion are also thought to be effective in terms of increasing the palatal area. Because the individuals in the control group were in the mixed dentition period, the increases in all palatal areas were significant.

Lanteri et al.[32] reported a significant increase in upper intermolar width in patients with unilateral posterior crossbite after treatment with Leaf Expander, which was similar to our findings. The increase in upper intermolar width was significantly greater in the treatment group than in the control group. In the present study, the significant increase in the width of the permanent first molars (despite the anchoring of the Leaf Expander from the deciduous second molars) could be due to early application of the SME protocol, which produced minimal skeletal effects and moved the permanent first molars buccally in the transverse direction. Furthermore, a statistically significant increase in the lower intermolar width was observed in the treatment group. However, unlike our findings, Lanteri et al.[32] reported no significant change (-0.02 mm) in the lower intermolar width among patients treated with the Leaf Expander. The increase in the lower intermolar width was significantly greater in the treatment group than in the control group. Cossellu et al.[33] reported that the increase in the lower intermolar width (1.24 mm) was lower in the group treated with the Leaf Expander compared with the group using the Haas appliance (1.43 mm), although the difference remained significant compared with the beginning of the treatment. This finding may be explained by the fact that the increase in the lower intermolar width as a result of treatment could have occurred with buccal tipping due to an increase in the upper intermolar width due to cusp relationships.

Although permanent first molars were not used as an anchorage source with the Leaf Expander, a significant increase in permanent molar angulation measurements was observed in the treatment group. However, Kartalian et al.[34] reported no statistically significant buccal tipping in posterior teeth after expansion.

Although Ladner and Muhl[35] reported an increase in palatal depth due to continued eruption of teeth after both SME and RPE, no significant changes were observed in our study. This finding can be explained by the fact that the measurement was performed after the passive expansion period rather than immediately after the active expansion period. This finding can be explained by the fact that although the depth decreased with the downward movement of the palatal processes after expansion, no significant change due to continued eruption of the teeth during treatment was observed.

In addition, we also found no significant changes in arch length between the groups. Wong et al.[36] the arch length measurements after applying a slow expansion protocol between treated and untreated patients with unilateral posterior crossbite. Similar to our findings, the authors did not detect any significant difference between the two groups in terms of arch length measurements. The absence of change in arch depth can be explained by the absence of a significant decrease in the inclination of the upper incisors. Akkaya et al.[26] examined the changes in arch perimeter between patients who underwent SME and RPE. Results showed significant increases in both groups, although no significant difference was found between the two groups.

Study Limitations

The lack of long-term follow-up was the most significant limitation of this study. In addition, more studies with long-term follow-up and comparisons with traditional expansion screw systems are needed in the future.

CONCLUSION

The NiTi memory Leaf Expander is a comfortable alternative to conventional RPE screws for maxillary expansion in mixed dentition cases. Significantly greater transversal width and area measurements were observed in treated patients compared with controls. The increase in maxillary intermolar width after expansion also resulted in an increase in lower intermolar width due to the cup relationship. Digital model area measurements showed that the Leaf expansion appliance provided skeletal and dental effects during the mixed dentition period.

Ethics

Ethics Committee Approval: We obtained the ethics committee report from the Karadeniz Technical University Faculty of Medicine of Scientific Research Ethics Committee (approval no.: 6, date: 28.06.2021) required for the research.

Informed Consent: Written informed consent forms were completed by all parents.

Footnotes

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

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

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Original Article

Comparing the Impact of Titanium and Stainless Steel Retainers on Lower Incisor Stability, Periodontal Health, and Retainer Survival: A Preliminary Study

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Main Points

- Titanium and stainless steel retainer wires were successful in maintaining lower incisor stability.
- Titanium and stainless steel retainer wires gave similar periodontal results.
- No retainer failure was observed in either group.

ABSTRACT

Objective: This study aims to compare the impact of titanium and stainless steel (SS) retainer wires on lower incisor stability and periodontal health.

Methods: Fifty patients between the ages of 14.1 and 29.5 years were recruited for the study. The impact of 0.027x0.011-inch rectangular titanium dead-soft wire retainers was compared with that of 0.0215-inch six-stranded SS wire retainers. The retainers were bonded to the mandibular arch, and 3D models were evaluated after completion of the orthodontic treatment (T1), at the third month (T2), and at the sixth month (T3). Little's irregularity index (LII), the intercanine width, the pocket depth, the plaque index, bleeding on probing, and retainer survival were analyzed. The generalized linear model method was used to compare scores on LII, the intercanine width, the pocket depth, and plaque index values. Cochran's Q test was used to compare intragroup bleeding.

Results: A significant increase was found in the irregularity index parameter according to time (p=0.004) but no statistically significant difference was found between groups in terms of the LII according to material and time (p=0.826). No significant difference was found in intercanine width parameters between the groups according to material and time (p=0.977). No statistically significant difference was found between the groups in terms of pocket depth and plaque index scores, according to material and time. No retainer failure was observed in either group.

Conclusion: Both retainer wires offer successful results in terms of stability parameters and periodontal parameters after six months.

Keywords: Fixed orthodontic retention, orthodontic stability, orthodontic splint, titanium retainer, stainless steel retainer, periodontal health

INTRODUCTION

"Retention" is defined as maintaining the ideal functional and aesthetic tooth positions achieved by orthodontic treatment[1] and has been described by Oppenheim[2] as a major problem in orthodontic treatment. Orthodontically treated cases may be exposed to dynamic and changing situations, especially in the third and fourth decades of

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life, and relapse has been observed in a significant percentage of cases of mandibular anterior teeth alignment.[3,4] However, dental changes in mandibular arches can be observed even in individuals who have never had orthodontic treatment.[5] After orthodontic treatment, fixed and removable retention appliances can be used to prevent relapse.[6] While various orthodontic retention protocols are available, emerging evidence suggests that fixed retention is superior to removable options in long-term follow-ups.[7-9] The advantages of fixed retention appliances are that they do not rely on patient cooperation and do not adversely affect smile aesthetics.

Zachrisson[10] recommended the routine use of 0.0215-inch six-stranded, flexible stainless steel (SS) wire for fixed retention as the gold standard and has claimed that the material allows for physiological tooth movement and gives successful results in terms of stability as long as it is passively adapted to the tooth surfaces. In an in vitro study,[11] comparing multistranded SS and dead-soft wire, more deformation was observed in the dead-soft wire group compared to the SS wire group. As a result of the forces of chewing and the use of dental floss, the interdental wire will be subjected to repeated deformation, and wire breakage may occur.[11] In recent years, other materials have been introduced, such as polyethylene[12] and glass fibers,[13] but metallic retainers offer lower costs and demonstrate equal or better clinical performance. Nickel-titanium wire produced using computer-aided design (CAD)/computer-aided manufacturing (CAM) technology is one of the latest fixed retention materials used today.[14] Although fixed retainers are a preferred method after the treatment of specific orthodontic malocclusions (e.g., generalized spacing, rotated teeth) and for patients who do not want to wear removable appliances, some problems may be encountered depending on the materials used.

Periodontal problems, metal allergy due to the nickel composition, and breakage are some of the disadvantages of fixed retainers. Additionally, evidence has been published that metallic orthodontic braces and SS lingual retainers cause artifacts and distortions due to their ferromagnetic properties and may decrease the diagnostic value of the magnetic resonance images (MRIs).[15-17] Studies have shown that this image artifact extends beyond the boundaries of the oral cavity in cases where SS retainers are used.[15,17] As a result, SS retainers are incompatible with dental MRI and may also interfere with head or neck landmarks beyond the retainer area. In cases where SS retention wires are used, orthodontists are asked to remove these wires when MRI is required. This creates a handicap both in terms of cost and the fact that repeated processes can damage teeth. Research indicates that artifacts from titanium and gold retainers are minimal and do not impact *in vivo* MRI quality, even when positioned directly next to retainer wires. Titanium and gold retainers are fully compatible with both head and neck MRI, as well as dental MRI.[18]

Although the necessary duration of retention is unclear, the suggested strategy for maintaining lower incisor stability after orthodontic treatment is to implement long-term or life-long retention.[19] While the literature includes many studies on the success of multistranded SS retainers, there are a limited number of studies on titanium lingual retainers.[20] This study aimed to compare 0.027x0.011-inch rectangular titanium dead-soft wire and 0.0215-inch six-stranded SS retainer wire used for fixed retention in terms of their success in preventing relapse and their effects on periodontal health. The null hypothesis of the study is that there would be no significant difference between the two types of retainers regarding stability and periodontal effects.

METHODS

The study protocol was approved by the Trakya University Faculty of Medicine Scientific Research Ethics Committee (approval no.: 17/08, date: 14.10.2019). Written informed consent was obtained from participants or their parents.

Sample Size Calculation

The sample size of the study was calculated using the G*Power 3.1.9.7 software. Based on a previous study,[21] to detect a 1 mm difference on Little's Irregularity Index (LII), the study sample size was calculated as 25 for each group (with a power of 90%, and a margin of error of 5%).

Study Sample

In this retrospective study, 50 patients who had completed their orthodontic treatment at the Trakya University Faculty of Dentistry, Department of Orthodontics were selected. A random selection was made among 65 individuals who met the inclusion criteria and had control records in the archive for the periods of the end of treatment (T1), the third month (T2), and the sixth month (T3). Individuals with complete orthodontic model records and periodontal examinations were included in our study.

Inclusion Criteria

The inclusion criteria were:

- Moderate crowding in the lower arch;
- Non-extraction fixed orthodontic treatment; and
- No periodontal disease before orthodontic treatment.

Exclusion Criteria

Cases with missing or restored teeth and lower incisors with morphological anomalies were not included in the study.

Fixed Retention Protocol

The study compared 0.027x0.011-inch rectangular titanium dead-soft wire (Retainium, Reliance Orthodontic Products, Itasca, USA) and 0.0215-inch six-stranded SS retainer wire (G&H Orthodontics, Franklin, USA) (Figure 1). The routine bonding protocol was as follows: retainer wires were bonded to all teeth in the lower jaw between canines.[21] Wires were bent on the plaster model by a single clinician (MSY) using a bird beak #139 plier (Rocky Mountain Orthodontics, Illkirch, France). The lingual surfaces of the lower teeth were cleaned with fluoride-free prophylaxis paste before the bonding. Enamel surfaces

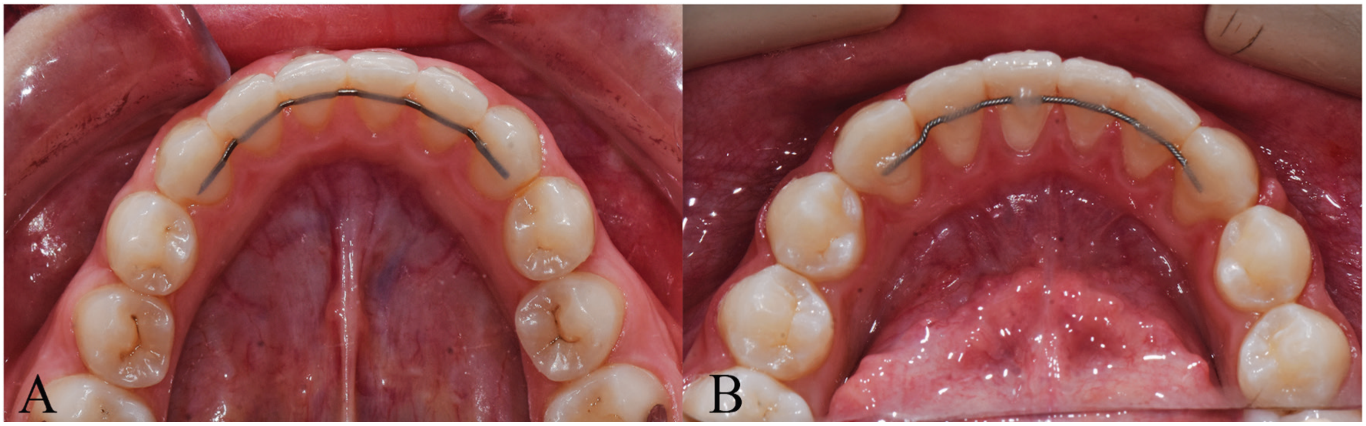

Figure 1. A) Titanium retainer, B) Stainless steel retainer

were etched with 37% orthophosphoric acid (Jade, Dharma Research, Miami, USA) for 30 seconds, washed with water and dried. A primer (Assure Plus, Reliance Orthodontic Products, Itasca, USA) was applied to the roughened enamel surfaces, slightly air-dried and cured on each tooth for 20 seconds using a 1200 mW/cm^2 LED light source (VALO Cordless Curing Light, Ultradent Products, South Jordan, USA). The retention wires were fixed passively and bonded to the tooth surface with a flowable composite (Flow Tain, Reliance Orthodontic Products, Itasca, USA). The adhesive was polymerized for 20 seconds with a 1200 mW/cm^2 LED light source on each tooth. All retainers were bonded by the same researcher (MSY). Advice on the brushing technique was given after the retainer was bonded, and patients were motivated at each control. No additional removable retention appliance was applied to either arch.

Orthodontic and Periodontal Records

For orthodontic records, alginate impressions (Zetalgin, Zhermack Group, Italy) were taken from the lower teeth of the patients immediately after the retainer wire was bonded (T1), at the third month (T2), and at the sixth month (T3), and a plaster model was obtained using a type IV plaster (Elite Rock, Zhermack, Italy). A digital model was obtained by scanning the plaster models with a 3D scanner (Maestro, AGE Solutions, Pisa, Italy). Little's Irregularity Index (LII) and intercanine width measurements were taken using reverse engineering OrthoModel software (OrthoModel V1.01, Istanbul, Turkey) on 3D models. The software allows for measurements in millimeters on scanned plaster models. For periodontal evaluation, pocket depth, plaque index, and bleeding on probing were measured at 0 months (T1), three months (T2), and six months (T3). During these appointments, the integrity of the wire and adhesive was also assessed for any potential failures.

Model Measurements

LII and Intercanine Width Measurements

Measurements in millimeters were taken at five contact points from the lower right canine tooth to the left canine. Scoring was based on measuring the linear displacement between the anatomical contact points of each mandibular incisor and its adjacent tooth; the sum of these five displacements indicates the degree of irregularity.[22] This procedure was performed on a total of 150 models from the 50 individuals included in the study. For the intercanine width measurements, the distance between the cusp tip of the lower canines in each model was measured in millimeters.[21] In the study, all values were obtained from the orthodontic models taken at the T1, T2, and T3 time points. All measurements were performed on 3D digital models by a single researcher (MSY).

Error of the Method

To determine the intraclass correlation coefficient (ICC), the LII and intercanine width measurements were repeated on 40 randomly selected digital models two weeks after the first measurements were taken.

Periodontal Measurements

Pocket Depth

To determine the pocket depth of the lower anterior six teeth, measurements in millimeters were taken using a Williams probe at three regions (the mesial, median, and distal) on the lingual surface.[23] To obtain the mean pocket depth value for a tooth, the arithmetic mean of the values recorded at three regions was taken and this measurement was repeated at 0 months (T1), three months (T2), and six months (T3).

Plaque Index

The Löe and Silness[24] plaque index was used to measure the presence of plaque on the lower anterior six teeth after the retainer wire was applied. Measurements were performed on the lingual side of the lower anterior six teeth at three different regions (the mesial, median, distal) using a scoring range from 0 to 3. To obtain the plaque index value of a tooth, the arithmetic mean of the values recorded at three regions was taken, and this process was repeated at 0 months (T1), three months (T2), and six months (T3).

Bleeding on Probing

Bleeding on probing was measured by recording the presence and absence of bleeding after probing the gingival sulcus on the lingual surfaces of the related teeth using the Williams probe.[23] The measurements were repeated at 0 months (T1), three months (T2), and six months (T3). Due to the dynamic nature of periodontal tissues, repeating periodontal measurements to test intra-examiner reliability was not possible.

Retainer Survival

After the retainer wire was bonded, the presence of breakage on the wire-adhesive surface, the debond on the adhesive-tooth surface, and the deformation or breakage of the wire were evaluated as failures. The observation of failures was repeated at all time points.

Statistical Analysis

Data analysis was conducted using IBM SPSS V23 (IBM Company, Chicago, IL, USA). The Shapiro-Wilk test assessed conformity to a normal distribution. The chi-square test compared categorical variables between groups, while an independent two-sample t-test was used for normally distributed data, and the Mann-Whitney U test for non-normally distributed data. The generalized linear models method was used to compare scores on LII, the intercanine distance, the pocket depth, and plaque index values according to material and time. Cochran's Q test was used to compare intragroup bleeding according to time. The ICC was used to examine the agreement between measurements. Analysis results were presented as frequency (percentage) for categorical data, as mean ± standard deviation, and median (minimum–maximum) for quantitative data. The significance level was taken as $p<0.05$.

RESULTS

Statistically significant, very good agreement was found between the first and second measurement values on LII [ICC=0.999 (0.998-0.999)] and for the intercanine width [ICC=0.996 (0.992-0.998); $p<0.001$].

No statistically significant difference was found between the groups in terms of age (titanium: mean of 18.4 years, multistranded SS: mean of 19 years) ($p=0.404$) or gender (titanium: 17 females and 8 males, SS: 19 females and 6 males) ($p=0.529$). The LII (titanium: 6.9±2.1; multistranded SS: 7.0±2.2) and intercanine width (titanium: 25.8±2 mm; multistranded SS: 25.9±1.9 mm) values at the T0 time point (before the orthodontic treatment) were similar for both groups ($p>0.05$). No statistically significant difference was found between the groups in terms of posttreatment and pretreatment (T1-T0) intercanine width measurements (titanium: 0.2±1.8, multistranded SS: 0.2±1.6; $p=0.259$).

Stability Parameters

The descriptive statistics and comparison of stability parameters are presented in Tables 1 and 2. The main effect of time on LII was statistically significant ($p=0.004$). The mean LII scores obtained at the T1 time point were lower than the values obtained at the T3 time point. The main effect of material (retainer type) on intercanine width was statistically significant ($p=0.003$). While the mean of the T1, T2, and T3 values of the intercanine width in the titanium group was 25.4 mm, the mean of the T1, T2, and T3 values in the SS group was found to be 26.1 mm. The main effect of the material and time interaction was not statistically significant for the LII and intercanine width measurements ($p>0.05$).

Periodontal Parameters

The descriptive statistics and comparison of pocket depth and plaque index are presented in Tables 3 and 4. The main effect of time on pocket depth for teeth 43, 42, 41, 31, 32, and 33 was statistically significant ($p<0.05$). The mean pocket depth measurements obtained at the T1 time point were lower than the values obtained at other time points.

The main effect of material (retainer type) on pocket depth for teeth 32 and 33 was statistically significant ($p<0.05$). The mean of the T1, T2, and T3 values of the pocket depth was 1.5 mm in the titanium group and 1.7 mm in the SS group for tooth 32. The mean of the T1, T2, and T3 values of the pocket depth was 1.7 mm in the titanium group and 1.9 mm in the SS group for tooth 33.

The main effect of the material and time interaction was not statistically significant for pocket depth and plaque index ($p>0.05$).

A comparison of the T3-T1 difference in terms of pocket depth and plaque index for each tooth according to the groups is presented in Table 5. There was no significant difference between the groups in terms of the T3-T1 difference in pocket depth and plaque index ($p>0.05$).

A comparison of intra-group and inter-group bleeding on probing scores is presented in Table 6. The intra-group comparison shows that no significant difference was found in terms of bleeding scores on probing at the T1, T2, and T3 time points. While there was a significant difference between the groups at the T2 time point, there was no difference between the groups in terms of bleeding on probing at the T3 time point ($p>0.05$). This difference at the T2 time point was due to the higher percentage of bleeding in individuals in the titanium group.

No breakage, detachment, or retainer loss was observed in either group during the observation period.

DISCUSSION

Long-term stability is one of the most challenging topics in orthodontics. Riedel[25] has suggested that teeth undergoing orthodontic treatment should be held in position to reorganize the periodontal and gingival fibers, allow neuromuscular adaptation, and to minimize changes that may occur with growth. The principle finding of this study is that when the interaction between material and time for LII and intercanine width is examined, no significant differences were observed between the groups.

Table 1. Descriptive statistics of little irregularity index and intercanine width according to material and time

Stability parameters	Time	Material		Total
		Titanium	Multistranded SS	
Little's irregularity index	T1	1.87±0.38	1.75±0.32	1.81±0.35[a]
	T2	1.97±0.46	1.95±0.37	1.96±0.41[a,b]
	T3	2.10±0.47	2.04±0.36	2.07±0.41[b]
	Total	1.98±0.44	1.91±0.37	1.95±0.41
Intercanine width	T1	25.52±1.17	26.20±1.35	25.86±1.30
	T2	25.48±1.20	26.07±1.38	25.77±1.31
	T3	25.45±1.24	26.04±1.38	25.74±1.33
	Total	25.48±1.19	26.10±1.36	25.79±1.31

[a,b]There is no difference between time points with the same letter in terms of irregularity index. T1: After the application of fixed retainer, T2: 3rd month, T3: 6th month)
SS, stainless steel

Table 2. Comparison of little irregularity index and intercanine width according to material and time

Stability parameters		Test statistics*	df	p-value
Little's irregularity index	Material	1.053	1	0.305
	Time	10.907	2	**0.004#**
	Material*Time	0.383	2	0.826
Intercanine width	Material	9.064	1	**0.003#**
	Time	0.219	2	0.896
	Material*Time	0.046	2	0.977

*Wald chi-square test, df: degree of freedom, #p<0.05
The statistical significance level was p<0.05

According to a randomized controlled study, most relapses occur during the six months of retention.[26] Therefore, we investigated relapse in the first six months. Gunay and Oz[21] compared 0.0175-inch six-stranded SS retainer wire with 0.0195-inch dead-soft wire. Their results indicated that the increase in the LII values in the dead-soft wire group was significantly higher. This is explained by the possibility that the dead-soft wire is more prone to deformation and could not be passively placed during the application because it was bent and applied in the patient's mouth.

In our study, the lack of a significant increase in LII values in both groups may be related to the thicker cross-section of the six-stranded SS wire (0.0215") and the titanium dead-soft wire used, compared to the wires in the previous study. Additionally, the retainers were bent on plaster models in our study.

Artun et al.[27] measured LII on plaster models and reported that 0.0205-inch flexible multistranded spiral wire bonded to all teeth completely prevented any change in LII at a three-year follow-up: the change was 0. Although this finding supports the success of preventing incisor crowding of the SS wire used in our study, we think that the 0.29 mm increase seen in our study is due to the fact that we made precise measurements on the 3D digital model.

Different types of dead-soft wires are used for orthodontic retention. The results of a study comparing four different wires over a one year[28] period showed that LII changes were statistically significantly fewer in the SS and NiTi groups than in the other groups. However, a significantly higher relapse was observed in the dead-soft wire group over a six-month retention period. This result contradicts our findings; this discrepancy may be due to the different designs of the dead-soft wires used. The fact that the dead-soft wire used in the above-mentioned study is braided and the dead-soft wire used in our study is a ribbon arch structure may result in differences in the deformation resistance. However, the study concluded that relapse was not clinically significant in any group after one year. Alrawas et al.[29] compared the CAD/CAM-supported NiTi wire, 0.017-inch multistranded SS wire, 0.027x0.011-inch rectangular titanium wire, and a vacuum-formed retainer (VFR) appliance in terms of relapse prevention success and periodontal effects in the short term. They found that the increase in LII scores was not significant between and within the groups. The findings were similar to the LII increase observed as 0.29 mm in the SS wire group and 0.23 mm in the titanium wire group at six-month follow-up in our study.

No statistically significant difference was found in our study between the intra-group and the inter-group values for intercanine width in terms of the material and time interaction. From T3 to T1, the intercanine width decrease was 0.07 mm in the titanium group and 0.16 mm in the SS wire group, which was not statistically significant in either intra-group or inter-group comparisons. Our findings are consistent with those of Alrawas et al.[29] However, according to Adanur-Atmaca et al.,[28] the six-month change in the intercanine distance showed a decrease of 0.32 mm in the dead-soft wire group, which is higher than our findings. This may be due to the different dead-soft wires used in the studies. The decrease in intercanine distance in the SS wire group is similar to the SS group value in our study.

In the current study, no breakage, debonding from the tooth, or deformation was observed in the retainer wires at the six-

Table 3. Descriptive statistics of pocket depth and plaque index according to material and time

Tooth	Time	Pocket depth			Plaque index		
		Material		Total	Material		Total
		Titanium	Multistranded SS		Titanium	Multistranded SS	
43	T1	1.74±0.36	1.85±0.37	1.80±0.36[a]	0.47±0.52	0.34±0.47	0.41±0.49
	T2	1.89±0.28	1.88±0.31	1.88±0.29[a,b]	0.70±0.64	0.45±0.60	0.57±0.63
	T3	1.92±0.41	2.09±0.39	2.00±0.40[b]	0.61±0.71	0.74±0.69	0.68±0.70
	Total	1.85±0.36	1.94±0.37	1.89±0.36	0.60±0.62	0.51±0.61	0.55±0.62
42	T1	1.58±0.42	1.62±0.32	1.60±0.37[a]	0.39±0.51	0.39±0.45	0.39±0.48
	T2	1.73±0.28	1.76±0.22	1.74±0.25[b]	0.70±0.60	0.37±0.53	0.53±0.59
	T3	1.85±0.36	1.84±0.237	1.84±0.30[b]	0.62±0.66	0.61±0.69	0.61±0.67
	Total	1.72±0.37	1.74±0.277	1.73±0.32	0.57±0.60	0.46±0.57	0.51±0.59
41	T1	1.50±0.33	1.54±0.38	1.52±0.35[a]	1.74±6.53	0.33±0.45	1.03±4.63
	T2	1.69±0.33	1.65±0.28	1.67±0.30[b]	0.67±0.65	0.35±0.54	0.51±0.61
	T3	1.77±0.43	1.78±0.30	1.78±0.37[b]	0.62±0.66	0.61±0.69	0.61±0.67
	Total	1.65±0.38	1.66±0.33	1.66±0.36	1.01±3.79	0.43±0.58	0.72±2.72
31	T1	1.52±0.30	1.56±0.31	1.54±0.30[a]	0.38±0.54	0.34±0.44	0.36±0.49
	T2	1.64±0.21	1.72±0.26	1.68±0.24[b]	0.65±0.65	0.35±0.54	0.50±0.61
	T3	1.73±0.37	1.77±0.32	1.75±0.34[b]	0.62±0.66	0.58±0.70	0.60±0.67
	Total	1.63±0.31	1.68±0.31	1.65±0.31	0.55±0.62	0.43±0.57	0.49±0.60
32	T1	1.48±0.36	1.64±0.34	1.56±0.36[a]	0.42±0.53	0.33±0.45	0.37±0.49
	T2	1.57±0.26	1.68±0.29	1.62±0.28[a]	0.66±0.62	0.38±0.53	0.52±0.59
	T3	1.72±0.40	1.82±0.34	1.77±0.37[b]	0.57±0.69	0.58±0.70	0.57±0.69
	Total	1.59±0.35	1.71±0.33	1.65±0.35	0.55±0.61	0.43±0.57	0.49±0.59
33	T1	1.66±0.39	1.89±0.20	1.78±0.33[a]	0.42±0.54	0.34±0.48	0.38±0.51
	T2	1.82±0.32	1.88±0.23	1.85±0.27[a,b]	0.62±0.65	0.43±0.60	0.53±0.63
	T3	1.88±0.44	2.04±0.43	1.96±0.44[b]	0.57±0.71	0.65±0.74	0.61±0.72
	Total	1.79±0.39	1.93±0.31	1.86±0.36	0.54±0.63	0.47±0.62	0.51±0.63

Values are presented as mean ± standard deviation
[a,b]There is no significant difference between time points with the same letter in terms of pocket depth and plaque index. T1: After the application of fixed retainer, T2: 3rd month, T3: 6th month
SS, stainless steel

month follow-up. In a study comparing the success rates of 0.0175-inch SS wire and 0.027x0.011-inch rectangular titanium wire, the failure rate was 8.9% for the titanium wire and 18.1% for the SS wire.[20] Although the success of the titanium wire was found to be higher, unlike in our study, the breakage and debonding of the wire may be due to the longer follow-up period (24 months).

In both groups, a significant increase was observed in the pocket depth parameter from time point T1 to T3, but this increase was not clinically significant. When the material and time interaction was evaluated, no statistically significant difference was observed in pocket depths both intra and inter groups. In healthy individuals, the depth of the anatomical gingival sulcus can vary between 0.25 mm and 3 mm.[30] In this study, the mean pocket depth of a tooth varied between 1.72 mm and 2.09 mm over the six months. This reveals that neither material formed pathological pockets over the six months.

In a study comparing the periodontal status of individuals whose fixed orthodontic treatment was completed four years prior, it was revealed that the mean pocket depth of the incisors of the fixed retainer group was 1.85 mm, while the pocket depth of the incisors in the control group was 1.7 mm.[31] These values are similar to the pocket depths in our study and support the view that fixed retainer wire will not cause a periodontal pocket. In a study comparing the periodontal effects of 0.0215-inch three-stranded SS wire and 0.027x0.011-inch eight-stranded wire, it was shown that there was no significant difference between the two materials in terms of pocket depth measurements.[32] There was no significant increase in pocket depths at the 24-month follow-up in either group. In our study, similar materials were used in terms of thickness, and our results are consistent.

When the plaque index results of our study were examined, no statistically significant difference was found in the interaction of material and time in any of the mandibular anterior teeth. Gökçe and Kaya[33] found that there was only a minor alteration in plaque index scores but no difference between the groups (0.0215" vs 0.0175" SS) in terms of periodontal health. Pandis et al.[34] found no significant difference in plaque index between short- and long-term follow-up periods when using a 0.0195" SS wire. Our results are in agreement with the literature.[28,29,32]

No significant intragroup difference was found between the T1, T2, and T3 time points in terms of the presence of bleeding on probing in both groups. When the presence of bleeding on probing was compared between the groups, a significant difference was found between the two groups in tooth 43 at the T1 time point. This difference is due to the fact that 76% of the individuals in the titanium group and 48% of those in the SS group had bleeding in tooth 43. This difference may be due to insufficient brushing of the right canine tooth region at the beginning of the retention period by the individuals in the titanium group. In the literature, there is evidence that right-handed individuals brush less effectively in their right quadrants.[35,36] Additionally, there was no significant difference in the other teeth at the beginning of the retention period and the difference in tooth 43 may be due to the fact that right-handed users were in the majority in the titanium group. In addition, the fact that the canine teeth are at the corner of the dental arch can make effective brushing difficult. However, we do not have any information on which hand the individuals in our study used for brushing.

A significant difference was found between the groups in terms of the rates of bleeding on probing at the T2 time point. This was attributed to the higher rate of bleeding in the titanium group. The difference between the groups disappeared at the T3 time point, with a reduction in bleeding in the titanium group and slightly increased bleeding in the SS group, resulting in no significant difference between the two groups. In the presence of retainers, an increase in periodontal parameters can be observed due to a lack of oral hygiene. Storey et al.[37] found a slight increase in periodontal parameters at one-year follow-up in their study using a thinner (0.0195 inch) SS wire. Rody et al.[38] found an increase in gingival crevicular fluid biomarker levels and gingivitis in teeth with fixed retainers. Studies on whether the placement of the retainer close to the gingiva or incisal affects gingival health show that the vertical position of the retainer does not influence periodontal health.[39,40] The reason may be that bleeding increased due to loss of oral hygiene motivation in the early stage in the titanium group, and rates

Table 4. Comparison of pocket depth and plaque index according to material and time

		Pocket depth			Plaque index		
Tooth		Wald χ^2	df	p-value	Wald χ^2	df	p-value
43	Material	2.418	1	0.120	0.745	1	0.388
	Time	8.697	2	**0.013#**	5.02	2	0.081
	Material*Time	1.829	2	0.401	2.699	2	0.259
42	Material	0.139	1	0.709	1.521	1	0.218
	Time	15.087	2	**0.001#**	3.778	2	0.151
	Material*Time	0.203	2	0.903	2.707	2	0.258
41	Material	0.007	1	0.932	1.787	1	0.181
	Time	13.822	2	**0.001#**	1.067	2	0.586
	Material*Time	0.358	2	0.836	1.901	2	0.387
31	Material	1.223	1	0.269	1.696	1	0.193
	Time	13.129	2	0.001	4.217	2	0.121
	Material*Time	0.146	2	0.929	1.54	2	0.463
32	Material	5.274	1	**0.022#**	1.598	1	0.206
	Time	10.749	2	**0.005#**	3.149	2	0.207
	Material*Time	0.213	2	0.899	1.617	2	0.445
33	Material	6.895	1	**0.009#**	0.38	1	0.538
	Time	6.955	2	**0.031#**	3.466	2	0.177
	Material*Time	1.63	2	0.443	1.178	2	0.555

#The statistical significance level was p<0.05, df, degrees of freedom

Table 5. Comparison of the T3-T1 difference in terms of pocket depth and plaque index according to materials

	Tooth	Titanium	Multistranded SS	Total	Test statistics	p-value
Pocket depth	43	0.17±0.42	0.24±0.41	0.21±0.41	t=-0.58	0.565
	42	0.27±0.47	0.21±0.34	0.24±0.41	t=0.462	0.646
	41	0.27±0.57	0.24±0.47	0.25±0.52	t=0.179	0.859
	31	0.21±0.46	0.21±0.49	0.21±0.47	t=0.006	0.995
	32	0.24±0.49	0.19±0.51	0.21±0.49	t=0.38	0.705
	33	0.21±0.43	0.15±0.48	0.18±0.45	t=0.515	0.609
	Tooth	**Titanium**	**Multistranded SS**	**Total**	**Test statistics**	**p-value**
Plaque index	43	0.13±0.63	0.40±0.73	0.26±0.69	t=-1.377	0.175
	42	0.22±0.63	0.21±0.77	0.22±0.70	t=0.07	0.945
	41	-1.12±6.60	0.28±0.74	-0.42±4.70	U=288.5	0.637
	31	0.24±0.65	0.24±0.72	0.24±0.68	t=-0.004	0.997
	32	0.14±0.68	0.25±0.72	0.20±0.70	t=-0.537	0.594
	33	0.14±0.62	0.30±0.74	0.22±0.68	t=-0.823	0.415

SS, stainless steel; t, independent samples t-test/Values are mean ± standard deviation. U, Mann-Whitney U test; T3-T1, difference between 0-6 months; The statistical significance level was p<0.05

Table 6. Comparison of intra-group and inter-group bleeding on probing

Tooth	Time	Bleeding on probing	Titanium (%)	Multistranded SS (%)	Total (%)	Test statistics	p-value
43	T1	Bleeding (-)	6 (24)	13 (52)	19 (38)	χ^2=4.16	0.041#
		Bleeding (+)	19 (76)	12 (48)	31 (62)		
	T2	Bleeding (-)	5 (20)	13 (52)	18 (36)	χ^2=5.556	0.018#
		Bleeding (+)	20 (80)	12 (48)	32 (64)		
	T3	Bleeding (-)	10 (40)	7 (28)	17 (34)	χ^2=0.802	0.37
		Bleeding (+)	15 (60)	18 (72)	33 (66)		
		Test statistics	Q=3.500	Q=6.00			
		p-value	0.174	0.051			
42	T1	Bleeding (-)	8 (32)	9 (36)	17 (34)	χ^2=0.089	0.765
		Bleeding (+)	17 (68)	16 (64)	33 (66)		
	T2	Bleeding (-)	4 (16)	13 (52)	17 (34)	χ^2=7.219	0.007#
		Bleeding (+)	21 (84)	12 (48)	33 (66)		
	T3	Bleeding (-)	8 (32)	10 (40)	18 (36)	χ^2=0.347	0.556
		Bleeding (+)	17 (68)	15 (60)	32 (64)		
		Test statistics	Q=2.462	Q=1.625			
		p-value	0.292	0.444			
41	T1	Bleeding (-)	9 (36)	10 (40)	19 (38)	χ^2=0.085	0.771
		Bleeding (+)	16 (64)	15 (60)	31 (62)		
	T2	Bleeding (-)	5 (20)	13 (52)	18 (36)	χ^2=5.556	0.018#
		Bleeding (+)	20 (80)	12 (48)	32 (64)		
	T3	Bleeding (-)	7 (28)	10 (40)	17 (34)	χ^2=0.802	0.37
		Bleeding (+)	18 (72)	15 (60)	33 (66)		
		Test statistics	Q=1.714	Q=1.059			
		p-value	0.424	0.589			
31	T1	Bleeding (-)	11 (44)	9 (36)	20 (40)	χ^2=0.333	0.564
		Bleeding (+)	14 (56)	16 (64)	30 (60)		
	T2	Bleeding (-)	7 (28)	14 (56)	21 (42)	χ^2=4.023	0.045#
		Bleeding (+)	18 (72)	11 (44)	29 (58)		
	T3	Bleeding (-)	7 (28)	9 (36)	16 (32)	χ^2=0.368	0.544
		Bleeding (+)	18 (72)	16 (64)	34 (68)		
		Test statistics	Q=2.286	Q=3.571			
		p-value	0.319	0.168			
32	T1	Bleeding (-)	10 (40)	9 (36)	19 (38)	χ^2=0.085	0.771
		Bleeding (+)	15 (60)	16 (64)	31 (62)		
	T2	Bleeding (-)	6 (24)	13 (52)	19 (38)	χ^2=4.16	0.041#
		Bleeding (+)	19 (76)	12 (48)	31 (62)		
	T3	Bleeding (-)	10 (40)	9 (36)	19 (38)	χ^2=0.085	0.771
		Bleeding (+)	15 (60)	16 (64)	31 (62)		
		Test statistics	Q=2.909	Q=2.667			
		p-value	0.234	0.264			
33	T1	Bleeding (-)	9 (36)	11 (44)	20 (40)	χ^2=0.333	0.564
		Bleeding (+)	16 (64)	14 (56)	30 (60)		
	T2	Bleeding (-)	7 (28)	14 (56)	21 (42)	χ^2=4.023	0.045#
		Bleeding (+)	18 (72)	11 (44)	29 (58)		
	T3	Bleeding (-)	12 (48)	11 (44)	23 (46)	χ^2=0.023	0.879
		Bleeding (+)	13 (52)	14 (56)	27 (54)		
		Test statistics	Q=3.167	Q=1.800			
		p-value	0.205	0.407			

χ^2 chi-square test; Q, Cochran's Q test; T1, after the bonding of fixed retainer; T2, 3rd month; T3, 6th month, (-), no bleeding; (+), bleeding; SS, stainless steel, #p<0.05

decreased when individuals were motivated during the control sessions. Although thicker wires were used in our study, the results were consistent with the literature.[29]

The results of a recent systematic review indicate that vacuum-formed retainers (VFRs) are associated with more discomfort and soreness when compared with fixed lingual retainers, but oral hygiene maintenance is better in the VFR group.[41] Results of the one-year follow-up study on bonded retainers and VFR are similar.[37] Bonded retainers are associated with greater plaque and calculus deposition than VFRs, but this does not appear to produce clinically significant, adverse periodontal problems. In the current study, both retainers produced similar results at the end of the six months and did not lead to a deterioration in periodontal status.

Furthermore, recent studies have shown that certain newly introduced compounds significantly impact the oral environment. The application of lysates[42] and postbiotics[43] can alter clinical and microbiological parameters in periodontal patients, suggesting that these products should also be evaluated in future clinical trials as adjuvants for long-term assessment of fixed retention.

Study Limitations

Some of the limitations of our study are that only the effects of lingual retainers on mandibular teeth were examined and only results over six months were analyzed. Another limitation of our study is its retrospective design. In this respect, prospective randomized studies are needed. The results of the findings obtained in this study indicated no difference between the two fixed retainer wires in terms of the success of preventing relapse and their effects on periodontal tissues in the short term. Both materials were effective in preventing relapse in the lower arch and did not have a negative effect on the periodontium. Thus, our study fails to reject the null hypothesis.

CONCLUSION

According to the data obtained from the study results, both retainer wires were successful in maintaining the stability of the mandibular incisors. Both retainer wires produced similar periodontal results. No retainer failure was observed in either group.

Ethics

Ethics Committee Approval: The study protocol was approved by the Trakya University Faculty of Medicine Scientific Research Ethics Committee (approval no.: 17/08, date: 14.10.2019).

Informed Consent: Written informed consent was obtained from participants or their parents.

Footnotes

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

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

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Original Article

Evaluation of Microleakage in Flash-Free and Conventional Ceramic Brackets: A Microcomputed Tomography Study

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Main Points

- Flash-free ceramic brackets and conventional ceramic brackets were similar in terms of microleakage.
- Ceramic brackets bonded with Blugloo™ adhesive were shown less microleakage than the other groups.
- Microleakage volume, percentage, and surface area did not differ between the occlusal and gingival areas of the bracket base.

ABSTRACT

Objective: The aim of this study was to evaluate and compare microleakage under the conventional and flash-free ceramic brackets bonded with different agents.

Methods: Forty extracted human maxillary premolar teeth were randomly divided into five groups. According to the groups, adhesive coated and conventional bracket systems were bonded to the tooth surfaces with the specified adhesive agents. To simulate a six-month oral environment, all teeth were subjected to a thermal cycle procedure. Micro-computed tomography (micro-CT) was used to view and measure the microleakage. Kruskal-Wallis test was used to compare the parameters and Mann-Whitney U test was used for the determination of the group that caused the difference. For intragroup comparisons Wilcoxon signed-rank test was used.

Results: Microleakage volume (mm^3) and microleakage percentage (%) measured in Blugloo™ group was found significantly lower ($p<0.05$) then other groups. There was no significant difference in microleakage volume (mm^3) and percentage (%) in comparison of gingival and occlusal regions ($p>0.05$).

Conclusion: Adhesive precoated flash-free brackets were not shown a significant difference compared to their conventional equivalent for microleakage volume. The brackets bonded with Blugloo™ adhesive were showed significant less microleakage than the other groups.

Keywords: Microleakage, microcomputed tomography, flash-free brackets, adhesive precoated brackets

INTRODUCTION

Orthodontic bonding without the right techniques and agents can lead to recurrent bracket failures, insufficient leveling, and white spot lesions.[1,2] To prevent these negative outcomes, companies are trying to produce more advanced bonding agents, and orthodontists are developing new bonding technique.

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A commonly used procedure to create a reliable bond between the orthodontic bracket and tooth surface is the use of light-curing adhesives. Light-curing adhesive-associated polymerization shrinkage can lead to gaps between the bonding material and enamel.[3] These microgaps may allow oral fluids, molecules, ions, and bacteria to pass through the enamel surface. Such microleakage can cause enamel demineralization.[1] The microleakage of bacteria and oral fluids under the orthodontic bracket can lead to the progression of white spot lesions and reduce the bonding strength of the brackets to the tooth surface.[1,2]

Microleakage under orthodontic brackets has been investigated using various bracket systems,[1] polymerization devices,[3] bonding methods[4-7] and adhesives.[1,2,8,9] Despite all the scientific studies, it is still unclear which method or agent will be more useful in preventing microleakage.[9]

Adhesive precoated brackets (APC™, 3M™ Unitek Corporation, CA) were first introduced in 1991. The aim is to save the clinician's time during direct bonding procedure.[10,11] The benefits of APC™ systems compared to conventional light-cured adhesives include faster bonding and easier cleaning.[12] It has also been reported that APC™ systems improve bond strength and reduce clinical failure rates.[13,14] The composite used in the precoating is a modified form of Transbond™ XT (3M™ Unitek Corporation, CA).

APC™ Flash-Free brackets are a popular product that 3M™ Unitek (Monrovia, CA). This brackets come as single packaged brackets and are precoated on a non-woven polypropylene mesh using a low-viscosity resin. This unique structure eliminates the need for cleaning the excessive adhesive and forms a seal to decrease microleakage.[9] It is stated that this bracket system provides sufficient bond strength,[5,15] reduces bonding time and minimizes microleakage compared to conventional bonding systems.[14,15] However, the disadvantage of these systems is their high cost.

To measure microleakage; various *in vitro* methods such as compressed air, radioactive adsorption, radioisotopes, neutron activation, bacterial activity, electrochemical method, dye penetration, scanning electron microscopy, and micro-computed tomography (micro-CT) have been used.[16-18] Among these, micro-CT technology offers significant advantages over two-dimensional (2D) methods. Researchers have indicated that micro-CT is an effective and feasible technique for evaluating polymerization shrinkage and microleakage.[19]

The objective of this research was to compare microleakage under flash-free ceramic brackets and conventional ceramic brackets using micro-CT after thermal cycling.

METHODS

Ethical approval was received from Hatay Mustafa Kemal University Tayfur Ata Sökmen Medical Faculty Clinical Research Ethics Committee with the number 2017/108 (decision no.: 14, date: 24.05.2017), and written informed consent was secured from all patients who agreed to participate in the study. According to the power analysis; with an effect size of 0.6358, a standard deviation of 0.008, an alpha level of 0.05, and a power of 0.8, it was assigned that a minimum of 7 teeth per group was required (version 3.1.9.3, G*Power; HHU Düsseldorf, Germany).[6] To increase reliability and prevent poteintial losses, 8 teeth were used for each group. Forty extracted maxillary premolars were randomly divided into 5 groups, each containing 8 teeth. The teeth included in this study met the following criteria: intact buccal enamel, no caries, no cracks, no restorations, and no prior orthodontic bonding. Until the test time (maximum 8 weeks), the teeth were stored in 0.1% (weight/volume) thymol solution to inhibit bacterial growth at room temperature.[9]

At the experimental stage, all teeth were polished with a flour-free paste for 10 seconds, then rinsed and air-dried. A 37% phosphoric acid gel (3M™ Dental Products, USA) was applied for 30 seconds to the buccal surface of the enamel. The enamel surface was then rinsed with water and dried with air for 20 s. A dull white area was observed on the etched surfaces of all teeth. The same bonding process was applied to all groups using different agents as detailed in Table 1. For all groups, a thin layer of light-cured primer was applied to the buccal surface for 5 seconds on all teeth. Dry air was used to thin the primer, which was then cured with light-emitting diode device (LED) for 10 seconds with a power of 1,000 mW/cm^2. Adhesive was applied on the bracket base for non-coated groups. The brackets were then positioned on the buccal enamel surface, and 300 grams of compression force was applied for 10 seconds using a force gage (P1025-00, Leone™, Italy).[6] Excessive adhesive resin around the brackets was removed with a probe, and the LED light was applied for 10 seconds each from the distal and mesial sides of each bracket for polymerization. Ceramic Clarity™ Advanced maxillary premolar brackets were used in all groups, and all bonding procedures were performed by the same practitioner.

Table 1. Experimental groups and bonding materials used according to groups

Group	Bracket	Primer	Adhesive
APC Flash-Free	**Clarity™ Advanced**	Transbond™ XT Primer	APC™ Flash-Free
APC PLUS	**Clarity™ Advanced**	Transbond™ XT Primer	APC™ PLUS
Transbond XT	**Clarity™ Advanced**	Transbond™ XT Primer	Transbond™ XT Light Cure Adhesive
Opal Bond MV	**Clarity™ Advanced**	Opal® Seal™	Opal® Bond™ MV
Blugloo	**Clarity™ Advanced**	Ortho Solo™ Primer	Blugloo™

After the bonding procedure, to simulate 6 months of intraoral thermal environment, all teeth underwent thermocycling (Julabo GmbH, FT 400, Seelbach, Germany) for 5000 cycles between 5 °C and 55 °C, with a dwell time of 30 seconds.[9,20] The samples were then kept in a 50% silver nitrate solution, used as a radiopaque staining solution for microleakage evaluation.

A Skyscan model 1272 (Kontich, Belgium) micro-CT system was used to receive the 3D X-ray images. Each tooth was placed in a central and vertical position in the sample holder. The X-ray source was set at 90 kV and 111 Ma. Each sample was rotated 360° with a rotation step of 0.50°. A 1-mm aluminum filter was used for all scanning procedures.

For the X-ray images, NRecon (Skyscan, Version 1.7.4.2) software was used. Image pollution and radiological artifacts were eliminated at this stage with 3 units smoothing, 8 units ring artifact correction, and 46% of beam hardening correction. The DICOM (Digital Imaging and Communications in Medicine) compatible images were converted to Bit Map Picture (BMP) format. The resolution of each image was 2452x2452 pixels, with pixel size ofv 9,000 microns. The BMP files were imported to CT-Analyzer software (CTAn, Version 1.18.4.0+, SkyScan, Belgium). The adhesive under the bracket was separated from the enamel, bracket, and air in all three dimensions using the region of interest (ROI) function for all samples (Figures 1, 2). All 3D images were then thresholded and linearized (Figures 3, 4). Volumetric and percentage (microleakage/ROI×100) measurements of microleakage were obtained using the same task list. Each model was sectioned occlusally and gingivally for evaluation. All analyses were performed by the same researcher.

Statistical Analysis

SPSS (version 22; IBM, Armonk, NY) software was used for statistical analysis. The normality of data distribution was determined using the Shapiro-Wilks test. The Kruskal-Wallis and Mann-Whitney U tests were used. For intragroup comparisons, the Wilcoxon signed-rank test was used. Significant differences were evaluated at $p<0.05$ level.

RESULTS

The mean and standard deviation values of the occlusal, gingival, and total microleakage in each group are presented in Table 2. The total microleakage volume of the Blugloo group was significantly lower than that of the APC Flash-

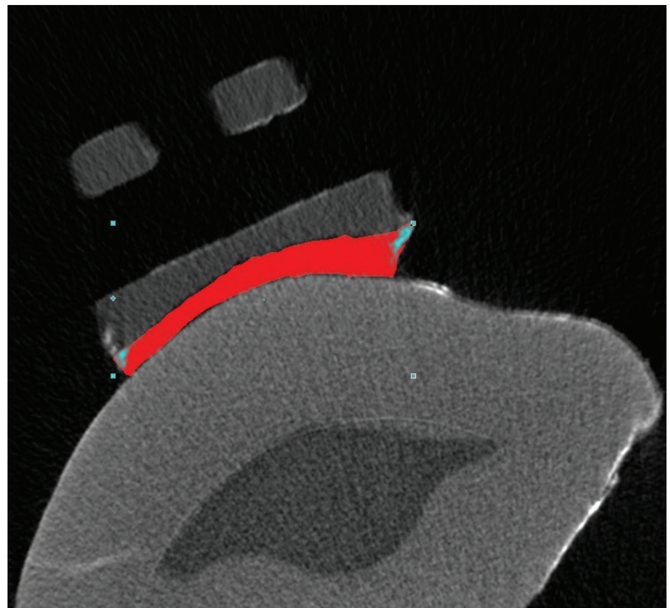

Figure 2. The working area, which was observed in red, was delineated using the ROI function
ROI, region of interest

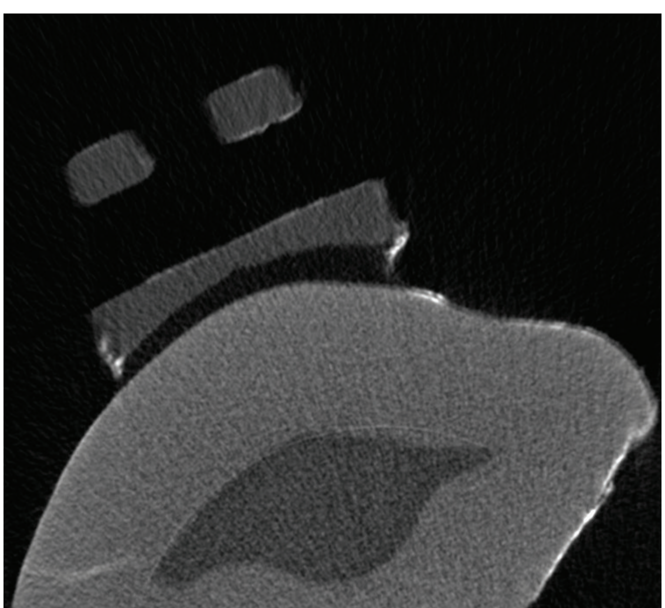

Figure 1. The unprocessed image of a slice shows the bracket, tooth, and adhesive

Figure 3. The threshold process prepares the processed 3D image for mathematical analysis using the generated ideal task list values

Free, APC PLUS, Transbond XT, and Opal Bond MV groups (p1=0.001; p2=0.011; p3=0.027; p4=0.004). On the other hand, no significant differences in total microleakage volume were observed between the other groups (p>0.05).

When the occlusal microleakage volume values were evaluated, the Blugloo group showed significantly lower values than compared to the APC Flash-Free, APC PLUS, Transbond XT, and Opal Bond MV groups (p1=0.006; p2=0.012; p3=0.027; p4=0.009). The occlusal microleakage volume of the Transbond XT group was significantly lower than that of the Opal Bond MV group (p=0.046). There were no significant differences between the other groups (p>0.05).

A significant difference was found in the gingival microleakage volume (p=0.017). The gingival microleakage volume of the Blugloo group was significantly lower than that of the APC Flash-Free, APC PLUS, Transbond XT, and Opal Bond MV groups (p1=0.003; p2=0.012; p3=0.012; p4=0.009). There were no significant differences between the other groups in terms of gingival microleakage volume values (p>0.05). A significant difference in the percentage of total microleakage was also observed between the groups (p=0.007). The microleakage percentage of the Blugloo group was lower than that of the APC Flash-Free, APC PLUS, Transbond XT, and Opal Bond MV groups (p1=0.001; p2=0.003; p3=0.016; p4=0.010). No significant differences were observed among the other groups(p>0.05).

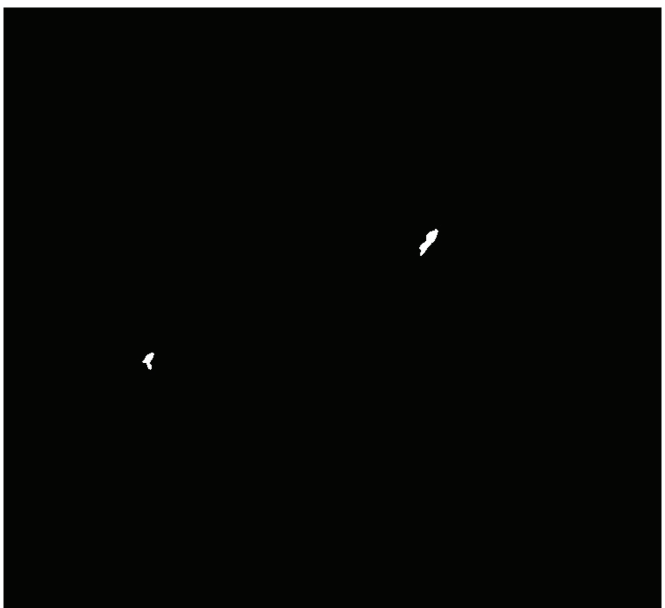

Figure 4. Binarization is the final step in separating black and white colors before 3D computation (white area demonstrates the microleakage)

When comparing the total microleakage surface areas of the the five experimental groups, the Blugloo group had a significantly lower total microleakage surface area than the other groups. These surface area results strongly support the 3D volume findings of microleakage.

The statistical comparison of microleakage volume, surface area, and percentage among the five groups in the occlusal and gingival regions is presented in Table 3. Intragroup comparisons indicated no significant differences between the occlusal and gingival regions (p>0.05).

DISCUSSION

Microleakage of bacteria and oral fluids between the enamel-adhesive surface is an undesired side effect of treatment with brackets. It may cause the development of white spot lesions and reduce the bonding strength of brackets.[1,2] These reasons make microleakage a curious topic. Therefore, various studies have been conducted to evaluate microleakage beneath brackets.[21,22]

In recent years, precoated bracket systems have been widely used in orthodontics. These brackets shorten the bonding time and reduce microleakage by providing good edge coverage. In the present study, the amount of microleakage under the brackets bonded with two different adhesive precoated

Table 2. Volumetric (mm^3), percentage (%), and surface area (mm^2) microleakage values and comparisons of the groups

3D Analysis		APC Flash-Free	APC PLUS	Transbond XT	Opal Bond MV	Blugloo	p-value
		Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	
Microleakage volume (mm^3)	Occlusal	0.006±0.005	0.012±0.019	0.004±0.003	0.019±0.019	0.001±0.001	**0.010***
	Gingival	0.010±0.009	0.015±0.019	0.014±0.022	0.015±0.016	0.001±0.001	**0.017***
	Total	0.015±0.008	0.025±0.038	0.015±0.021	0.035±0.034	0.001±0.001	**0.012***
Microleakage percentage (%)	Occlusal	0.3±0.19	0.63±1.05	0.26±0.18	1.21±1.13	0.09±0.1	**0.012***
	Gingival	0.6±0.56	0.88±1.19	1.13±1.88	1.13±1.21	0.06±0.04	**0.015***
	Total	0.91±0.5	1.52±2.19	1.39±1.89	2.35±2.1	0.15±0.12	**0.007***
Microleakage surface area (mm^2)	Occlusal	0.81±0.55	1.36±1.63	0.49±0.3	1.54±1.15	0.15±0.12	**0.004***
	Gingival	0.87±0.65	1.6±1.78	1.39±1.92	1.34±1.52	0.13±0.08	**0.011***
	Total	1.68±0.74	2.96±3.3	1.88±1.99	2.88±2.34	0.28±0.17	**0.003***

Kruskal-Wallis test, *p<0.05

Table 3. Microleakage comparisons of the occlusal and gingival regions

Group	3D Parameters	Occlusal Mean±SD	Gingival Mean±SD	p-value
APC Flash- Free	Microleakage volume (mm^3)	0.006±0.005	0.010±0.009	**0.484**
	Microleakage percentage (%)	0.3±0.19	0.6±0.56	**0.401**
	Microleakage surface area (mm^2)	0.81±0.55	0.87±0.65	**0.779**
APC PLUS	Microleakage volume (mm^3)	0.012±0.019	0.015±0.019	**0.674**
	Microleakage percentage (%)	0.63±1.05	0.88±1.19	**0.327**
	Microleakage surface area (mm^2)	1.36±1.63	1.6±1.78	**0.674**
Transbond XT	Microleakage volume (mm^3)	0.004±0.003	0.014±0.022	**0.401**
	Microleakage percentage (%)	0.26±0.18	1.13±1.88	**0.327**
	Microleakage surface area (mm^2)	0.49±0.3	1.39±1.92	**0.484**
Opal Bond MV	Microleakage volume (mm^3)	0.019±0.019	0.015±0.016	**0.484**
	Microleakage percentage (%)	1.21±1.13	1.13±1.21	**0.779**
	Microleakage surface area (mm^2)	1.54±1.15	1.34±1.52	**0.575**
Blugloo	Microleakage volume (mm^3)	0.001±0.001	0.001±0.001	**0.398**
	Microleakage percentage (%)	0.09±0.1	0.06±0.04	**0.398**
	Microleakage surface area (mm^2)	0.15±0.12	0.13±0.08	**0.735**

Wilcoxon signed-rank test, *$p<0.05$

systems and three different traditional adhesive systems were compared.

Various methods have been used to investigate microleakage under orthodontic brackets. The most commonly used *in vitro* method is the dye penetration method.[7,8,23,24] This method involves staining microleakage areas using dye solutions and evaluating them usually with a stereomicroscope. However, in this technique, the depth of dye penetration is measured in two dimensions on limited slices, which may not represent the entire 3D image of the microleakage volume.[6] Therefore, the reliability is low compared to 3D methods.[16,25] Micro-CT is a 3D method that generates reliable and comprehensive data in microleakage studies.[26] This novel method was preferred due to its reliability in this study. An *in vitro* experimental design was developed to ensure standardization and eliminate patient-derived differences.

The advantages of the micro-CT technique include its noninvasive nature, which does not damage the samples, capability to perform repetitive scanning of the same sample, potential for 3D analysis, method reliability, and ability to apply different tests to the sample. However, micro-CT studies require significant time and effort to scan, image reconstruction, and analysis each sample. In addition, it is an expensive method, and the small sample size in micro-CT studies can be considered as a limitation.[27,28]

Radiopaque staining solutions such as barium nitrate, lead nitrate, and silver nitrate have been frequently used in previous micro-CT studies to evaluate microleakage.[29] Nguyen[29] reported that a 50% silver nitrate solution is highly successful and convenient for assessing leakage in the micro-CT method. Zhao et al.[30] and Eden et al.[18] used 50% silver nitrate solution for determining the microleakage of composite restorations using micro-CT. Also, Öztürk et al.[6] used a 50% silver nitrate solution in their micro-CT study to evaluate microleakage areas under the brackets. Considering previous studies, a 50% silver nitrate solution was used in the present study. In different microleakage studies, the immersion time of the samples in the silver nitrate solution ranged from 1 hour to 24 hours.[18,29,31] In the present study, a pilot study was conducted to determine the immersion time of the samples in the silver nitrate solution, and the optimal time for monitoring leakage. Based on these findings, the immersion time was set at 12 hours for this study.

The APC™ Flash-Free system uses brackets with low-viscosity resin applied on a polypropylene nonwoven mesh. This system eliminates the need for resin cleaning after application, creates a seal to reduce microleakage, and decreases the total bonding time.[9] However, according to the results of the present study microleakage volume of APC™ Flash-Free, APC Plus, and noncoated Transbond XT groups were similar. Kim et al.[9] compared microleakage under the APC™ Flash-Free and APC™ PLUS brackets using the dye penetration method and found no significant difference. Grünheid et al.[5] evaluated the microleakage of APC™ Flash-Free and APC™ II products and found no significant difference. The findings from these studies align with the results of the present study.

In a recent study examining microleakage under stainless steel brackets, it was reported that conventional brackets exhibited more microleakage than the APC Flash-free and APC plus groups.[32] However, this study used stereomicroscopy and was limited to selected sections. Because the present study was not conducted on selected sections, it included the entire 3D microleakage volume. It is thought that the micro-CT method strengthens the results of the present study.

The results of the present study showed that the microleakage volume in the Blugloo group was significantly lower than in the other experimental groups. The reason for this result is thought to be the special structure of the adhesive, as Blugloo™ is specficially formulated for use with ceramic brackets.

In their microleakage study using the dye penetration method, Uysal et al.[33] reported that gingival microleakage scores were higher than the occlusal scores of the brackets for all groups. In contrast, in a micro-CT study, Öztürk et al.[6] reported higher values of occlusal microleakage than gingival microleakage for two experimental groups and no significant differences between the other groups. In the present study, no significant differences were observed between the occlusal and gingival microleakage volumes across the groups. The reasons for this difference between studies were thought to be the anatomical differences in the teeth used and the differences in brackets, adhesives, and methods. However, microleakages are volumetric data; therefore, 3D methods are considered to provide more accurate evaluations.

In modern orthodontic practice, the use of metal brackets is common. Despite this, ceramic brackets were selected for the present study to ensure higher quality measurements by preventing metal artifacts in micro-CT images. This can be seen as a limitation of the present study. However, Ramoglu et al.[8] reported no significant differences in microleakage between metal and ceramic brackets. Considering the results of this study, the use of ceramic brackets may not be an important limitation.

CONCLUSION

Flash-free ceramic brackets and conventional ceramic brackets demonstrated similar levels of microleakage. However, ceramic brackets bonded with Blugloo™ adhesive exhibited significantly reduced microleakage. The microleakage observed in the occlusal and gingival regions of the brackets was comparable.

Ethics

Ethics Committee Approval: Ethical approval was received from Hatay Mustafa Kemal University Tayfur Ata Sökmen Medical Faculty Clinical Research Ethics Committee with the number 2017/108 (decision no.: 14, date: 24.05.2017).

Informed Consent: Written informed consent was secured from all patients who agreed to participate in the study.

Footnotes

Author Contributions: Concept - G.Ü., E.B.K.; Design - G.Ü., E.B.K.; Data Collection and/or Processing - G.Ü.; Analysis and/or Interpretation - G.Ü., E.B.K.; Literature Search - G.Ü.; Writing - G.Ü.

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

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Original Article

External Apical Root Resorption in Endodontically Treated and Vital Teeth after Orthodontic Treatment: A Retrospective Study

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Main Points

- Long treatment duration and extraction treatment were significantly associated with external apical root resorption (EARR).
- The presence of endodontically treated teeth (ETT) did not increase an individual's risk of EARR.
- ETT is more resistant to EARR than contralateral vital pulp.

ABSTRACT

Objective: This retrospective study aimed to assess the presence and amount of external apical root resorption (EARR) in endodontically treated teeth (ETT) and contralateral teeth with vital pulp (VPT) following orthodontic treatment.

Methods: The study sample included panoramic radiographs of 503 patients (314 females and 189 males; 16.29 years±3.98) with 620 ETT and 580 VPT. The tooth length was measured on digital panoramic radiographs, which were collected at the beginning and end of the orthodontic therapy for each subject. The pre- and post-orthodontic treatment radiographic evaluation included the percentage of EARR in ETT and contralateral VPT for all tooth types. Any relationship between EARR and orthodontic treatment type (one- and two-phase; extraction and non-extraction), duration, and patients' age and gender were investigated. Mann-Whitney U, Wilcoxon signed rank, Kruskal-Wallis and Spearman correlation tests were applied for comparisons and to test the correlations.

Results: A statistically significant difference was observed in all orthodontic treatment groups when ETT and VPT were compared in terms of EARR ($p<0.05$). EARR was positively correlated with orthodontic treatment duration and type ($p<0.05$) but was not influenced by patient age or gender. Statistically significant EARR was observed in the two-phase extraction orthodontic treatment group for both ETT and VPT. In VPT, a statistically significant EARR was found in the one-phase extraction treatment group compared with the non-extraction treatment group, whereas no significant difference was found in ETT.

Conclusion: ETT showed significantly lower EARR than VPT. ETT can therefore be moved safely during orthodontic treatment.

Keywords: External root resorption, orthodontic treatment, endodontics, root canal treatment

INTRODUCTION

Tooth root resorption is a complicated and unpredictable pathological condition that affects the cementum, root dentin, and apex and can lead to the irreversible loss of tooth structure.[1] Higher levels of root resorption have been observed during orthodontic tooth movement compared with the natural root resorption process in humans.[2] When orthodontic stresses are applied to teeth, blood flow in the periodontal ligament changes,

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and a local inflammatory response is created to aid tooth movement.[3] External apical root resorption (EARR) is an undesirable condition that may also be a possible pathological consequence of orthodontic tooth movement. Orthodontically induced EARR is a condition in which the root surface is eroded, leading to the loss of cementum. Once the dentin is affected, this erosion becomes permanent and cannot be reversed.[3] Since orthodontically induced EARR is considered irreversible when it affects the dentin, it is crucial to identify factors that may predispose individuals to clinically significant EARR.[4] Several factors are potential risk factors and induce EARR during orthodontic treatment, including patient age, gender, nutrition, genetics, type of orthodontic appliance, magnitude of applied force, treatment type, treatment duration, and the amount of tooth movement.[5,6]

The possibility of experiencing endodontically treated teeth (ETT) has become even more frequent, with the expanded request for orthodontic treatment among adults. Therefore, predicting the prognosis of ETT after orthodontic treatment and their resistance to EARR is even more important for clinicians in their orthodontic planning. In the literature, the results of studies on whether ETT differs in resorption compared with contralateral teeth with vital pulp (VPT) after orthodontic treatment have been controversial. It has been considered that ETT may be more resistant to EARR than VPT.[7-10] On the contrary, Mah et al.[11] Reported higher EARR in ETT. Some studies have also found no difference in the amount of EARR observed between ETT and contralateral VPT.[12-14] The reasons for these controversial results could be due to the differences in the types of teeth included in the studies, the absence of evaluation of orthodontic treatment types in some studies, or the small sample size of patients and teeth included.

To the best of our knowledge, no previous study has evaluated the EARR resulting from one-phase and two-phase orthodontic treatments in all tooth types and compared their effects on root resorption in both ETT and VPT. Hence, our primary purpose was to assess the presence of EARR resulting from orthodontic treatment in ETT and to compare it with that of contralateral VPT. Second, the relationship between EARR levels and possible predisposing factors, such as treatment type and duration and patient age and sex, was also evaluated in the present study. The first null hypothesis tested was that orthodontic treatments applied to ETT and contralateral VPT did not result in root resorption. The second hypothesis was that the treatment type did not alter the degree of root resorption in ETT and VPT.

METHODS

Sample Selection

Ethical approval for this retrospective study was obtained from the Clinical Research Ethics Committee of Akdeniz University Faculty of Medicine (approval no.: 164, dated: 4 April 2022). The study materials were selected from the archives of Akdeniz University Faculty of Dentistry, Department of Orthodontics.

The records of 4673 patients who were treated from 2012 to 2023 were examined. The analysis focused on the pre- and post-treatment panoramic radiographs of 503 patients (314 females and 189 males; mean age 16.29 years ± 3.98) and 620 teeth (395 belonging to females and 225 belonging to males) that matched the following inclusion criteria: (1) the presence of anamnestic records, treatment planning, and clinical notes in patients' files; (2) high-quality pre-treatment and post-treatment panoramic radiographs; (3) at least one tooth that had been root-filled pre-orthodontically; and (4) teeth without fractures on their incisal or occlusal surfaces.

The quality of the root canal filling was evaluated based on the density of the filling, the taper of the filling, and the distance from the end of the filling to the radiographic apex.[15] The criteria used in this study to evaluate the technical quality of the filling were as follows: (1) length, root canal filling 0-2 mm from the radiographic apex; (2) homogeneity, homogeneous root canal filling, good condensation with no visible voids; and (3) tapering, steady and uniform tapering from the coronal to the apical region, reflecting the canal's original shape.

The exclusion criteria were as follows: (1) individuals with craniofacial anomalies, systemic disorders, or parafunctional habits like bruxism; (2) subjects who underwent endodontic treatment during orthodontic treatment; (3) patients with incomplete orthodontic treatment; and (4) ETT extraction during orthodontic treatment.

The distribution of the ETT based on the tooth number is shown in Figure 1. Out of 620 ETTs, 40 did not exhibit contralateral VPT. The sample was accepted as 580 when comparing the contralateral side to the ETT. In total, 620 ETT and 580 VPT were used to assess the association between EARR percentage and sex, age, treatment duration, and treatment type, whereas 580 ETT and contralateral VPT were compared in terms of the percentage of EARR according to treatment type.

According to the post-hoc power analysis, a Cohen's d of 0.85 was calculated from the comparison of the percentage of EARR in ETT between the one- and two-phase groups in the extraction treatment. The statistical power of the study was 99% with a margin of error of 0.05 given n1=166 and n2=46. The sample size was estimated using the G*Power 3.1.9.2 software.

All orthodontic treatments were performed by a team of residents under the supervision of a single expert. The patients were treated with two different modalities: the "one-phase orthodontic treatment", where patients received only fixed orthodontic treatment and the "two-phase orthodontic treatment", where the first phase involved various orthodontic appliances (monoblock, twin-block, Teuscher, face mask, chin cap and maxillary expansion appliances) followed by fixed orthodontic treatment. For all patients, the fixed orthodontic appliances were conventional Roth systems with a slot size of

	Right upper quadrant													Left upper quadrant
N	5	72	14	7	1	13	31	27	17	1	12	13	93	5
Tooth number	7	6	5	4	3	2	1	1	2	3	4	5	6	7
	7	6	5	4	3	2	1	1	2	3	4	5	6	7
N	16	126	8	2	0	2	2	0	0	0	2	11	129	11
	Right lower quadrant													Left lower quadrant

Figure 1. The chart, representing the distribution of ETTs based on the tooth number
N, Sample of the ETT

0.018 inches. The standard archwire sequences ranged from 0.014-inch nickel-titanium to 0.016x0.022-inch stainless steel.

The effect of orthodontic treatment type on the level of EARR was evaluated based on the application of orthopedic and fixed orthodontic treatment together (two-phase) or fixed orthodontic treatment alone (one-phase). Second, the effect of extraction- or non-extraction-fixed orthodontic treatment was assessed. The one- and two-phase treatment groups according to the extraction decision was performed and the extraction and non-extraction treatment groups were then compared based on the treatment phases. Age at the initiation of treatment, treatment duration, and percentage of EARR in ETT and VPT were also evaluated. Moreover, ETT and contralateral VPT were compared with each other in terms of the percentage of EARR according to the treatment phase and extraction decision.

Radiological Assessment

In this study, measurements were made on digital panoramic radiographs taken at the beginning (T0) and end of treatment (T1). Panoramic radiographs were obtained using a Planmeca ProMax panoramic device (Planmeca, Helsinki, Finland) for all patients. The positioning light guides incorporated into the machine were used to standardize the position of the head. The images were obtained using the Planmeca Romexis Viewer program (v.2.7.0.R; Planmeca, Finland).

The lengths of the crowns and roots of the teeth were measured using the Planmeca Romexis Viewer program to determine the amount of EARR occurring between T0 and T1 according to the method described by Linge and Linge.[12] The reference points and lines for the pre- and post-orthodontic treatment measurements are shown in Figure 2. The cementoenamel junction (CEJ) was initially identified as a linear connection between two specific locations, specifically the mesial and distal CEJs. The crown lengths on the pre- and post-treatment radiographs were then determined in ETT and contralateral VPT by measuring the longest distance from the incisal or occlusal edge to the CEJ. The root lengths on the pre- and posttreatment radiographs were also calculated in the ETT and

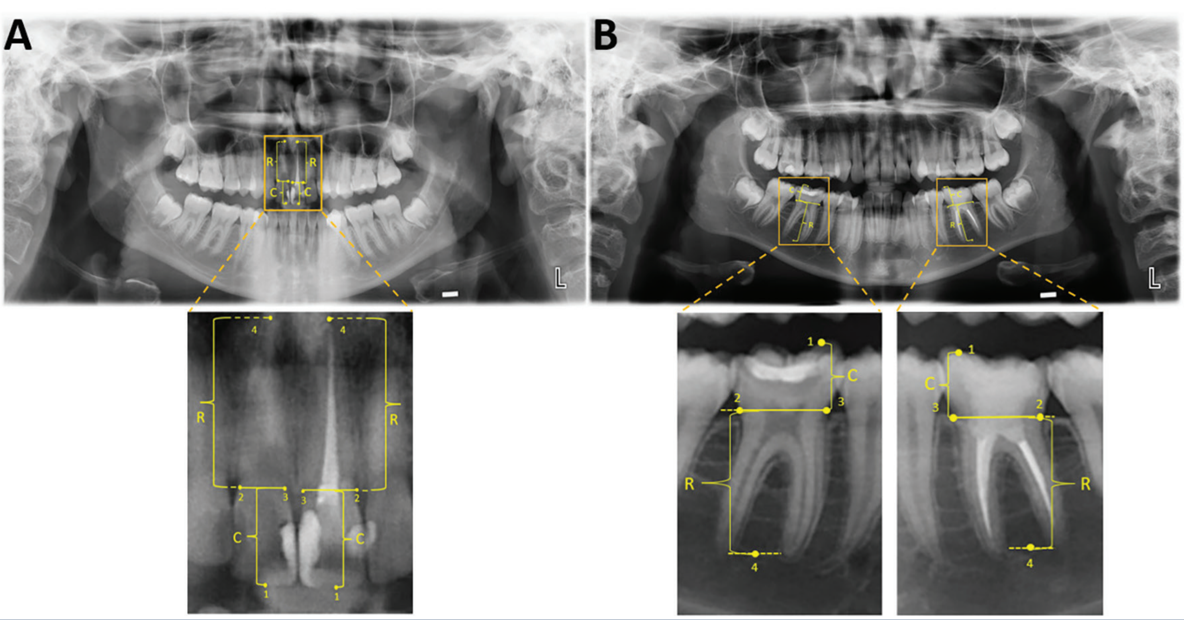

Figure 2. Measurements of crown and root lengths of single-rooted **(A)** and multiple-rooted teeth **(B)**
1-incisal or occlusal edge; 2-distal CEJ; 3-mesial CEJ; 4-iroot apex; R-root length; C-crown length

contralateral VPT by measuring the distance from the CEJ to the root apices. The root lengths of teeth with multiple roots were calculated by measuring the distance from the CEJ to the midpoint on the line between the root apexes. The buccal roots of the upper and premolars were measured.

First, the amount of EARR was calculated in millimeters as follows: root length pre-orthodontic treatment (R1) root length post-orthodontic treatment (R2) × (crown length before orthodontic treatment/crown length after orthodontic treatment).[12] Then, EARR was defined as the percentage shortening per tooth as follows: EARR×100/R1. Using percentage values is a more efficient approach for conducting comparisons because individual discrepancies in tooth root length can diminish the significance of millimeter-based comparisons of root resorption values.

Statistical Analysis

Analyses were performed using SPSS 23.0 software (SPSS Inc., Chicago, Illinois, USA). To determine the method error, 60 patients were randomly selected and measured by the same researcher within a 2-week interval. The intraclass correlation coefficient was used to assess intraobserver reliability and was found to be 0.98. The assumption of normality was evaluated by using the Shapiro-Wilk test. The Mann-Whitney U test was used for intragroup comparison of pre-treatment age, treatment duration, and percentage of patients with EARR. The same test was used for gender comparison. The Wilcoxon signed rank test was used for the intergroup comparison of the percentage of EARR. Statistically significant cases were defined as those with a $p<0.05$. The Spearman correlation test was used to evaluate the correlation between pre-treatment age, treatment duration, and the percentage of patients with EARR.

RESULTS

The data include information on characteristics such as age at the beginning of treatment, treatment duration, treatment type, number of teeth, tooth group, and percentage of EARR in ETT and VPT. Table 1 presents both the comparison of the one- and two-phase orthodontic treatment groups regarding whether teeth were extracted or not, and the results of the compared extraction and non-extraction groups in the one- and two-phase treatment. Differences were observed in the age at the beginning of treatment, treatment duration, and percentage of EARR in ETT and VPT between the one-phase and two-phase extraction treatment groups. In the one-phase extraction group, the age at the beginning of treatments was higher, whereas the duration of treatment and the percentage of EARR in both ETT and VPT were lower ($p<0.05$).Differences were also observed in the age at the beginning of treatment, treatment duration, and the percentage of EARR in ETT and VPT between the one-phase and two-phase groups in the non-extraction treatment. The age at the beginning of treatment, treatment duration, and percentage of EARR in both ETT and VPT were reduced in the one-phase group compared with the two-phase group in the non-extraction treatment. Significant differences were observed in the age at the beginning of treatment, treatment duration, and percentage of EARR in ETT and VPT between the extraction and non-extraction groups in the one-phase treatment ($p<0.05$). These values were higher in the extraction group than in the non-extraction group. The percentage of EARR in ETT and VPT between the extraction and non-extraction groups in the two-phase treatment was found to be different ($p<0.05$). These values were higher in the extracted group than in the non-extracted group.

Comparisons of the percentage of EARR in ETT and VPT between the one- and two-phase treatment groups are presented in Table 2. The percentage of EARR was significantly higher in VPT than in ETT in both the one- and two-phase treatment groups.

Comparisons of the percentage of EARR in ETT and VPT between the extraction and non-extraction treatment groups are presented in Table 3. Similar to the findings in the phase comparison, the percentage of EARR was higher in the VPT group than in the ETT group in both the extraction and non-extraction treatment groups.

Treatment duration showed a statistically significant, positive but weak correlation with EARR in ETT and VPT ($p<0.001$; $r=0.19$ and $r=0.226$, respectively). Patient age was not significantly correlated with EARR on ETT and VPT (Table 4).

Table 5 presents the comparison of the EARR percentage according to the tooth group in the ETT and VPT. The tooth group significantly impacted apical root resorption in ETT ($p<0.05$), but it did not affect vital teeth ($p>0.05$).

Gender had no statistically significant effect on the percentage of EARR in ETT and VPT.

DISCUSSION

A total of 503 patients, including 620 ETT and 580 VPT, were included in the study based on the specified inclusion and exclusion criteria. This study assessed the differences in tooth lengths of all tooth types in ETT and contralateral VPT before and after orthodontic treatment using digital panoramic radiography. The results from both the one- and two-phase, as well as the extraction and non-extraction treatment groups, were compared within each group and between groups. The present study revealed that the EARR was significantly greater in VPT than in ETT. As a result, the first hypothesis was rejected. Additionally, the amount of EARR was partially influenced by the treatment type in both ETT and VPT; thus, the second hypothesis was partially supported.

Previous studies[7-10] have examined the assessment of root resorption during orthodontic treatment and compared ETT and VPT results. Lee and Lee[7], in their retrospective study reviewing different teeth in 35 patients and reported significantly less EARR in ETT compared with the contralateral VPT. Kurnaz and Buyukcavus[8] examined the mandibular molars

Table 1. Comparison of the one- and two-phase treatment groups based on the extraction and the extraction and non-extraction treatment groups based on the treatment phase

	Treatment phase	Extraction orthodontic treatment				Non-extraction orthodontic treatment				Treatment type	One-phase orthodontic treatment				Two-phase orthodontic treatment			
		n (teeth)	Mean±SD	Median (Q1-Q3)	p-value	n (teeth)	Mean±SD	Median (Q1-Q3)	p-value		n (teeth)	Mean±SD	Median (Q1-Q3)	p-value	n (teeth)	Mean±SD	Median (Q1-Q3)	p-value
Pre-treatment age (year)	One	166	17.65±5.04	16.49 (14.89-18.08)	**<0.001**	282	16.33±3.6	16.03 (14.48-17.41)	**<0.001**	Ext	166	17.65±5.04	16.49 (14.89-18.08)	**0.002**	46	15.11±3.88	14.5 (13.24-15.41)	0.767
	Two	46	15.11±3.88	14.5 (13.24-15.41)		126	14.83±2.33	14.26 (13.59-15.73)		Non-ext	282	16.33±3.6	16.03 (14.48-17.41)		126	14.83±2.33	14,26 (13.59-15.73)	
Treatment duration (months)	One	166	28.39±9.85	27.8 (22.07-34.53)	**0.01**	282	20.99±10.06	20.03 (12.93-27.07)	**<0.001**	Ext	166	28.39±9.85	27.8 (22.07-34.53)	**<0.001**	46	34.98±10.21	33.95 (24.93-41.83)	0.08
	Two	46	34.98±10.21	33.95 (24.93-41.83)		126	31.69±10.86	30.55 (22.2-40.33)		Non-ext	282	20.99±10.06	20.03 (12.93-27.07)		126	31.69±10.86	30.55 (22.2-40.33)	
ETT: T0-T1 (%)	One	166	4.92±3.99	4.48 (1.77-7.06)	**0.002**	282	4.75±4.27	3.75 (1.78-6.76)	0.547	Ext	166	4.92±3.99	4.48 (1.77-7.06)	0.55	46	7.26±4.99	6.39 (4.27-9.81)	**0.003**
	Two	46	7.26±4.99	6.39 (4.27-9.81)		126	5.45±5.39	3.88 (1.88-7.08)		Non-ext	282	4.75±4.27	3.75 (1.78-6.76)		126	5.45±5.39	3.88 (1.88-7.08)	
VPT: T0-T1 (%)	One	159	7.06±4.6	6.78 (3.26-10.16)	**0.006**	264	5.87±4.34	5.27 (2.45-7.84)	0.196	Ext	159	7.06±4.6	6.78 (3.26-10.16)	**0.005**	42	9.49±5.27	9.11 (5.96-12.43)	**<0.001**
	Two	42	9.49±5.27	9.11 (5.96-12.43)		115	6.68±5.18	5.53 (2.87-8.59)		Non-ext	264	5.87±4.34	5.27 (2.45-7.84)		115	6.68±5.18	5.53 (2.87-8.59)	

SD: Standard deviation; The statistical significance level was p<0.05 p: Intragroup comparison (Comparison of One and Two phase groups in Extraction treatment; Comparison of One and Two phase groups in Non-extraction treatment; Comparison Extraction and Non-extraction groups in One phase treatment; Comparison Extraction and Non-extraction groups in Two phase treatment): Mann-Whitney U test. Significant differences are indicated in bold (p<0.05). ETT: endodontically treated teeth; VPT: contralateral teeth with vital pulp

of 69 patients and observed more root resorption in vital molars than in endodontically treated molars post orthodontically. In addition, Grissom et al.[9] conducted a study to evaluate the amount of root resorption in 76 (38 endodontically-treated and 38 vital contralateral) teeth with CBCT and found that ETT was more resistant to external root resorption than their contralateral VPT. In another study, Kolcuoglu and Oz[10] evaluated the difference in root resorption between endodontically treated and vital premolars in premolar-extracted orthodontic treatment using micro-CT and reported that ETT was less susceptible to root resorption than VPT. The findings of the present study were in accordance with the abovementioned results. However, some studies[12-16] reported no significant differences in root resorption between ETT and contralateral VPT. The disagreement in the results between previous findings and the current study may be attributed to the inclusion of different types of teeth and study samples, such as incisors and molars. To the best of our knowledge, all types of teeth were included in the present study, and the total sample size was the largest of all similar studies. Moreover, the outcomes of two-phase orthodontic treatment, which includes orthopedic treatment and one-phase orthodontic treatment with only fixed appliances, were investigated.

The mechanism and role of pulp tissue have been researched histologically by some researchers, but it is still complicated. Kaku et al.[17] found that injured and stretched pulp cells express receptor activator of nuclear factor kappa-B ligand (RANKL), macrophage colony stimulating factor (M-CSF), and inflammatory cytokines; thereby, odontoblastic activity starts and inflammatory apical root resorption occurs. They assumed that tensile forces on the pulp cells through the apical foramen induced by orthodontic tooth movement cause an increase in the expression of these factors, which may lead to inflammatory root resorption. Bender et al.[18] suggested that the absence of neuropeptide release from the removed pulp leads to a decrease in CGRP-IR fibers and less resorption in ETT. In addition, calcium hydroxide-based root canal materials have been reported to have a positive effect on the healing process of periapical tissue and the repair of orthodontic root resorption in endodontically treated dog teeth.[19] These factors may explain the lower EARR observed in ETT in those studies.

Previous studies[7,8,20] in the literature have indicated a positive correlation between EARR and the type and duration of orthodontic treatment. It was reported that there was no significant difference between extraction and non-extraction treatment protocols in terms of resorption in ETT, while more resorption was observed in VPT in treatment protocols involving extraction.[7,8,21] Only one study[22] reported that both VPT and ETT showed more resorption in non-extraction cases than in extraction cases. According to the results of our study, orthodontic treatment involving extractions resulted in greater EARR in VPT patients compared with patients without extractions, which is consistent with previous studies.[7,8,21]

Very few studies[20,23,24] have compared one- and two-phase treatment protocols in terms of root resorption. Seker et al.[24] reported a significant increase in the incidence of EARR in patients treated with two-phase treatment compared to those treated

Table 2. Comparison of the EARR percentage in the one- and two-phase orthodontic treatment groups of ETT and VPT groups

Percentage of the EARR	One-phase orthodontic treatment				Two-phase orthodontic treatment			
	n (teeth)	Mean±SD	Median (Q1-Q3)	p-value	n (teeth)	Mean±SD	Median (Q1-Q3)	p-value
ETT:T0-T1 (%)	423	4.92±4.24	4.31 (1.77-7.09)	**<0.001**	157	6.25±5.44	4.76 (2.26-7.99)	**0.001**
VPT:T0-T1 (%)	423	6.32±4.47	5.61 (2.73-8.71)		157	7.43± 5.33	6.54 (3.61-9.58)	

SD: Standard deviation; The statistical significance level was p<0.05; p: Intergroup comparison (Comparison of EARR level of ETT and VPT in One phase treatment; Comparison of EARR level of ETT and VPT in Two phase treatment): Wilcoxon signed rank test. Significant differences are indicated in bold (p<0.05).
ETT: endodontically treated teeth; VPT: contralateral teeth with vital pulp

Table 3. Comparison of the EARR percentage in the extraction and non-extraction orthodontic treatment groups for ETT and VPT

Percentage of EARR	Extraction orthodontic treatment				Non-extraction orthodontic treatment			
	n (teeth)	Mean±SD	Median (Q1-Q3)	p-value	n (teeth)	Mean±SD	Median (Q1-Q3)	p-value
ETT:T0-T1 (%)	201	5.56±4.38	5.1 (2.05-7.69)	**<0.001**	379	5.13±4.76	4.07 (1.84-7.09)	**<0.001**
VPT:T0-T1 (%)	201	7.57±4.84	6.93 (3.7-10.56)		379	6.12±4.62	5.34 (2.72-8.09)	

SD: Standard deviation; The statistical significance level was p<0.05; p: Intergroup comparison (Comparison of EARR level of ETT and VPT in Extraction treatment; Comparison of EARR level of ETT and VPT in Non-extraction treatment): Wilcoxon signed rank test. Significant differences are indicated in bold (p<0.05). ETT: endodontically treated teeth; VPT: contralateral teeth with vital pulp

Table 4. Correlation of pre-treatment age and treatment duration with EARR percentage in ETT and VPT

	Correlation	VPT T0-T1 (%)	Pre-treatment age	Treatment duration (months)
ETT:T0-T1 (%) n=620	r	0.245	-0.011	0.190
	p	**<0.001**	0.784	**<0.001**
VPT:T0-T1 (%) n=580	r		-0.047	0.226
	p		0.258	**<0.001**

Spearman Correlation Test. Significant differences are indicated in bold (p<0.05). ETT: endodontically treated teeth; VPT: contralateral teeth with vital pulp

Table 5. Comparison of the EARR percentage according to the tooth group during ETT and VPT

Tooth group	ETT T0-T1 (%)		VPT T0-T1 (%)	
	n (teeth)	Median (Q1-Q3)	n (teeth)	Median (Q1-Q3)
Maxillary anterior	90	5.25 (2.32-8.67)	85	7.52 (4.04-10.39)
Maxillary premolar	46	4.35 (1.34-6.64)	46	6.86 (3.63-11.57)
Maxillary molar	175	4.27 (2.04-7.41)	175	5.3 (2.42-8.49)
Mandibular anterior	4	13.14 (8.37-15.22)	4	7.9 (3.94-8.93)
Mandibular premolar	23	2.59 (0.75-4.86)	23	5.65 (4.65-10.29)
Mandibular molar	282	4.02 (1.8-6.67)	247	5.61 (2.84-8.22)
p		**0.002**		0.077

Kruskal-Wallis test. Significant differences are indicated in bold (p<0.05); ETT, endodontically treated teeth; VPT, contralateral teeth with vital pulp

with fixed appliances alone. However, Faxén Sepanian and Sonnesen[23] found that the one-phase treatment group showed significantly higher EARR than the two-phase treatment group. On the other hand, no significant differences were reported between two-phase and one-phase treatment protocols regarding the incidence of EARR.[20] In the present study, the EARR incidence for both ETT and VPT in the two-phase extraction treatment group was statistically significant when compared with that of one-phase extraction. The longer treatment period in the two-phase treatment group was probably associated with increased root resorption, which in turn could be attributed to greater teeth movements during orthodontic extraction therapy and variations in the level of orthodontic forces utilized in the orthopedic treatment.

A possible relationship between sex and root resorption in both ETT and VPT was also evaluated in the present study; the amount of EARR did not show any significant difference with sex in accordance with previous studies.[7,21] On the contrary, only one study found the EARR to be more frequent in males than females.[20] This result was attributed to the longer treatment duration in male patients. Another possible factor affecting the level of EARR, chronological age, was also investigated. In the current study, the age range was 8.9-43.9 years and the sample was substantial. There was no correlation between age and EARR level, however, similar to previous studies.[20,25] In contrast, Lee and Lee[7] reported a positive correlation between age and root resorption in ETT but not in VPT. This result can be attributed to the sample size. Moreover, the extent of root resorption varied among the tooth groups; this variable was incorporated into the study analysis. Previous studies[20,25] have indicated that maxillary incisors exhibit the highest frequency of resorption, followed by mandibular incisors. McFadden et al.[26] reported that mandibular incisors are more susceptible to root resorption following intrusion movements than maxillary incisors. In our study, the greatest amount of EARR in both the ETT and VPT was observed first in the mandibular anterior teeth, followed by the maxillary anterior teeth. This outcome may be attributed to several factors, including the cortical bone of the socket, alveolar bone on the buccal surface, intrusion movements, and unequal distribution of teeth among the tooth groups.

Digital panoramic radiographs, intraoral periapical radiographs, and three-dimensional images (cone beam computed tomography, CBCT) are commonly used to evaluate EARR following orthodontic treatment.[9,14,21] Three-dimensional imaging has been shown to have greater accuracy and repeatability in evaluating EARR than two dimensional images.[27,28] Despite its accuracy, the use of CBCT for routine orthodontic records has been contested because of the higher radiation dose.[4] Periapical films have been accepted as superior to panoramic images because of the lesser image distortion and greater detail resolution.[29] However, it has been reported that the effective radiation dose of panoramic radiography is lower than that of traditional full-mouth periapical radiography.[30] Apajalahti and Peltola[25] also evaluated root length changes using panoramic radiographs, as periapical radiographs are not routinely taken during orthodontic treatment, and panoramic images provide high-quality results. Root resorption is usually diagnosed on panoramic radiography due to advantages such as low radiation exposure, view of the entire dental arch, and low cost.[31] In the present study, tooth length was measured using digital panoramic radiography. This is because serial periapical radiographs and three-dimensional imaging are not routinely performed during orthodontic treatment. Instead, panoramic radiographs are more routinely used in orthodontic records and are easily accessible for retrospective analysis.[4,25]

For measurements on panoramic radiographs, like root resorption, where reproducibility is crucial, the palatal root of the maxillary first molars was found to be unreliable, whereas the maxillary first molar buccal roots were reproducible on panoramic radiographs.[32] Therefore, the buccal roots of the maxillary molar and premolar teeth were included in this study, similar to previous studies.[21] Common errors in panoramic radiography are generally caused by head positioning. Stramotas et al.[33] reported that linear measurements on panoramic radiographs acquired at different times are sufficiently accurate if the occlusal plane is positioned similarly on both occasions and the extent of tilting does not exceed 10°. In the present study, the same panoramic machine and guide lights were used for all radiographs of each patient to reduce head positioning errors. Moreover, the objective was to compare the EARR on pre- and post-treatment radiographs instead of determining the exact values of root loss.

In this study, care was taken to ensure that root canal treatments were of a certain quality, and teeth that did not meet the specified criteria were excluded from the study because cases with unsuccessful root canal treatment (such as a short root canal filling, lack of filling homogeneity) had a risk of affecting the objectives of our study. In future studies, such cases and the results of orthodontic treatment can be compared retrospectively.

Study Limitations

Our study has some notable strengths that set it apart from other studies in the existing literature. First, a large sample size was evaluated comprehensively in this retrospective study. It is important to note the challenge of identifying a large sample size including ETT in orthodontic patients. Second, the amount of EARR was assessed in different types of orthodontic treatment modalities together with the treatment duration (extraction vs. non-extraction; one-phase vs. two-phase). Nevertheless, the main limitation of this study was the utilization of two-dimensional digital panoramic radiographs, which have lower sensitivity compared with three-dimensional imaging techniques. While prior research[7,8,21,22] has utilized panoramic radiographs to assess EARR, it would be advantageous to perform future investigations using three-dimensional imaging.

CONCLUSION

The findings of the present study indicate that ETT is less susceptible to EARR than VPT. When the pre- and post-orthodontic treatment panoramic radiographs were compared, different EARR values were observed in all teeth. Significantly associated risk factors were long treatment durations and extraction treatment. This study concluded that the potential complications of EARR in ETT might not be a factor to consider when planning orthodontic treatment.

Ethics

Ethics Committee Approval: Ethical approval was obtained from the Clinical Research Ethics Committee of Akdeniz University Faculty of Medicine (approval no.: 164, date: 4 April 2022).

Informed Consent: Informed consent was obtained from all patients who were treated, and the patients' individual materials were used in these consent forms.

Footnotes

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

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Original Article

Accuracy of 3D Printer Technologies Using Digital Dental Models

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Main Points

- No difference was observed between 3D printers in the dimensional tooth measurements.
- The mean root mean squared value in the stereolithography (SLA) group was presignificantly higher than that in the Digital Light Processing (DLP) and PolyJet groups.
- DLP and PolyJet printers produce more accurately than SLA technology.
- SLA, DLP, and PolyJet technologies are clinically appropriate for model production in the orthodontic field.

ABSTRACT

Objective: This study aimed to compare the manufacturing accuracy of different printing techniques - Stereolithography (SLA), Digital Light Processing (DLP), and PolyJet-using digital dental models.

Methods: The study included cast models of 30 patients aged between 12 and 20 years. The selected models were scanned using an intraoral scanner, and surface topography format files were obtained. The models were produced from 3D printers with SLA, DLP, and PolyJet technology and scanned with an intraoral scanner. The digital files of the reference and printed models were superimposed with reverse engineering software. Root mean squared (RMS) values and point registration differences were evaluated. Furthermore, digital mesiodistal measurements of the teeth were taken to determine the point registration deviation values. Descriptive statistics were used to evaluate the measurements. ANOVA was used to evaluate differences between normally distributed data. In addition, a box plot was used to show the variability in the measurements, and the Bland-Altman test was used to examine the agreement between the measurements.

Results: According to the digital superimposition data of DLP-SLA-PolyJet technologies, PolyJet had the smallest RMS (0.145±0.10 mm), followed by DLP and SLA (0.161±0.12 mm and 0.345±0.23 mm, respectively). In the mesiodistal dimensional measurement evaluations, there was no statistically significant difference ($p>0.05$) between the averages of the main reference and DLP, PolyJet, and SLA measurements for all teeth.

Conclusion: According to the results of this study, all three production technologies are clinically usable at the model production stage. However, SLA was found to be less accurate than DLP and PolyJet.

Keywords: 3-dimensional, 3-dimensional printing, digital dentistry, digital models

INTRODUCTION

In the field of dentistry, computer-aided design and computer-aided manufacturing (CAD/CAM) systems comprise three functional elements: data recording in the virtual environment, design preparation using software,

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and restoration production.[1] In recent years, 3D printing, also known as additive manufacturing, has emerged as a preferred technology. The process involves the deposition of successive layers of material to create a product, thereby representing a fundamental contrast to subtractive production technology.[2]

These systems are widely used in dental aligners, occlusal and surgical splints, indirect bonding trays, and surgical guides for mini screw placement in orthodontics.[3,4] The use of digital models is becoming increasingly prevalent due to the inherent disadvantages of plaster models, including rapid deterioration, difficulties in transfer, and the risk of cross-infection. The production of a physical dental model can be expedited by eliminating several steps in the traditional model-making process. Furthermore, the production of multiple copies without distortion is a more efficient process.[5]

Stereolithography (SLA) and Digital Light Processing (DLP) technologies are among the most widely used 3D printer technologies in dentistry due to their printing accuracy, speed, cost, and quality. In the SLA process, each layer is created by irradiating a photopolymerised ultraviolet (UV) laser along the object contour. After polymerization, the platform moves vertically according to the layer thickness, and the new layer is hardened by laser. This process is repeated to create a 3D product.[6] DLP technology is analogous to SLA technology in the polymerisation step, but the light source is distinct. DLP technology employs a high-resolution projector to simultaneously harden the entire layer. These technologies are frequently preferred in the field of orthodontics.[7] PolyJet technology employs a method of product creation that involves spraying hundreds of nozzle heads on a table surface with liquid resin. Then, curing with UV light is initiated immediately. Different materials can be sprayed with a large number of nozzles. A 16 µm layer thickness can be printed with high accuracy.[8] Another important difference between PolyJet and SLA and DLP printing techniques is that there is no post-production curing process. This technology is accepted as an accurate method but is more time-consuming and costly.[8]

In 3D printing, accuracy represents both accuracy and precision. The accuracy of a 3D-printed model may be affected by a number of factors throughout the manufacturing process, including model scanning, the design of the surface topography (STL) file, the production stage of the product, and post-production operations. The surface quality and accuracy of 3D printers are constrained by the thickness of the layers added successively along the z-axis, which gives rise to greater inaccuracies.[9]

Several studies have compared the accuracy of 3D printing technologies for dental use.[10-13] Baek et al.[10] compared SLA, DLP, and PolyJet technologies for the production of mandibular first molar teeth using different printer technologies. In addition, Camardella et al.[11] Manufactured dental models using different designs and compared SLA and Polyjet technologies. Salmi et al.[12] Compared the production efficiencies of SLS, 3DP, and PolyJet using 3D medical skulls. Emir and Ayyıldız[13] evaluated the accuracy of 3D printers by producing dental models designed using three different technologies. In light of the aforementioned data, this study aimed to compare the manufacturing accuracy of SLA, DLP, and PolyJet printing technologies using dental models obtained from different patients.

The null hypothesis of this study is that there is no difference in the production accuracy among SLA, DLP, and PolyJet technologies.

METHODS

The process is shown in the flowchart (Figure 1). The International Organization for Standardization (ISO) 5725-116 was used for the accuracy definition.[14] Ethical permission was obtained from University of Health Sciences Turkey, Gülhane Scientific Research Ethics Committee (approval no.: 2020-527: date: 29.112.2020) prior to study initiation.

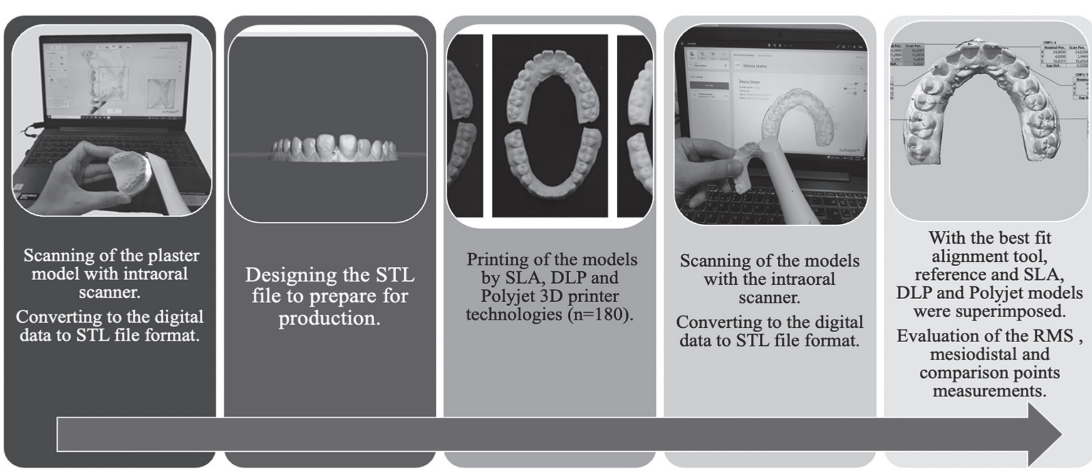

Figure 1. Flowchart of the study
SLA, stereolithography; DLP, Digital Light Processing; STL, surface topography; RMS, root mean squared

Sample Size Determination

Based on the power analysis obtained using G*Power 3.1.9.7 software, the effect size of the reference Emir and Ayyıldız[13] study was calculated as 0.425. At an effect level of 0.25 (effect size: 0.25), at least 159 samples are required for a 95% test power. Considering any potential error in the model production, a total of 180 patient models (30 maxillary and 30 mandibular models per group) from individuals aged 12-20 years between the ages of 12 and 20 were included in the study.

Inclusion Criteria

This retrospective study included the dental models of individuals with the following characteristics: no permanent tooth deficiencies, complete permanent dentition, no extensive restorations on teeth, to significant material loss due to caries or parafunctional habits, and crowding or a diastema between 0-4 mm.

Exclusion Criteria

The study excluded individuals in the deciduous and mixed dentition periods, those with excessive material loss or extensive restorations on teeth, individuals with crowding or diastema greater than 4 mm, models unsuitable for digital scanning from plaster models, and models for which proper scan data could not be obtained.

Study Design and Printing Process

Selected plaster models were scanned using the 3Shape Trios (Trios POD, 3Shape, Copenhagen, Denmark) intraoral scanner. STL files were designed in Autodesk Meshmixer software (version 3.5.474), and the digital files for 60 production-ready dental models were transferred to Formlabs PreForm 3.4.6 software from Formlabs™ Form 2™ (MIT Media Lab, Somerville, MA, USA). The STL files were positioned in parallel with the printer table, and two pairs of lower-upper models were present in each production run. The models were fabricated with a layer thickness of 0.100 mm using grey V4 resin (Formlabs™ Form 2™, MIT Media Lab, Somerville, MA, USA). The support structures of the fabricated models were separated by applying a manual force. The models were washed in a Form Wash tank for 20 min. They were then cured in a Form Cure tank at 60°C for 60 min.

The same digital files were transferred to an Asiga ® (Asiga, Sydney, Australia) 3D printer connected to Asiga Composer software using DLP technology. All models were placed horizontally on the machine with the occlusal plane parallel to the build platform and a pair of lower-upper models in each production. The printing layer thickness of the produced models was 50 µm. The raw material used was Dentamodel resin (Asiga, Sydney, Australia). The printed models were separated from the printing table. Support structures were then manually removed from the model. The uncured resin was cleaned in an ultrasonic bath with 99.8% isopropyl alcohol for 10 minutes. The models were polymerised for 10 minutes in the Asiga Flash ultraviolet polymerisation unit (Asiga, Sydney, Australia).

Additionally, the same digital files were transferred to GrabCAD Print 1.43 software connected to a (Stratasys J750, Eden Prairie, MN) 3D printer with PolyJet technology. STL files were placed parallel to the printer table, and multiple models were printed at once due to the large table. Verowhite resin (Stratasys, Eden Prairie, MN), which is matte and white, was used in the production. Waste material was removed from the model using a Powerblast 1.5-2 bar high-pressure cleaner. The printing process was shown in the flow chart (Figure 2).

Root Mean Square, Mesiodistal, and Comparison Point Measurements

The printed models were again scanned with a 3Shape Trios (Trios POD, 3Shape, Copenhagen, Denmark) intraoral scanner and digital files were created. When the model scans were completed, the reference and print model files were imported into Rapidform XOV/Verifier software (Rapidform, Inus Technology, S. Korea) for digital superimposition. The reference files were considered the control files, and the test files were considered the experimental files. Superimposition was performed using the best-fitting method, and the distances between the surface data and all points were converted to root mean square (RMS) values (Figure 3). RMS is a general method

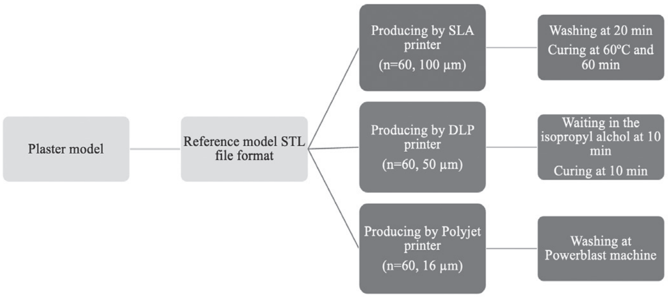

Figure 2. The process of 3D printing
SLA, stereolithography; DLP, Digital Light Processing; STL, surface topography

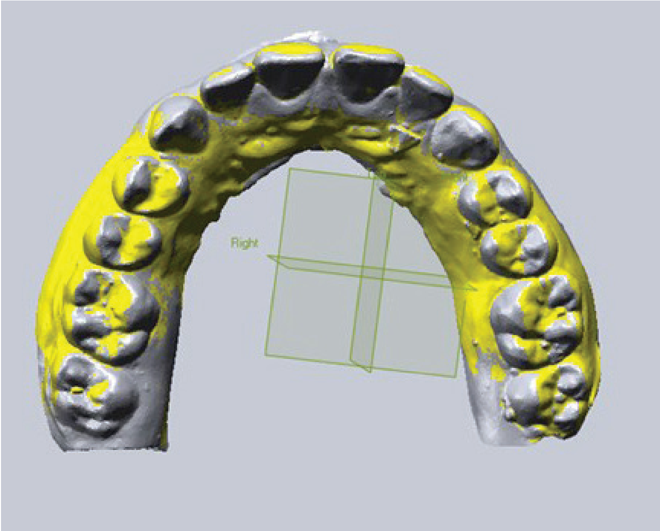

Figure 3. Best-fit alignment of reference and test models using reverse engineering software

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to evaluate the mean error value by directly comparing two data groups with the same coordinate system. A higher RMS value indicates a large error between the reference and measurement data.

$$RMS = \frac{1}{\sqrt{n}}\sqrt{\sum_{i=1}^{n}\left(x_{1,i} - x_{2,i}\right)^2} \quad (1)$$

X1 in Equation (1) is the data point of reference i, X2 is the data point of experimental group i, and N is the number of all measurement points.

After superimposition, color surface maps were obtained for 3D comparison. The maximum critical value was ±0.25 mm, and the maximum nominal value for color spectra was ±0.025 mm. 0.25 mm is the threshold value of clinical admission for creating orthodontic movement. The maximum tooth movement per aligner ranged from 0.25 to 0.30 mm.[15] In the case of clear aligner therapy, dental models have an accuracy error below this value.[16]

After 3D comparison, the deviation values of the deepest point of the central fossa of the first molars, the cusps of the canines, and the midpoints of the incisal edges of the central incisors were used in the models for measurements (Figure 4). MeshLab software (v2022.02) was used to perform the dimensional measurements (Figure 5). The maximum distance measurements of the first molar, canine, and central incisors in the models from the occlusal surface between the mesial and distal contact points were made using the digital measurement tab in the software.

Statistical Analysis

The MedCalc version 20.113 (MedCalc Software Ltd, Acacialaan 22, Belgium) computer software was used for statistical analysis. In this study, ANOVA was used to evaluate whether there was a difference between the means of the main reference, DLP, PolyJet, and SLA measurements. In addition, two independent sample t-tests were used for pairwise comparisons between measurement techniques and group means. The BlandAltman and intraclass correlation coefficient (ICC) methods were used to evaluate the compatibility of the measurements obtained with the DLP, PolyJet, and SLA 3D printers with the main reference measurements. The paired t-test was used to determine whether there were statistically significant differences between the first and second measurements. The level of statistical significance was set as $p<0.05$. A box plot was used to visualize the visual distribution of variability in the RMS values.

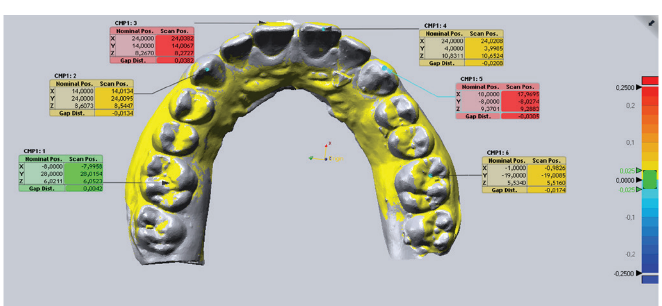

Figure 4. Comparison points of the printing models. **Point 1:** Deepest point of the central fossa of the right first molar, **Point 2:** Tubercle apex of the right canine tooth, **Point 3:** Midpoint of the incisal edge of the right central incisor, **Point 4:** Midpoint of the incisal edge of the left central incisor, **Point 5:** Tubercle apex of the left canine tooth, **Point 6:** Deepest point of the central fossa of the left first molar

RESULTS

Dimensional Measurement Results

Measurements were performed by a single researcher. The measurements of the models of five patients randomly selected from the groups were repeated two weeks apart by the same researcher using the same methodology and software. The ICC is a value between 0 and 1, where values below 0.5 indicate poor reliability, values between 0.5 and 0.75 indicate moderate reliability, values between 0.75 and 0.9 indicate good reliability, and values above 0.9 indicate excellent reliability.[17] According to the ICC statistics of the present study, there was a perfect match between these 4 measurements for R1 and L1 teeth in the 95% confidence interval (0.964-0.961), and there was a good match between the measurements for R6, R3, L3 and L6 (0.849-0.887) teeth (Table 1).

According to the ANOVA test results for six different teeth, no statistically significant difference was observed between the means of the measurements made for six different teeth of the product obtained from the main reference and three different printers ($p>0.05$). In other words, there was no statistically significant difference between the mean of the main reference measurement values for all teeth and the mean of the

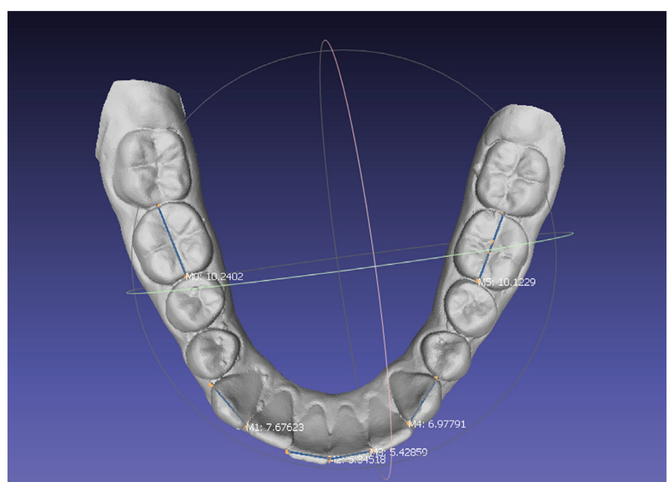

Figure 5. Mesodistal dimensional measurements. **R6:** Measurement of the distance between the mesial and distal contact points of the occlusal surface of the right 1st molar, **R3:** Distance between the mesial and distal contact points of the right canine tooth, **R1:** Distance between the mesial and distal contact points of the incisal edge of the right central tooth, **L1:** Distance between the mesial and distal contact points of the incisal edge of the left central tooth, **L3:** Distance between the mesial and distal contact points of the left canine tooth, **L6:** Distance between the mesial and distal contact points of the occlusal surface of the left 1st molar

measurements obtained using the DLP, PolyJet, and SLA printers (p>0.05). In comparing DLP, PolyJet, and SLA measurements for each tooth, no statistically significant difference was observed between the means of the measurements of these three printers (p>0.05) (Table 2).

For six teeth (R6, R3, R1, L1, L3, L6), a double independent sample-t test was used to determine whether there was a statistically significant difference between the means of the dimensional measurement values made in the software from the reference model and the models obtained from 3 printers. There was no statistically significant difference between the means of the groups in all binary combinations (Reference-SLA, Reference-DLP, Reference-PolyJet, SLA-DLP, SLA-PolyJet, DLP-PolyJet) that may occur between the means of the four measurements (p>0.05). Bland-Altman statistics were performed in the 95% confidence interval to examine the agreement between the main reference measurements and the measurements of three different printer models (SLA, DLP, and PolyJet). According to Bland-Altman statistics, the measurements obtained from three printers in the comparisons of six teeth were compatible with the main reference measurements.

Table 1. ICC statistical results for dimensional tooth measurements

Tooth	ICC value	(95% CI)
R6	0.887	(0.839,0.925)
R3	0.856	(0.796,0.903)
R1	0.964	(0.947,0.976)
L1	0.961	(0.942,0.974)
L3	0.849	(0.788,0.899)
L6	0.884	(0.835,0.923)

R6: Measurement of the distance between the mesial and distal contact points of the occlusal surface of the right 1st molar, R3: Distance between the mesial and distal contact points of the right canine tooth, R1: Distance between the mesial and distal contact points of the incisal edge of the right central tooth, L1: Distance between the mesial and distal contact points of the incisal edge of the left central tooth, L3: Distance between the mesial and distal contact points of the left canine tooth, L6: Distance between the mesial and distal contact points of the occlusal surface of the left 1st molar.
*There is a perfect agreement between these 4 measurements (0.964-0.961) for the R1 and L1 teeth at the 95% confidence interval, and a good agreement between the measurements for the R6, R3, L3 and L6 (0.849-0.887) teeth
ICC, interclass correlation coefficient; CI, confidence interval

RMS Value Results

When RMS values were examined according to DLP-SLA-PolyJet digital surface overlap data, the PolyJet printer had the lowest RMS value (0.145±0.10 mm). The DLP printer followed, with an RMS value of 0.161±0.12 mm. The SLA printer had the largest RMS value (0.345±0.23 mm). According to the ANOVA results, there was a statistically significant difference between the RMS means between at least two groups (p<0.001). According to the results of the Tukey Honestly Significant Difference (HSD) test, there was a statistically significant difference between the "SLA-DLP" and "SLA-PolyJet" RMS means (p<0.001). The mean RMS value of the SLA group (0.345±0.23 mm) was greater than that of the DLP group (0.161±0.12 mm), and this difference was statistically significant. Similarly, the mean RMS value of the SLA group was 0.345±0.23 mm, which was larger than the mean RMS value of the PolyJet group (0.145±0.10 mm) (Table 3). On the other hand, no statistically significant difference was observed between the means of the "DLP-PolyJet" groups (p=0.999>0.05). A box plot was used to visualize the visual distribution of variability in the RMS values (Figure 6).

3D Comparison Points with Superimposition Results

According to the results of the ANOVA test conducted to determine whether there was a difference between each group's means of DLP, PolyJet, and SLA measurements for 6 different teeth, a statistically significant difference was found inthe point comparison means of at least two groups for 6 different teeth (p<0.001). The Tukey HSD test for R6 and L6 teeth revealed statistically significant differences between the point measurement means of "SLA-DLP" and "SLA-PolyJet" (p<0.001). The SLA mean point comparison was higher than the DLP point comparison mean (0.169±0.234, 0.152±0.192) (0.52±0.675, 0.429±0.577), and these differences were statistically significant. Similarly, the mean SLA point comparison (0.52±0.675, 0.429±0.577) is greater than the PolyJet point comparison mean (0.121±0.147, 0.194±0.244), and these differences were also statistically significant. On the other hand, there was no statistically significant difference between the "DLP-PolyJet" point comparison means.

Table 2. ANOVA test results for reference, DLP, PolyJet, and SLA mesiodistal dimensional tooth measurements

Tooth	Reference	DLP	PolyJet	SLA	p-value
R6	10.506±0.641	10.463±0.676	10.582±0.733	10.497±0.706	0.813
R3	7.421±0.671	7.487±0.686	7.453±0.742	7.475±0.696	0.958
R1	7.138±1.704	7.154±1.724	7.104±1.707	7.117±1.716	0.999
L1	7.035±1.723	7.079±1.689	6.995±1.810	7.130±1.856	0.978
L3	7.322±0.722	7.396±0.704	7.323±0.689	7.479±0.637	0.552
L6	10.426±0.660	10.387±0.678	10.443±0.740	10.430±0.700	0.975

R6: Measurement of the distance between the mesial and distal contact points of the occlusal surface of the right 1st molar, R3: Distance between the mesial and distal contact points of the right canine tooth, R1: Distance between the mesial and distal contact points of the incisal edge of the right central tooth, L1: Distance between the mesial and distal contact points of the incisal edge of the left central tooth, L3: Distance between the mesial and distal contact points of the left canine tooth, L6: Distance between the mesial and distal contact points of the occlusal surface of the left 1st molar
*The statistical significance level was p<0.05
DLP, Digital Light Processing; SLA, stereolithography

According to the results of the Tukey HSD test for R3 and L3 teeth, there were statistically significant differences between the point-comparison means of "SLA-DLP" and "SLA-PolyJet" (p<0.001). The mean SLA point comparison was higher than the DLP point comparison mean (0.188±0.248, 0.188±0.231) and the PolyJet point comparison mean (0.158±0.191, 0.187±0.227), respectively (0.691±0.248, 0.688±0.231), and this size was statistically significant. On the other hand, no statistically significant difference was observed between the "DLP-PolyJet" point comparison means.

According to the results of the Tukey HSD test for R1 and L1 teeth, statistically significant differences were observed between the point-comparison means of "SLA-DLP" and "SLA-PolyJet" (p<0.001). The mean SLA point comparison was higher than the DLP point comparison mean (0.217±0.270, 0.212±0.263) and the PolyJet point comparison mean (0.199±0.208, 0.198±0.233), respectively (0.638±0.553, 0.639±0.537), and this size was statistically significant. Conversely, no statistically significant difference was found between the "DLP-PolyJet" point comparison means (Table 3).

DISCUSSION

In the present study, it was compared whether there is a difference between the manufacturing accuracy of dental models produced using SLA, DLP, and PolyJet 3D printer technologies. The best-fit algorithm method was employed in the reverse engineering software to evaluate the accuracy of the printed models in comparison with the reference models. The best-fit algorithm method was selected in instances where the mean deviation between the reference model and the measurement data was minimal. Previous studies have investigated dimensional accuracy and presented their findings in absolute measurements in millimeters or dimensional ratios in percentage.[18-20] However, it should be noted that deviations can occur, both in a positive and negative direction, from the reference model. The RMS value defines the deviation from this mean value as the mean of the squares of all data. Therefore, this study focused on the preferred RMS value in recent studies.[10-13]

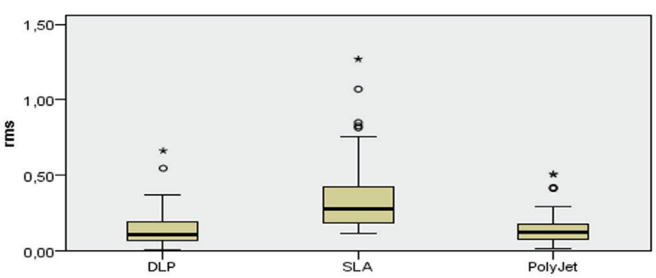

Figure 6. Comparison of total RMS values of the DLP, SLA, and PolyJet printing technologies
SLA, stereolithography; DLP, Digital Light Processing

According to the results of our study, DLP-SLA-PolyJet technologies showed that Polyjet technology had the lowest RMS mean according to RMS data (0.145±0.10 mm), followed by DLP and SLA technologies (0.161±0.12 mm and 0.345±0.23 mm, respectively). Kim et al.[9] compared the accuracy of different printing technologies using dental models in a recent study and stated that the PolyJet technique showed the highest accuracy with an RMS value of 0.78 mm, followed by SLA, DLP, and fused filament fabrication technologies (0.107, 0.143 and 0.188, respectively). The layer thickness was produced for each printer technology at the most accurate settings. The authors reported that the thinnest layer thickness used in PolyJet technology positively affected accuracy.[21-23] In this study, PolyJet showed the thinnest layer thickness and gave the most accurate results. Post-production curing in SLA and DLP techniques produced using the photopolymerization method may affect the dimensional accuracy of the products.

Yoo et al.[24] compared the accuracy of producing a 3-unit fixed prosthesis model using SLA, DLP, and MJP printing technologies similar to our study. The authors concluded that the MJP models revealed greater accuracy than those produced using DLP and SLA technologies. No significant differences were observed in terms of precision, and the three technologies were considered suitable for dental model production. These findings are in accordance with the results of our study.

Table 3. Descriptive statistics of the comparison points and RMS values

	DLP				SLA				PolyJet				
Tooth	Mean±SD	Min.	Max.	Median	Mean±SD	Min.	Max.	Median	Mean±SD	Min.	Max.	Median	p-value
R6	0.169±0.234[a]	0	1.48	0.069	0.520±0.675[b]	0	3.63	0.271	0.121±0.147[a]	0	0.6	0.066	**<0.001***
R3	0.188±0.248[a]	0	0.98	0.081	0.691±0.561[b]	0.06	2.38	0.523	0.158±0.191[a]	0	0.82	0.097	**<0.001***
R1	0.217±0.270[a]	0	1.14	0.090	0.638±0.553[b]	0	2.32	0.549	0.199±0.208[a]	0	0.89	0.141	**<0.001***
L1	0.212±0.263[a]	0	1.16	0.100	0.639±0.537[b]	0.01	2.44	0.479	0.198±0.233[a]	0	0.92	0.095	**<0.001***
L3	0.188±0.231[a]	0	0.86	0.075	0.688±0.619[b]	0.01	2.43	0.498	0.187±0.227[a]	0	0.99	0.103	**<0.001***
L6	0.152±0.192[a]	0	1.16	0.100	0.429±0.577[b]	0	3.36	0.25	0.194±0.244[a]	0	0.93	0.088	**<0.001***
RMS	0.161±0124[a]	0	0.66	0.107	0.345±0.237[b]	0.11	1.27	0.273	0.145±0.103[a]	0.01	0.51	0.120	**<0.001***

R6: Deepest point of the central fossa of the right first molar, R3: Tubercle apex of the right canine tooth, R1: Midpoint of the incisal edge of the right central incisor, L1: Midpoint of the incisal edge of the left central incisor, L3: Tubercle apex of the left canine tooth, L6: Deepest point of the central fossa of the left first molar
*The statistical significance level was p<0.05; Groups with different letters are significantly different from each other
RMS, root mean square; SD, standard deviation; Min., minimum; Max., maximum; DLP, Digital Light Processing; SLA, stereolithography

Camardella et al.[11] conducted a comparative analysis of the accuracy of dental models produced with different model base designs using SLA and PolyJet technologies. The results showed that the models printed with the PolyJet printer were more accurate in all designs, independent of the design of the model base. Additionally, the authors also attributed the higher RMS values of SLA technology to the higher post-polymerization shrinkage in SLA. In this study, SLA produced the least accuracy compared to other technologies, supporting the study of Camardella et al.[11]

Zhang et al.[21] investigated the impact of model accuracy on different printing technologies. A comparison was conducted between models produced using SLA and DLP technologies with a layer thickness of 100 µm, which revealed that DLP technology demonstrated superior performance in terms of speed and accuracy compared to SLA.

Salmi et al.[12] conducted a study comparing 3D medical skull models produced using selective laser sintering (SLS), 3DP, and PolyJet technologies and concluded that the size error of the PolyJet model was 0.18±0.12 µm, the error of the SLS model was 0.79±0.26 µm, and that of the 3DP model, it was 0.67±0.43 µm. The models produced with a PolyJet printer had the lowest size error and showed higher accuracy than those produced with 3DP and SLS. The authors stated that differences in accuracy might be due to the imaging, segmentation, and production stages. The fact that PolyJet, which showed the highest accuracy in this study, gives more accurate results than other technologies can be associated with the fact that the curing process is in production.

In their study on the effect of the additive manufacturing process and storage conditions on the dimensional accuracy and stability of 3D-printed dental models, Yousef et al.[25] found that the RMS value of models produced from a DLP 3D printer had a significantly higher average than those produced with a MultiJet 3D printer. These findings support our conclusion that Multijet technology provides more accurate results.

Baek et al.[10] reported that SLA models showed higher accuracy than DLP and PolyJet models in studies that printed mandibular first molars using SLA, DLP, and PolyJet technologies ($p<0.05$). This difference in the results was due to the following reasons: curing of the model during the production stages, the conditions after polymerization, the dimensional smallness of the produced object, and the thickness of the thin layer. The degree of post-production resin shrinkage is contingent upon the dimensional levelling and the modelling material employed, and may potentially impact the accuracy of the manufactured models. In their study, Emir and Ayyıldız[13] reported mean RMS values of 51 µm for SLA, 46 µm for DLP, and 58 µm for PolyJet. Despite the layer thickness (16 µm) of the PolyJet printer being less than that of the DLP printer (50 µm), the DLP models demonstrated superior accuracy compared to the PolyJet models. It was concluded that high-resolution printers could produce models with minute details, but that the accuracy of the printed materials could be affected. The raw material scale used in PolyJet printing technology is diverse and consists of various colors, transparencies, and hardness values. Emir and Ayyıldız[13] employed transparent and bright resin in PolyJet printing technology; since this product is transparent, a thin-layer scanning spray was applied to the PolyJet models to scan the surface. The deviations observed in the PolyJet models may be due to the thickness of the screening spray. In the present study, matte and white resin were selected for two reasons: firstly, high-resolution models could be produced, and secondly, no additional processing was required for scanning due to the matte surface. Therefore, PolyJet manufactures detailed products with high accuracy.

Study Limitations

According to the literature, 0.20-0.50 mm is considered as an acceptable range for clinical accuracy in dental models.[26,27] This study evaluated the RMS values of the SLA, DLP, and PolyJet technologies, concludng that three are suitable for clinical use. In addition, clinicians can choose the technology based on the aim, quantity, and size of the model, working time, and cost. Future, more comprehensive studies could use improved and updated versions of the same devices. Further optimization of these technologies may focus on the following aspects: clinical efficiency with less raw material, low cost, high performance, and production speed.

Conclusion

Root mean square values indicated that the mean value in the SLA group was noticeably higher compared to the DLP and PolyJet groups, while the DLP and PolyJet groups exhibited comparable mean values.

• The SLA, DLP, and PolyJet production technologies used in this study are clinically available for model production in terms of orthodontics. However, DLP and PolyJet printers produce more accurately than SLA technology.

Ethics

Ethics Committee Approval: Ethical permission was obtained from University of Health Sciences, Gülhane Scientific Research Ethics Committee (approval no. 2020-527: date: 29.112.2020) before the study initiation.

Informed Consent: This retrospective study was conducted using plaster models obtained from patients at the University of Health Sciences Turkey, Gülhane Faculty of Dentistry, Department of Orthodontics.

Footnotes

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

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

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TURKISH JOURNAL OF ORTHODONTICS

Original Article

Comparison of the Effects of Fixed and Removable Functional Orthodontic Treatment on the Mandibular Trabecular Bone in Fractal Analysis

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Main Points

- The correction of skeletal Class II malocclusion has been successfully achieved with both removable and fixed functional appliances.
- The effects of Twin Block and Herbst appliances are not limited to dentoalveolar changes; they also contribute to the remodelling of the mandibular trabecular structure.
- The fractal dimension analysis analysis revealed that notable alterations in the trabecular configuration of the condylar region of the mandible occurred following functional treatment.

ABSTRACT

Objective: The aim of this retrospective study was to compare the effects of the Twin block and Herbst appliances on the mandibular trabecular pattern using fractal dimension analysis (FDA) of panoramic radiographs (PRs).

Methods: The PRs of 50 subjects with skeletal Class II malocclusion who underwent the Twin block (T-group, average age: 11.63±0.87; 25 girls, 25 boys), 50 subjects with skeletal Class II malocclusion who underwent the Herbst (H-group, average age: 11.72±0.91; 27 girls, 23 boys), and 50 controls (C-group average age: 11.67±0.83; 24 girls, 26 boys) were selected. The condyle, corpus, and angulus regions of all groups in the mandible were examined using FDA.

Results: The condylar region ($p \leq 0.001$) and corpus mandible in the treatment groups (T-group: right, $p \leq 0.05$, left, $p \leq 0.01$; H-group: $p \leq 0.05$), as well as the left and right condylar region ($p \leq 0.001$) and left corpus mandible ($p \leq 0.05$) in the C-group, all indicated substantial increases in FDA between T0 and T1. Inter-group comparisons indicated that the T-group had greater variances in the condyle ($p \leq 0.001$) compared to the H group.

Conclusion: As the findings revealed both Twin block and Herbst appliances not only contributed to the dentoalveolar structure but also provided remodeling of the mandibular trabecular structure. Consequently, the null hypothesis was rejected.

Keywords: Functional, Cl II, fractal, dental radiography

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INTRODUCTION

Functional therapy aims to induce mandibular elongation by stimulating cellular condylar growth and to correct Class II malocclusion associated with mandibular retrognathia by altering the position of the mandible in both the sagittal and vertical planes.[1,2] While some authors have reported increased mandibular length[3] and improvements in condylar cellular activity,[2,4] others have argued that this treatment method is ineffective for mandibular growth.[5,6] In addition, it has been reported that more dentoalveolar changes are observed in the treatment of Class II malocclusion with functional appliances.[7]

Although several studies have examined the Twin block and Herbst effects with different imaging methods, especially cephalometric analysis, they yielded uncertain results, as predicted, because they do not show structural alterations of the mandibular trabecular.[4,6,8,9] In some of the studies evaluating the effects of Twin block and Herbst appliances on the mandible, some researchers pointed out the superiority of Twin block in terms of skeletal efficiency,[10,11] conversely, Song et al.[12] reported that the Herbst appliance exerted a more prominent effect on the mandible compared with the Twin block and activator groups. On the other hand, some researchers reported no significant dentoalveolar or skeletal differences between the two treatment groups.[13]

Fractal dimension analysis (FDA), which measures the trabecular bone pattern, bone marrow, and trabecular bone interface, is an effective mathematical method that provides reliable results for the analysis of bone structure and trabecular pattern.[14] This study was designed considering that despite studies investigating the effects of functional therapy on the mandibular trabecular structure with the use of FDA-based PR therapy, it supports the consensus and contributes to the literature by comparing the effects of different functional appliances on the mandibular structure. Therefore, the aim of this study was to compare changes with two different functional orthodontic appliance treatments on the mandibular trabeculae via the FDA of panoramic radiographs (PRs) and to evaluate the effect of sex differences. Untreated control samples were also collected for comparison with the treatment groups.

The null hypothesis was that no difference would be found among the effects of the Twin block, Herbst, and control groups on the mandibular trabecular structures.

METHODS

Study samples were obtained from the archives of Karadeniz Technical University and Yeditepe University, Faculty of Dentistry. The study was approved by the Scientific Research Ethics Committee of Karadeniz Technical University, Faculty of Dentistry (approval number: 2022-7, date: 29.07.2022).

Sample size was determined via power analysis (G*Power, Ver. 3.1.9.2, Franz Faul; Universitat Kiel, Germany), concluding that 46 subjects per group was sufficient. Calculation of the sample size based on the study of Akan and Ünlü Kurşun[15] displayed that 46 patients would be sufficient for each group with a power >80%, an alpha error of 0.05, a beta error of 0.20, and an effect size of 0.55. To safely maintain the power of the study, 50 subjects were added to each group. Therefore, the radiographs of a total of 150 subjects were chosen in accordance with inclusion criteria, consisting of 50 Class II individuals who underwent Twin block treatment (T-group, mean age: 11.63±0.87; 25 females, 25 males), 50 individuals who received the Herbst appliance (H-group, mean age: 11.72±0.91; 27 females, 23 males), and 50 control subjects (C-group, mean age: 11.67±0.83; 24 females, 26 males).

Selection of patients for the twin block and Herbst groups was performed by assessing pre- (T0) and post-treatment (T1) radiographs. Those meeting the following inclusion criteria were chosen: pre-treatment Class II malocclusion (SNB ≤80Åã), the use of Twin block and Herbst appliances alone to enhance mandibular improvement, the initiation of treatment in the MP3 cap period according to the hand-wrist recording, and good compliance with functional treatment. To determine the skeletal maturation stages, pre-treatment hand-wrist radiographs of the patients were obtained by an orthodontist according to the method described by Björk.[16] The control group comprised 50 growing subjects who were matched with the treatment group for sex and maturation stage. All control subjects had Angle Class I occlusion with normal overjet and overbite and all teeth present. Moreover, this group consisted of patients who applied for routine dental treatment, had not previously undergone orthodontic treatment, and did not have any systemic diseases or craniofacial deformities.

Cephalometric radiographs and digital PRs were obtained for patients in the treatment groups at T0 and T1. In the H group, the T1 period occurs immediately after removal of the Herbst appliance. The mean treatment duration in the T group was 1.00±0.47 years. In the H group, the mean treatment duration was 0.97±0.46 years.

Twin block appliances consisting of upper and lower acrylic blocks interlocked at approximately 70° to the occlusal plane, which are routinely used in clinics, were applied to the patients.[17] The functional bite for the Twin block appliance was performed with the patient biting forward in the maximum protrusion that was comfortable. This approach allowed for the increased overjet to be corrected with a single advancement. The Herbst appliance was cast cobalt chromium, as described by Pancherz and Ruf.[18] In this design, the Herbst framework was extended posteriorly from the canines to include all teeth. Whenever possible, the occlusion was advanced to an edge-to-edge relationship.

For comparison of treatment outcomes with growth-related alterations in the mandibular trabeculae, the C group included individuals who had two digital PRs obtained for standard dental examination at two different periods. The mean interval between these radiographs was 0.99±0.45 years. Cephalometric radiographs of control subjects who underwent routine dental procedures, not orthodontic treatment, were not included due to ethical concerns.

All patients underwent lateral cephalometric radiographs using Kodak 9000 (Extraoral Imaging System, Carestream Health, Inc., USA), and measurements were performed using Nemoceph Version 6.0 software (NemoStudio 2020, Software Nemotec S.L, Madrid, Spain). Cephalometric evaluation included skeletal and dentoalveolar measurements (Figure 1).

Fractal Dimension of PRs

Radiographic images for all patients were acquired using the Kodak 9000 Extraoral Imaging System (Carestream Health, Inc., USA) with an exposure time of 14.3 s (70 kVp, 10 mA). and the Sirona Orthophos XG3 device (Sirona, New York, USA) with an exposure time of 14.1 s (64 kVp, 8 mA). To ensure consistency and standardization of the images acquired from the two panoramic X-ray devices, the matrix dimensions and image sizes were meticulously assessed and validated.

PRs were measured using ImageJ software version 1.53 (National Institutes of Health, Bethesda, MD). The FDA was performed using software developed by White and Rudolph[19], employing the box-counting method. Regions of interest (ROIs) were in 50×50-pixel size range and were chosen from three different areas of the mandible (both right and left sides), as follows:

Region 1: The condylar process, including the subcortical condylar region.

Region 2: The mandibular angle, encompassing the mid-trabecular zone between the mandibular angle and the inferior cortical border of the mandibular canal.

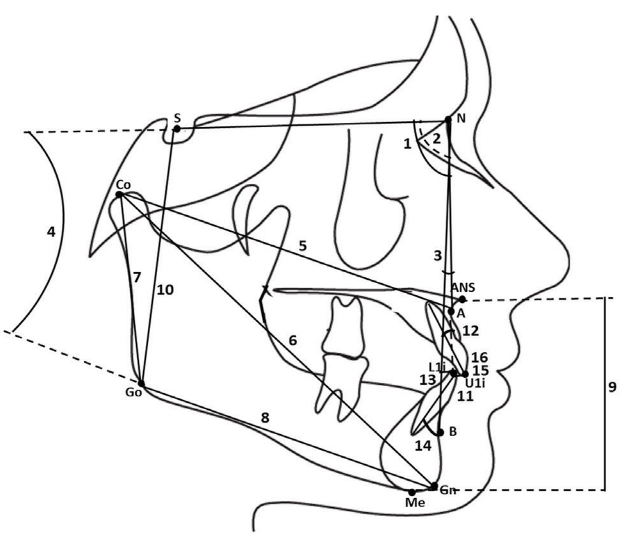

Figure 1. Cephalometric measurements. Skeletal measurements: (1) SNA; (2) SNB; (3) ANB; (4) GoGn/SN; (5) Co-A; (6) Co-Gn; (7) Co-Go; (8) Go-Gn; (9) ANS-Me; (10) S-Go. Dentoalveolar measurements: (11) 1-NA (°); (12) 1-NA (mm); (13) 1-NB (°); (14) 1-NB (mm); (15) overjet; (16) overbite

Region 3: The mandibular body, located above the mandibular canal between the first and second molars (Figure 2).

The PRs of the patients in the groups were converted into Tagged Image File Format (TIFF) images. Selected ROIs were duplicated, and a Gaussian filter with a sigma value of 35 was applied to the duplicated images. These processed images were subsequently subtracted from the originals. To differentiate between bone marrow cavities and trabeculae, a pixel gray value of 128 was applied to all pixel locations, with a threshold also set at 128-gray. The fractal dimension (FD) values were calculated after the image preprocessing steps were performed, which included binary conversion, erosion, dilation, inversion, and skeletonization (Figure 3).

Statistical Analysis

Data analysis was performed using the SPSS 22 package program. Normal distributed paired groups were compared using the t-test, whereas ANOVA was used for comparisons of three or more groups. The Mann-Whitney U test was used for comparisons between paired groups without normal distribution, and the Kruskal-Wallis-H test was used for comparisons between three or more groups. The paired t-test was used for paired groups with normal distribution. The Wilcoxon signed test was used for paired groups without normal distribution. Descriptive statistics (mean, median, standard deviation, minimum-maximum) were used to evaluate the study data. The level of significance was accepted as 0.05, where a value of $p \le 0.05$ indicated a significant difference and a value of $p > 0.05$ indicated no significant difference.

RESULTS

Cephalometric measurements of 25 randomly selected patients were repeated by the same orthodontist who was blinded to the groups 1 month after the initial measurements to determine intra-observer reliability. Fractal measurements of 75 randomly selected patients were also repeated by the same maxillofacial radiologist blinded to the groups approximately 1 month after the initial measurements to permit calculations of the intraclass correlation coefficient, with a confidence interval of 95%. The intraexaminer error was assessed at $p \le 0.05$ and was considered statistically negligible. With a mean intraclass correlation value of 0.826 (confidence interval =0.749 -0.898), the interclass correlation coefficient measurement demonstrated high reliability.

Cephalometric Measurements

Table 1 presents a comparison of pretreatment cephalometric measurements between the Twin block and Herbst groups. The comparison of differences in cephalometric measurement changes between treatment groups were given in Tables 2 and 3. It was revealed that the difference values of SNA, SNB, Co-Gn, Co-Go, Go-Gn, ANS-Me, and S-Go (p=0.001) in the T group were significantly higher than those in the H group, whereas the difference values of ANB (p=0.001), 1-NB (mm) ($p \le 0.05$), 1-NB

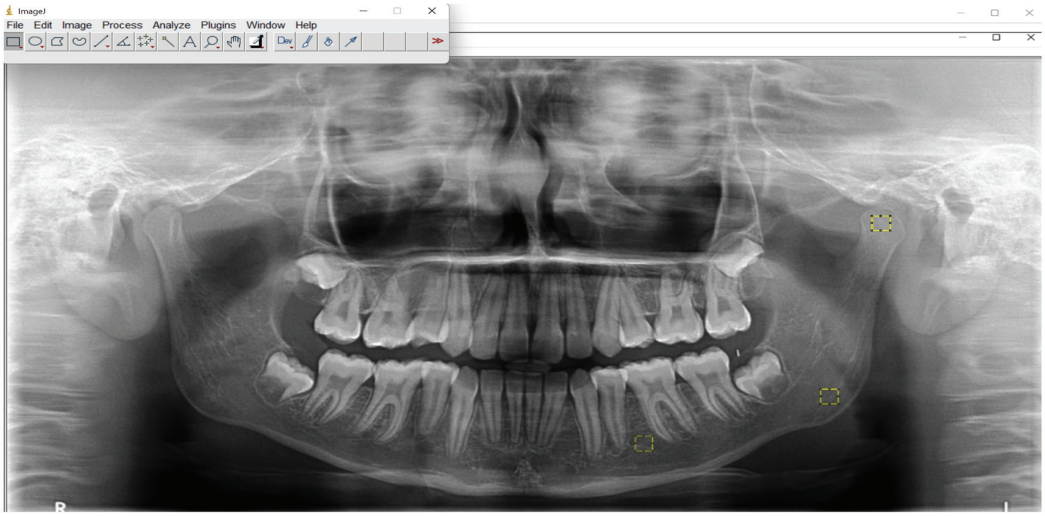

Figure 2. Locations of the ROIs from three different areas of the mandible (condyler, angulus mandible, corpus mandible)
ROI, regions of interest

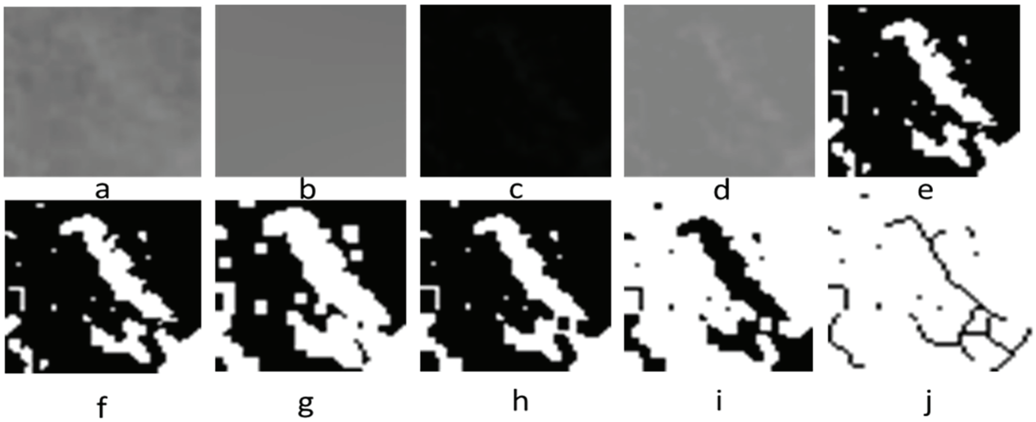

Figure 3. Stages of fractal dimension analysis: a) cropped region of interest, b) blurred image of duplicated region of interest, c) the blurred image was subtracted from the original image, d) addition of a gray value of 128 to each pixel location, e) threshold, f) binary, g) erode, h) dilate, i) invert, j) skeletonize

(°) (p≤0.01), and overjet (p=0.001) were lower. Although it was not statistically significant, the GoGn/SN difference values were higher in the T group than in the H group (Table 4, p>0.05).

Fractal Dimension Analysis

The initial comparison (T0) of chronological age and FDA measurements between all groups were given in Table 5. There was no difference among the groups regarding initial patient age (p>0.05). FDA showed that at the start of the treatment, the control group had higher FDA values in both the left and right mandibular corpus (p≤0.01) and condylar region (right, p≤0.001; left, p≤0.01) compared with the treatment groups. The FDA values of the H group were lower in the right angulus mandible than those of the T and C groups (p≤0.05) (Table 5).

A comparison of chronological ages and FDA changes between the T0 and T1 periods within and among the groups are presented in Table 6. Right and left condyle FDA values (p≤0.001) and mandibular corpus (right, p≤0.05; left p≤0.01, p≤0.05) increased significantly in the treatment groups, whereas only the left condyle region (p≤0.001) and left corpus mandible FD values (p≤0.05) increased significantly in the control group. Inter-group comparisons revealed that both the right and left condylar processes of the T group indicated greater variations in FDA values (p≤0.001) (Table 6).

Intra-group pre- and post-treatment changes in chronological age and FD parameters between genders are presented in Table 7. The right mandibular corpus value was significantly higher in the T group for girls (p≤0.001) whereas right condylar process value was significantly higher in the T group boys (p≤0.05) at T0. There were no significant differences in FDA values between girls and boys in the T1 period (p>0.05) (Table 7).

Table 1. Comparison of the mean values of the cephalometric parameters during pre-observation (T0) period among the Twin block and Herbst groups

Twin block (n=50)					Herbst (n=50)				T-H Mann-Whitney U test	
	Mean±SD		Min.-Max.		Mean±SD		Min.-Max.		Mean Difference±SD	p-value
Skeletal Measurements										
SNA	80.3	1.5	78.0	83.00	81.3	1.8	78.0	85.0	-0.97±0.34	0.008**
SNB	74.3	1.2	72.0	77.00	75.9	1.6	72.0	79.0	-1.68±0.29	0.000***
Anb	6.0	1.2	5.0	10.00	5.4	1.1	4.0	9.0	0.67±0.24	0.006**
GoGn/Sn	32.3	3.3	24.0	39.00	32.5	4.1	23.0	41.0	-0.17±0.75	0.589
Co-A	83.54	3.55	77.4	92.00	81.80	4.73	70.00	93.60	1.74±0.84	0.031*
Co-Gn	104.31	7.56	92.90	131.20	102.55	6.97	91.00	120.70	1.76±1.45	0.307
Co-Go	46.55	4.15	39.30	60.70	47.79	5.32	37.70	61.10	-1.24±0.95	0.303
Go-Gn	65.04	3.29	57.00	71.00	65.68	5.71	54.20	77.60	-0.64±0.93	0.443
ANS-Me	59.40	4.97	50.40	78.00	59.88	4.35	51.20	68.90	-0.48±0.93	0.484
S-Go	72.19	4.85	62.60	81.20	72.71	6.21	59.80	88.90	-0.51±1.11	0.739
Dentoalveolar Measurements										
1-NA, mm	5.46	2.05	3.00	11.80	4.43	2.16	-6.20	7.90	1.04±0.42	0.092
1-NA, °	28.9	5.2	16.0	40.0	24.4	5.7	10.0	40.0	4.50±1.10	0.000***
1-NB, mm	3.47	1.62	1.00	7.70	3.06	1.26	0.20	5.50	0.42±0.29	0.448
1-NB, °	24.4	5.3	13.0	39.0	24.8	4.8	14.0	34.0	-0.35±1.01	0.631
Overjet	6.89	1.30	4.20	9.80	5.81	1.09	3.40	8.20	1.08±0.24	0.000***
Overbite	4.39	1.00	1.50	6.00	4.41	1.31	1.40	8.00	-0.01±0.23	0.908

Independent samples Mann-Whitney U test; *p≤0.05; **p≤0.01; ***p≤0.001
T, Twin block; H, Herbst; SD, standard deviation; Min., minimum value; Max., maximum value

Table 2. Comparison of the cephalometric changes occured during post- (T1) and pre-treatment (T0) for Twin block group

T0					T1				T1-T0 Wilcoxon test	
n=50	Mean±SD		Min.-Max.		Mean±SD		Min.-Max.		Mean±SD	p-value
Skeletal Measurements										
SNA	80.3	1.5	78.0	83.00	80.42	1.51	78.0	84.0	0.04±0.67	0.670
SNB	74.3	1.2	72.0	77.00	77.92	0.92	76.0	81.0	3.62±0.90	0.000***
ANB	6.0	1.2	5.0	10.00	2.52	1.29	1.0	5.0	-3.56±0.81	0.000***
GoGn/Sn	32.3	3.3	24.0	39.00	33.00	3.49	25.0	39.0	0.64±1.26	0.001***
Co-A	83.54	3.55	77.4	92.00	84.05	4.13	76.1	92.20	0.52±1.87	0.082
Co-Gn	104.31	7.56	92.90	131.20	110.87	9.07	94.20	140.00	6.56±4.02	0.000***
Co-Go	46.55	4.15	39.30	60.70	51.41	4.77	45.00	65.00	4.86±3.63	0.000***
Go-Gn	65.04	3.29	57.00	71.00	69.93	3.75	60.00	77.20	4.89±2.25	0.000***
ANS-Me	59.40	4.97	50.40	78.00	63.79	6.06	53.00	79.00	4.39±2.61	0.000***
S-Go	72.19	4.85	62.60	81.20	76.48	4.95	65.00	84.50	4.29±3.00	0.000***
Dentoalveolar Measurements										
1-NA, mm	5.46	2.05	3.00	11.80	2.91	1.55	0.20	5.60	-2.55±1.38	0.000***
1-NA, °	28.9	5.2	16.0	40.0	22.6	5.2	13.0	33.0	-6.32±3.36	0.000***
1-NB, mm	3.47	1.62	1.00	7.70	6.23	2.35	2.60	11.70	2.76±1.14	0.000***
1-NB, °	24.4	5.3	13.0	39.0	31.1	6.8	19.0	45.0	6.69±4.41	0.000***
Overjet	6.89	1.30	4.20	9.80	3.39	1.20	2.00	7.00	-3.50±1.00	0.000***
Overbite	4.39	1.00	1.50	6.00	2.07	0.82	0.50	4.10	-2.33±1.01	0.000***

Wilcoxon test: ; ***p≤0.001
T0, pre-treatment; T1, post-treatment; SD, standard deviation; Min., minimum value; Max., maximum value

Table 3. Comparison of the cephalometric changes occured during post- (T1) and pre-treatment (T0) for Herbst group

T0					T1				T1-T0 Wilcoxon test	
n=50	Mean±SD		Min.-Max.		Mean±SD		Min.-Max.		Mean±SD	p-value
Skeletal Measurements										
SNA	81.3	1.8	78.0	85.0	80.9	1.8	77.0	84.0	-0.41±0.57	0.000***
SNB	75.9	1.6	72.0	79.0	77.2	1.5	74.0	80.0	1.25±0.77	0.000***
ANB	5.4	1.1	4.0	9.0	3.7	1.3	1.0	7.0	-1.69±0.71	0.000***
GoGn/SN	32.5	4.1	23.0	41.0	32.7	4.47	25.0	42.0	0.22±1.24	0.249
Co-A	81.80	4.73	70.00	93.60	82.08	4.33	72.30	93.90	0.27±2.58	0.305
Co-Gn	102.55	6.97	91.00	120.70	105.19	7.04	93.00	124.00	2.64±4.35	0.000***
Co-Go	47.79	5.32	37.70	61.10	49.41	4.56	41.40	62.10	1.62±2.94	0.001***
Go-Gn	65.68	5.71	54.20	77.60	66.06	7.09	47.00	77.60	0.38±7.79	0.000***
ANS-Me	59.88	4.35	51.20	68.90	60.78	4.06	50.40	69.70	0.90±3.38	0.022*
S-Go	72.71	6.21	59.80	88.90	74.72	5.88	61.70	89.40	2.01±3.11	0.000***
Dentoalveolar Measurements										
1-NA, mm	4.43	2.16	-6.20	7.90	2.39	1.11	0.20	4.20	-2.03±2.34	0.000***
1-NA, °	24.4	5.7	10.0	40.0	19.7	4.9	10.0	34.0	-4.78±4.12	0.000***
1-NB, mm	3.06	1.26	0.20	5.50	6.23	1.45	2.20	8.90	3.17±1.11	0.000***
1-NB, °	24.8	4.8	14.0	34.0	33.4	4.7	19.0	41.0	8.59±3.61	0.000***
Overjet	5.81	1.09	3.40	8.20	3.02	0.92	1.00	5.40	-2.79±1.02	0.000***
Overbite	4.41	1.31	1.40	8.00	2.18	0.91	0.40	4.00	-2.22±1.41	0.000***

Wilcoxon test; ***p≤0.001
T0, pre-treatment; T1, just after the removal of Herbst appliance; SD, standard deviation; Min., minimum value; Max., maximum value

Table 4. Comparison of differences in time-dependent cephalometric changes between the treatment groups

	Twin block (T) T1-T0				Herbst (H) T1-T0				T-H Wilcoxon test	
	Mean±SD		Min.-Max.		Mean±SD		Min.-Max.		Mean±SD	p-value
Skeletal Measurements										
SNA	0.04	0.67	-1.0	1.0	-0.41	0.57	-1.0	1.0	-0.19±0.66	0.001***
SNB	3.6	0.90	2.0	5.0	1.25	1.52	-1.0	3.0	2.43±1.45	0.001***
ANB	-3.5	0.81	-5.0	-2.0	-1.7	0.71	-3.0	0.0	-2.61±1.21	0.001***
GoGn/SN	0.64	1.2	-2.0	4.0	0.22	1.24	-3.0	3.0	0.43±1.26	0.086
Co-A	0.52	1.87	-2.50	5.60	0.27	2.58	-7.90	8.70	0.40±2.24	0.521
Co-Gn	6.56	4.02	0.10	16.40	2.64	4.35	-7.10	17.30	4.58±4.61	0.001***
Co-Go	4.86	3.63	0.80	19.20	1.62	2.94	-5.00	10.20	3.23±3.66	0.001***
Go-Gn	4.89	2.25	0.70	10.80	0.38	7.79	-8.00	11.70	2.61±6.16	0.001***
ANS-Me	4.39	2.61	0.40	10.70	0.90	3.38	-7.90	10.20	2.63±3.48	0.001***
S-Go	4.29	3.00	-1.50	9.70	2.01	3.11	-4.00	10.70	3.14±3.25	0.001***
Dentoalveolar Measurements										
1-NA, mm	-2.55	1.38	-6.20	-0.60	-2.03	2.34	-5.00	9.50	-2.29±1.93	0.688
1-NA, °	-6.3	3.3	-13.0	-2.0	-4.7	4.12	-15.0	15.0	-5.54±3.82	0.193
1-NB, mm	2.76	1.14	1.00	5.10	3.17	1.11	0.80	7.70	2.97±1.14	0.041*
1-NB, °	6.6	4.4	-2.0	19.0	8.5	3.61	4.0	18.0	7.65±4.12	0.002**
Overjet	-3.50	1.00	-5.20	-2.00	-2.79	1.02	-5.00	0.50	-3.14±1.07	0.001***
Overbite	-2.33	1.01	-4.90	-0.30	-2.22	1.41	-5.00	1.10	-2.27±1.22	0.981

Wilcoxon test; *p≤0.05; **p≤0.01; ***p≤0.001
SD, standard deviation; Min., minimum value; Max., maximum value

A gender-based comparison of chronological ages and FDA parameters between T1 and T0 were given in Table 8. In the T group, a significant increase in FDA values was observed in the right and left condylar regions in girls (p≤0.001). In boys, in addition to similar findings in the condylar regions, significant increases were noted in the mandibular corpus (right, p≤0.05; left, p≤0.01) and the left angulus mandible (p≤0.05). In the H group, significant increases were observed in the right and left condylar regions in girls (p≤0.001). In boys, in addition to similar findings in the condylar region, a significant increase was observed in the right angulus mandible (p≤0.05). In the control group, while there was no significant change in girls, only a significant increase was observed in the left corpus mandible in boys (p≤0.01) (Table 8).

DISCUSSION

Due to the effectiveness of CBCT in revealing three-dimensional images, the morphology of maxillofacial bone structure has led to an increase in investigations in many areas of dentistry, including orthodontics.[20,21] However, CBCT should not be

Table 5. Comparison of the mean values of the chronological ages and fractal dimension parameters during pre-observation (T0) period among the groups

	Twin block (n=50) T0	Herbst (n=50) T0	Control (n=50) T0	ANOVA test Among the groups			
	Mean±SD	Mean±SD	Mean±SD	p-value	T-H	H-C	T-C
Age, y	11.63±0.87	11.72±0 .91	11.67±0.83	0.668			
Proc. condylaris (right)	1.12±0.74	1.25±0.10	1.35±0.10	0.000***		***	***
Angulus mandibula (right)	1.32±0.13	1.27±0.12	1.34±0.10	0.013*	*	*	
Corpus mandibula (right)	1.22±0.10	1.19±0.12	1.26±0.11	0.004**		**	**
Proc. condylaris (left)	1.21 ±0.13	1.22±0.12	1.28±0.13	0.010**		**	**
Angulus mandibula (left)	1.31±0.10	1.31±0.11	1.35±0.11	0.065			
Corpus mandibula (left)	1.20±0.13	1.22±0.12	1.28±0.13	0.010**		**	**

ANOVA test; *p≤0.05; **p≤0.01; ***p≤0.001
T, Twin block; H, Herbst; C, Control; SD, standard deviation; Min., minimum value; Max., maximum value

Table 6. Comparison of fractal dimension changes obtained during post- (T1) and pre-observation (T0) periods among the groups

	Twin block (n=50)				Herbst (n= 50)			
	T0	T1	T1-T0		T0	T1	T1-T0	
	Mean±SD	Mean±SD	Mean Difference±SD	p-value	Mean±SD	Mean±SD	Mean difference±SD	p-value
Age, y	11.63±0.87	12.63±0.79	1.00±0.477	0.000***	11.72±0.91	12.69±0.96	0.97±0.462	0.000***
Proc. condylaris (right)	1.12±0.07	1.38±0.09	0.264±0.105	0.000***	1.25 ±0.10	1.39±0.112	0.142±0.089	0.000***
Angulus mandibula (right)	1.32±0.10	1.32±0.08	0.005±0.104	0.717	1.27 ±0.12	1.30±0.123	0.026±0.132	0.152
Corpus mandibula (right)	1.22±0.10	1.25±0.12	0.035±0.118	0.041*	1.19±0.12	1.23±0.125	0.041±0.123	0.020*
Proc. condylaris (left)	1.21±0.13	1.36±0.11	0.151±0.130	0.000***	1.22±0.12	1.41±0.086	0.187±0.061	0.000***
Angulus mandibula (left)	1.31±0.10	1.33±0.11	0.023±0.146	0.271	1.31±0.11	1.30±0.116	-0.003±0.133	0.862
Corpus mandibula (left)	1.20±0.13	1.26±0.11	0.059±0.134	0.003**	1.22±0.12	1.26±0.114	0.043±0.116	0.011*

	Control (n=50)				ANOVA test Among the groups			
	T0	T1	T1-T0					
	Mean±SD	Mean±SD	Mean difference±SD	p-value	p-value	T-H	H-C	T-C
Age, y	11.67±0.83	12.66±0.86	0.99±0.455	0.000***	0.620			
Proc. condylaris (right)	1.35±0.10	1.36±0.11	0.009±0.137	0.616	0.000***	***	***	***
Angulus mandibula(right)	1.34±0.10	1.36±0.11	0.016±0.146	0.426	0.703			
Corpus mandibula (right)	1.26±0.11	1.31±0.11	0.042±0.152	0.055	0.953			
Proc. condylaris (left)	1.28±0.13	1.38±0.10	0.011±0.130	0.000***	0.000***	***	***	***
Angulus mandibula (left)	1.35±0.11	1.36±0.10	0.004±0.131	0.836	0.613			
Corpus mandibula (left)	1.28±0.13	1.33±0.11	0.054±0.149	0.014*	0.811			

T, Twin block; H, Herbst; C, Control; SD, standard deviation; *p≤0.05; **p≤0.01; ***p≤0.001

performed for research purposes only and/or as a routine record of orthodontic treatment because of ethical concerns when diagnostic information can be easily obtained using low-dose conventional radiographs. Therefore, FDA on panoramic radiographs may be an effective method for examining bone trabecular patterns at different time points during treatment.

In growing patients, removable and fixed functional appliances can be preferred for the correction of Class II malocclusion due to mandibular retrognathia.[1,2] The main aim here is to achieve a skeletal effect rather than a dentoalveolar effect.[3] There are several reasons for including pubertal patients and using Twin block and Herbst appliances in the study groups.[16,22] It is known that the Twin block appliance is more commonly preferred by patients due to its design, which contributes positively to patient cooperation.[17] Many studies have acknowledged that skeletal effects can be effectively achieved using the Herbst appliance.[8,9,13,18] Therefore, we used these appliances to maximize skeletal effects and aimed to examine their holistic effects by comparing them with each other and the control group. In addition, we aimed to assess only the effects of functional appliances in all measurements and to eliminate the effect of fixed orthodontic treatment in comparisons by performing measurements immediately after removing the Herbst appliance in the T1 period in the H group.

The study of the structural properties of trabecular bone is considered advantageous due to its high metabolic activity.[23]

Table 7. Comparison of the pre- (T0) and post-treatment (T1) fractal dimension parameters for treatment groups and observation period changes of control group between genders

	Twin block (n=50)							
	T0				**T1**			
	Girls (n=25)	**Boys (n=25)**	**G-B**		**Girls**	**Boys**	**G-B**	
	Mean±SD	**Mean±SD**	**P**	**Test**	**Mean±SD**	**Mean±SD**	**P**	**Test**
Age, y	11.59±0.83	11.67±0.81	0.602		12.58±0.61	12.68±0.56	0.552	
Proc. condylaris (right)	1.12±0.07	1.12±0.07	0.880		1.36±0.09	1.41±0.07	0.072	
Angulus mandibula (right)	1.32±0.10	1.31±0.09	0.919		1.31±0.09	1.33±0.07	0.325	
Corpus mandibula (right)	1.26±0.09	1.17±0.08	0.000	***	1.27±0.12	1.23±0.13	0.306	
Proc. condylaris (left)	1.10±0.06	1.10±0.06	0.981		1.34±0.12	1.38±0.10	0.198	
Angulus mandibula (left)	1.33±0.10	1.29±0.11	0.200		1.30±0.09	1.37±0.12	0.039	*
Corpus mandibula (left)	1.23±0.14	1.17±0.11	0.146		1.26±0.11	1.26±0.12	0.870	
	Herbst (n=50)							
	T0				**T1**			
	Girls (n=27)	**Boys (n=23)**	**G-B**	**Girls (n=27)**	**Boys (n=23)**	**G-B**		
	Mean±SD	**Mean±SD**	**P**	**Test**	**Mean±SD**	**Mean±SD**	**P**	**Test**
Age, y	11.74±0.43	11.70±0.51	0.444		12.63±0.36	12.55±0.46	0.392	
Proc. condylaris (right)	1.25±0.10	1.25±0.10	0.959		1.40±0.09	1.37±0.13	0.476	
Angulus mandibula (right)	1.28±0.11	1.27±0.14	0.738		1.30±0.10	1.31±0.14	0.660	
Corpus mandibula (right)	1.20±0.12	1.17±0.11	0.467		1.24±0.12	1.21±0.11	0.467	
Proc. condylaris (left)	1.23±0.08	1.21±0.09	0.326		1.42±0.08	1.39±0.08	0.305	
Angulus mandibula (left)	1.32±0.08	1.28±0.13	0.200		1.31±0.09	1.29±0.14	0.500	
Corpus mandibula (left)	1.23±0.12	1.19±0.11	0.235		1.27±0.11	1.25±0.10	0.477	
	Control (n=50)							
	T0				**T1**			
	Girls (n=24)	**Boys (n=26)**	**G-B**	**Girls (n=24)**	**Boys (n=26)**	**G-B**		
	Mean±SD	**Mean±SD**	**P**	**Test**	**Mean±SD**	**Mean±SD**	**P**	**Test**
Age, y	11.68±0.61	11.67±0.49	0.711		12.65±0.74	12.68±0.24	0.762	
Proc. condylaris (right)	1.34±0.11	1.36±0.10	0.412		1.36±0.10	1.36±0.12	0.895	
Angulus mandibula(right)	1.35±0.10	1.33±0.10	0.417		1.35±0.12	1.36±0.11	0.624	
Corpus mandibula (right)	1.24±0.10	1.28±0.11	0.236		1.28±0.11	1.33±0.10	0.144	
Proc. condylaris (left)	1.33±0.10	1.41±0.10	0.011	*	1.37±0.09	1.40±0.11	0.322	
Angulus mandibula (left)	1.35±0.11	1.36±0.10	0.735		1.38±0.09	1.34±0.11	0.152	
Corpus mandibula (left)	1.31±0.13	1.25±0.12	0.140		1.33±0.12	1.34±0.11	0.844	

G; girls, B; boys; SD, standard deviation; *p≤0.05; ***p≤0.001

Table 8. Comparison of the fractal dimension parameters between post- (T1) and pre-observation (T0) periods for different genders in the groups

Twin block (n=50)					
		T0	T1	T1-T0	
Girls (n=25)		Mean±SD	Mean±SD	Mean difference±SD	p-value
Girls (n=25)	Age, y	11.59±0.83	12.58±0.61	0.99±0.42	0.000***
	Proc. condylaris (right)	1.12±0.07	1.36±0.09	0.242±0.114	0.000***
	Angulus mandibula (right)	1.32±0.10	1.31±0.09	-0.008±0.109	0.702
	Corpus mandibula (right)	1.26±0.09	1.27±0.12	0.006±0.078	0.702
	Proc. condylaris (left)	1.10±0.06	1.34±0.12	0.239±0.134	0.000***
	Angulus mandibula (left)	1.33±0.10	1.30±0.09	-0.029±0.102	0.158
	Corpus mandibula (left)	1.23±0.14	1.26±0.11	0.029±0.125	0.252
Boys (n=25)	Age, y	11.67±0.81	12.68±0.56	1.01±0.35	0.000***
	Proc. condylaris (right)	1.12±0.07	1.41±0.07	0.286±0.091	0.000***
	Angulus mandibula (right)	1.31±0.09	1.33±0.07	0.019±0.100	0.345
	Corpus mandibula (right)	1.17±0.08	1.23±0.13	0.064±0.144	0.035*
	Proc. condylaris (left)	1.10±0.06	1.38±0.10	0.283±0.124	0.000***
	Angulus mandibula (left)	1.29±0.11	1.37±0.12	0.076±0.165	0.030*
	Corpus mandibula (left)	1.17±0.11	1.26±0.12	0.090±0.138	0.003**

SD, standard deviation; *p≤0.05; **p≤0.01; ***p≤0.001

Previous studies have utilized fractal analysis to predict the effect of orthodontic appliances, orthodontic treatment duration, midpalatal suture maturation, pubertal growth, and skeletal development.[24-26] Recently, researchers have investigated the changes in functional appliances on the mandibular bone using the FDA of PRs.[15,27-29] It is our contention that this study will contribute to the extant literature by comparing the effects of both functional appliances on the mandibular bone using the FDA.

One of the primary goals of functional therapies is stimulating condylar growth and remodeling of the glenoid fossa to provide anterior positioning of the mandible and, consequently, to improve the facial profile.[1,2,4] Therefore, the primary focus of functional therapy is the mandibular condyle region. This study was specifically designed to evaluate the effects of functional appliances on the mandibular trabecular structure objectively using the FDA. There is consensus that the FDA reflects changes in trabecular bone density and mineral loss, as assessed by radiographs.[19,30]

No major differences in mandibular length and vertical skeletal relationships existed before treatment (Table 1). However, the fact that the T group had more severe mandibular retrognathia before treatment can be explained by the notion that mandibular advancement (MA) can be more effective with the Twin block appliance.[10,11] These results suggest that the T group exhibited a greater overjet and a higher degree of upper incisor proclination prior to treatment, consistent with the findings of Schaefer et al.[11]

Separate FDA results from each group were included in this study, among which both treatment groups displayed greater changes in the FDA values in the left and right condyle regions. At the same time, FDA values significantly increased in the right and left mandibular corpus. In this study, cephalometric measurements showed that mandibular advancement and elongation were achieved with the use of both functional appliances in pubertal Class II patients (Co-Gn, Co-Go, Go-Gn). Previous studies have reported that alterations in mandible length induced by functional treatment are closely correlated with increased condylar growth.[1,2,4] These data suggest that removable and fixed functional appliances may alter the bone structures of the condyle, which may be associated with mandibular growth.

In this study, FDA revealed significant increases in the right and left condylar regions among all groups. For the T group, a comparison of FDA values in the condylar processes by sex pointed out a substantial increase in both females and males on the right and left sides, whereas FDA values in the mandible corpus increased significantly on both the right and left sides in males alone. The results of this group are similar to those of Cesur et al.[27] with respect to gender. These changes may be attributed to the overall increase in length of the mandible with functional treatment. Mandibular retrognathia therapy does not only incorporate stimulation of condylar activity but also includes posterior repositioning through functional treatment during the growth period through remodeling of the mandible.[4,15] Another point that needs to be emphasized is that the Twin block appliance is selectively trimmed, as the acrylic part extending to the occlusal surface of the mandibular posterior teeth aims to enhance the occlusal relationship. This can be explained by the fact that the posterior mandibular teeth may display higher eruption in the T group than in the H group, similar to the study of Schaefer et al.[11] Therefore, it can be concluded that the changes occurring in the T group, especially in the corpus region, display significantly higher skeletal effects while contributing to dental effects, which is also supported by the significant increase in both anterior and posterior height. In the H group, a comparison of FDA values in the condyle region by sex revealed significant increases in the right and left condyle processes in both females and males, which was consistent with the findings of Amuk et al.[29] In addition, Schafer et al.[11] compared the Twin block and Herbst appliances. Both groups reported a similar increase in mandibular length, with a significant increase in vertical ramus height noted in the T group. However, in our study, similar to previous studies,[10,11] greater significant increases in mandibular length parameters were observed in the T group compared with the H group. A high fractal value reflects increased trabecular bone density, suggesting bone apposition in the region, whereas a low fractal value indicates reduced trabecular bone density.[19,30]

In the present study, overjet improvement not only resulted from the changes in mandibular skeletal parameters, and similar to the study finding of Song et al.,[12] significant protrusion was observed in the lower incisors, prominently in the H group. According to the researchers,[11-13] this movement is considered acceptable as long as the positions of the incisors are within an appropriate range after functional orthopedic treatment.

Study Limitations

Although many scientific studies have noticed the high credibility of FDA on PRs, future research using three-dimensional imaging may provide further insights. As this was a retrospective study, differences in activation strengths were not evaluated. Considering that differences in the effectiveness of force may cause changes in the mandibular structures, future studies should include clinically standardize patients and require long-term examination. In addition, clinical findings related to TMJ were not evaluated in this study and were not associated with radiographic findings.

CONCLUSION

Treatment with both Twin block and Herbst appliances led to significant improvements in skeletal and dental cephalometric parameters.

Both treatment groups exhibited notable increases in FDA values in the left and right corpus of the mandible, particularly in the condylar regions. Comparative analysis of FDA values revealed significant changes in the trabecular patterns of the right and left condyles of the mandible. The Twin Block and Herbst appliances not only induced dentoalveolar changes but also contributed to the remodeling of the mandibular trabecular structure and skeletal correction.

Ethics

Ethics Committee Approval: Ethical permission was obtained from Karadeniz Technical University, Faculty of Dentistry, Scientific Research Ethics Committee (approval number: 2022-7, date: 29.07.2022).

Informed Consent: A retrospective study.

Footnotes

Author Contributions: Concept - N.K., C.A., D.G.Ç., A.T.A; Design - N.K., A.T.A.; Data Collection and/or Processing - D.G.Ç., A.A.Y.; Analysis and/or Interpretation - D.G.Ç., S.T.D., A.A.Y.; Literature Search - N.K., C.A.; Writing - N.K., C.A.

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ERRATUM

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In the 2024-2 June issue of Turk J Orthod; there was an inadvertent mistake in the submission and acceptance dates of the article published with the doi number "DOI: 10.4274/TurkJOrthod.2023.2023.78". The corrections are as follows;

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