DOI: 10.4274/TurkJOrthod.2023.2023.73

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

Nurver Karslı[1], Can Arslan[2], Derya Germeç Çakan[2], Ayşe Tuba Altuğ[3], Senem Tuğra Dönmez[4], Asya Atasoy Yücesan[4]

[1]Karadeniz Technical University Faculty of Dentistry, Department of Orthodontics, Trabzon, Turkey
[2]Yeditepe University Faculty of Dentistry, Department of Orthodontics, İstanbul, Turkey
[3]Ankara University Faculty of Dentistry, Department of Orthodontics, Ankara, Turkey
[4]Karadeniz Technical University Faculty of Dentistry, Department of Oral Diagnosis and Radiology, Trabzon, Turkey

Cite this article as: Karslı N, Arslan C, Germeç Çakan D, Altuğ AT, Tuğra Dönmez S, Atasoy Yücesan A. Comparison of the Effects of Fixed and Removable Functional Orthodontic Treatment on the Mandibular Trabecular Bone in Fractal Analysis. *Turk J Orthod.* 2024; 37(4): 265-275

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

Corresponding author: Nurver Karslı, **e-mail:** dtnurverkarsli@hotmail.com
Received: May 27, 2023 **Accepted:** November 20, 2023 **Publication Date:** 31 December, 2024

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.

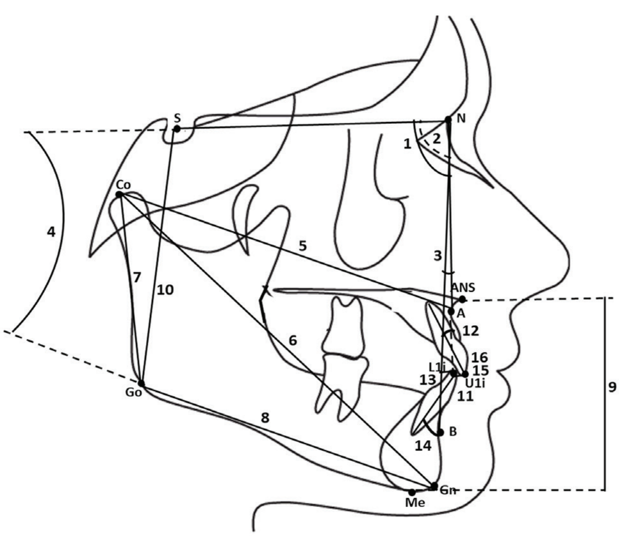

Figure 1. Cephalometric measurements. Skeletal measurements: (1) SNA; (2) SNB; (3) ANB; (4) GoGn/SN; (5) Co-A; (6) Co-Gn; (7) Co-Go; (8) Go-Gn; (9) ANS-Me; (10) S-Go. Dentoalveolar measurements: (11) 1-NA (°); (12) 1-NA (mm); (13) 1-NB (°); (14) 1-NB (mm); (15) overjet; (16) overbite

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 $p \leq 0.05$ 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 $p \leq 0.05$ 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) ($p \leq 0.05$), 1-NB

Turk J Orthod 2024; 37(4): 265-275

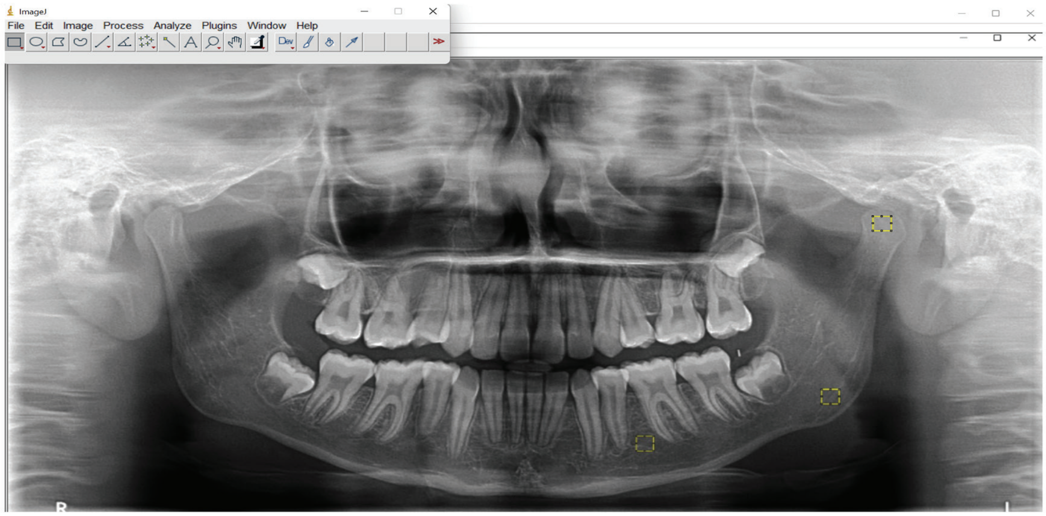

Figure 2. Locations of the ROIs from three different areas of the mandible (condyler, angulus mandible, corpus mandible)
ROI, regions of interest

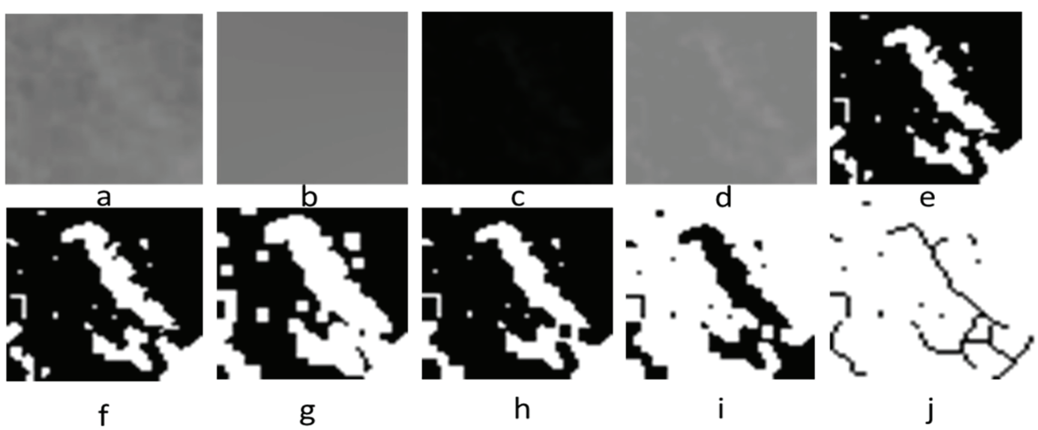

Figure 3. Stages of fractal dimension analysis: a) cropped region of interest, b) blurred image of duplicated region of interest, c) the blurred image was subtracted from the original image, d) addition of a gray value of 128 to each pixel location, e) threshold, f) binary, g) erode, h) dilate, i) invert,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

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

Financial Disclosure: The authors declare that this study has received no financial support.

REFERENCES

1. Moss ML, Salentijn L. The primary role of functional matrices in facial growth. *Am J Orthod Dentofacial Orthop.* 1969;55(6):566-577. [CrossRef]
2. Ruf S, Baltromejus S, Pancherz H. Effective condylar growth and chin position changes in activator treatment: a cephalometric roentgenographic study. *Angle Orthod.* 2001;71(1):4-11. [CrossRef]
3. De Almeida MR, Henriques JF, Ursi W. Comparative study of the Fränkel (FR-2) and bionator appliances in the treatment of Class II malocclusion. *Am J Orthod Dentofacial Orthop.* 2002;121(5):458-466. [CrossRef]
4. Pancherz H, Ruf S, Kohlhas P. "Effective condylar growth" and chin position changes in Herbst treatment: a cephalometric roentgenographic long-term study. *Am J Orthod Dentofacial Orthop.* 1998;114:437-446. [CrossRef]
5. Zymperdikas VF, Koretsi V, Papageorgiou SN, Papadopoulos MA. Treatment effects of fixed functional appliances in patients with Class II malocclusion: a systematic review and meta-analysis. *Eur J Orthod.* 2016;38(2):113-126. [CrossRef]
6. O'Brien K, Wright J, Conboy F, et al. Effectiveness of early orthodontic treatment with the Twin block appliance: A multicenter, randomized, controlled trial. Part 1: Dental and skeletal effects. *Am J Orthod Dentofacial Orthop.* 2003;124(3):234-243. [CrossRef]
7. Tulley WJ. The scope and limitations of treatment with the activator. *Am J Orthod.* 1972;61(6):562-577. [CrossRef]
8. Ruf S, Pancherz H. Temporomandibular joint remodeling in adolescents and young adults during Herbst treatment: A prospective longitudinal magnetic resonance imaging and cephalometric radiographic investigation. *Am J Orthod Dentofacial Orthop.* 1999;115(6):607-618. [CrossRef]
9. Jakobsone G, Latkauskiene D, McNamara JA Jr. Mechanisms of Class II correction induced by the crown Herbst appliance as a single-phase Class II therapy: 1 year follow-up. *Prog Orthod*. 2013;14:27. [CrossRef]
10. Baysal A, Uysal T. Dentoskeletal effects of twin block and herbst appliances in patients with Class II division 1 mandibular retrognathy. *Eur J Orthod*. 2014;36(2):164-172. [CrossRef]
11. Schaefer AT, McNamara JA Jr, Franchi L, Baccetti T. A cephalometric comparison of treatment with the Twin-block and stainless steel crown Herbst appliances followed by fixed appliance therapy. *Am J Orthod Dentofacial Orthop.* 2004;126(1):7-15. [CrossRef]
12. Song Y, Yu YL, Shen H, Zhang J. [Comparative study of the clinical effects of three different functional appliances on the treatment of skeletal class II malocclusion]. *Hua Xi Kou Qiang Yi Xue Za Zhi.* 2008;26(4):406-408. [CrossRef]
13. O'Brien K, Wright J, Conboy F, et al. Effectiveness of treatment for Class II malocclusion with the Herbst or twin-block appliances:

a randomized, controlled trial. *Am J Orthod Dentofacial Orthop.* 2003;124(2):128-137. [CrossRef]

14. Arsan B, Köse TE, Çene E, Özcan İ. Assessment of the trabecular structure of mandibular condyles in patients with temporomandibular disorders using fractal analysis. *Oral Surg Oral Med Oral Pathol Oral Radiol*. 2017;123(3):382-391. [CrossRef]
15. Akan B, Ünlü Kurşun B. Structural changes in the trabecular bone of the mandibular condyle in growing patients with sagittal jaw discrepancy treated with the twin-block appliance. *Orthod Craniofac Res.* 2021;25(1):142-149. [CrossRef]
16. Björk A. Timing of interceptive orthodontic measures according to the stages of maturation. *Trans Eur Orthod Soc.* 1972;61-74. [CrossRef]
17. Clark WJ. The twin block technique. A functional orthopedic appliance system. *Am J Orthod Dentofacial Orthop.* 1988;93:1-18. [CrossRef]
18. Pancherz H, Ruf S. The herbst appliance. research-based updated clinical possibilities. *World J Orthod.* 2000;1(1):17-31. [CrossRef]
19. White SC, Rudolph DJ. Alterations in the trabecular pattern of jaws in patients with osteoporosis. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 1999;88(5):628-635. [CrossRef]
20. Servais JA, Gaalaas L, Lunos S, Beiraghi S, Larson BE, Leon-Salazar V. Alternative cone-beam computed tomography method for the analysis of bone density around impacted maxillary canines. *Am J Orthod Dentofacial Orthop.* 2018;154(3):442-449. [CrossRef]
21. Akbulut S, Bayrak S. Evaluation´ of mandibular alveolar bone in patients with different vertical facial patterns: A cross-sectional CBCT study. *J Orofac Orthop.* 2022;85(2):89-97. [CrossRef]
22. Ruf S, Pancherz H. When is the ideal period for Herbst therapy-early or late? *Semin Orthod.* 2003;9(1):47-56. [CrossRef]
23. Shrout MK, Farley BA, Patt SM, et al. Effect of region-of-interest variations on morphologic data and gray level values extracted from digitized dental radiographs. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 1999;88(5):636-639. [CrossRef]
24. Akbulut S, Bayrak S, Korkmaz YN. Prediction of rapid palatal expansion success via fractal analysis of hand-wrist radiographs. *Am J Orthod Dentofacial Orthop.* 2020;158:192-198. [CrossRef]
25. Kang D, Kwak KH, Kim SS, Park SB, Son WS, Kim YI. Application of fractal analysis of the midpalatal suture for estimation of pubertal growth spurts. *Oral Radiol*. 2017;33:199-203. [CrossRef]
26. Arslan S, Korkmaz YN, Buyuk SK, Tekin B. Effects of reverse headgear therapy on mandibular trabecular structure: A fractal analysis study. *Orthod Craniofac Res.* 2022;25:562-568. [CrossRef]
27. Cesur E, Bayrak S, Kursun-Çakmak EŞ, Arslan C, Köklü A, Orhan K. Evaluating the effects of functional orthodontic treatment on mandibular osseous structure using fractal dimension analysis of dental panoramic radiographs. *Angle Orthod.* 2020;90:783-793. [CrossRef]
28. Bolat Gümüş E, Yavuz E, Tufekci C. Effects of functional orthopedic treatment on the mandibular trabecular bone in class II patients using fractal analysis. *J Orofac Orthop*. 2022;84(Suppl 3):155-164. [CrossRef]
29. Amuk M, Gul Amuk N, Yılmaz S. Treatment and posttreatment effects of Herbst appliance therapy on trabecular structure of the mandible using fractal dimension analysis. *Eur J Orthod*. 2022;44(2):125-133. [CrossRef]
30. Sánchez I, Uzcátegui G. Fractals in dentistry. *J Dent*. 2011;39(4):273-292. [CrossRef]