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Original Article

Fractal Perspective on the Rapid Maxillary Expansion Treatment; Evaluation of the Relationship Between Midpalatal Suture Opening and Dental Effects

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A R T I C L E I N F O

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Objective: This retrospective study investigates the relationship between the midpalatal suture opening and the dental effects of Rapid Maxillary Expansion (RME) treatment using fractal analysis.
Methods: The participants of this study were selected from the patients who underwent Cone Beam Computed Tomography(CBCT) scans in 2019 and were treated with banded type Maxillary Expander. This study included 20 participants (with a mean age of 10.64±10.64, ranging from 8 to 13 years): 12 males and 8 females. Patients went through CBCT scan and images taken were analyzed using the ImageJ program. The following parameters were measured and analyzed before and after RME treatment: fractal dimensional value of Midpalatal suture(MPS), Distobuccal(DB), Mesiobuccal(MB), Palatal(P), Total distance, Cortical bone and linear values of External maxilla, Internal maxilla, Palatal roots, distance of Central fosses and angular values of Tipping value of 16 and 26. We used Spearman's nonparametric test for non-normal variables to investigate the correlation between changes in MPS and other variables.
Results: The results showed a strong positive correlation between the MPS and Right MB (0.34, $p<0.05$) and Left MB (0.59, $p<0.05$) variables and a strong negative correlation between the MPS and the External maxillary variables (-0.53, $p<0.05$).
Conclusion: The results of the study have shown a strong correlation between right and left MB and External Maxilla. RME caused a reduction in buccal alveolar bone thickness and a slight reduction in MPS thickness in growing patients. Therefore, we suggest that fractal analysis can be used to evaluate the skeletal and dental effects of RME in patients.

1. Introduction

The Rapid Maxillary Expansion (RME) is a technique commonly preferred in dentofacial orthopedic treatments as well as in oral surgery, Ear Nose Throat (ENT), and plastic surgery [1]. RME has also been used to expand the lateral skeleton of the maxilla by opening the midpalatal suture [2]. The expansion force acts on the all facial sutures, especially midpalatal suture with strong intermittent forces via the periodontal ligament hyalinization of the anchor teeth, preferably to achieve more orthopedic and less dental effects [3].

However, there are still problems in RME treatment, such as displacement and tipping of anchor teeth to buccal side [4]. In addition, it has been shown by computed tomography (CT), that RME treatment can cause teeth to shift outward during the alveolar process, which can damage periodontal tissue support and reduce gingival recession, root resorption, thickness and height of buccal bone or fenestrations [5, 6]. According to previous literature, that RME can cause a reduction in the alveolar buccal bone thickness of the permanent first molars on maxilla when they were used as anchor teeth. [7] . In addition, RME could cause to bending of the alveolar process and dental tipping, both of which are considered dentoalveolar expansion, and account for 6% to 13% and 39% to 49% of the total expansion, respectively. These effects are considered skeletal expansion and, in most cases are the only effect of force application. The effects of force

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application via RME lead both skeletal expansion and dentoalveolar expansion [8]. Molar tipping can lead to dental root resorption [9], loss of periodontal tissue level [6] and fenestrations of the buccal cortical bone [10]. Therefore, RME treatment aims maximum skeletal expansion and minimal dentoalveolar expansion.

To analyze midpalatal suture, a CBCT (Cone Beam Computed Tomography)-based method is used. This method allows the visualization of midpalatal suture in vivo without overlapping anatomical structures. Therefore, CBCT provides both qualitative and quantitative measurements to assess the changes in midpalatal suture in response to force application via RME [11].

Kauffman first introduced the term "Fractal" in 1970 [12]. An image texture consists of the sum of many small components of the patterns. This methods for texture analysis can be classified into structural and statistical studies. It is numerically expressed as "fractal dimension" (FD) [13] which a statistical texture analysis based on fractal mathematics for describing complex shapes and structural patterns. FD measures self-similarity and indicates the complexity of a figure and expresses the roughness of the texture by characterizing the self-similarity of the gray-level variations of the texture over different scales [14]. Subsequent studies on fractal analysis and its use to identify patterns in cranial sutures have shown that fractal dimensions are comparable with concentrated stresses [15].

In this study, null hypothesis was opening of the midpalatal suture would cause more skeletal effects and less alveolar bone reduction and our first objective was to investigate the changes in the midpalatal suture and alveolar bone density ratio in response to RME treatment using CBCT images. Therefore, our second objective was to investigate whether fractal analysis can be used as a criterion for diagnosing skeletal and dental changes after RME treatment.

2. Methods and materials

This retrospective study was approved by the Ethics Committee of Istanbul Aydin University with the number 2020/315.

In this study, out of 20 patients (aged 8–13 years), 12 were male and 8 were female. The mean age of participants was 10.64 years (SD:1.511) (Table 1).

2.1. Patient selection, evaluation of alveolar bone and midpalatal suture thickness

The inclusion criteria in this study were as follows: patients with RME treatment, patients with maxillary transverse deficiency with posterior unilateral or bilateral cross-bite before RME treatment, the absence of any previous systemic diseases in the patient records, and CBCT scans of good quality without movement artifacts for initial and final diagnostic records. Exclusion criteria included patients with cleft lip and palate, congenital anomalies and bone defects, incisal canal cysts and missing records or poor quality CBCT scans. In a previous study, researchers used Hyrax-type expanders with different types of screw for patients. Expansion period was continued until the maxillary first molars palatal cusps the reached the mandibular first molars buccal cusps for over-expansion.(Fig. 1). CBCT images were taken before (T0) and after four months of retention (T1). During this period, the patients had no other orthodontic treatment.

Table 1
Descriptive summary of the patient's age.

	n	Age Mean (SD)	Range
Female	8	10.50 (1.425)	9–13
Male	12	10.75 (1.595)	8–13
Total	20	10.64 (1.511)	8–13

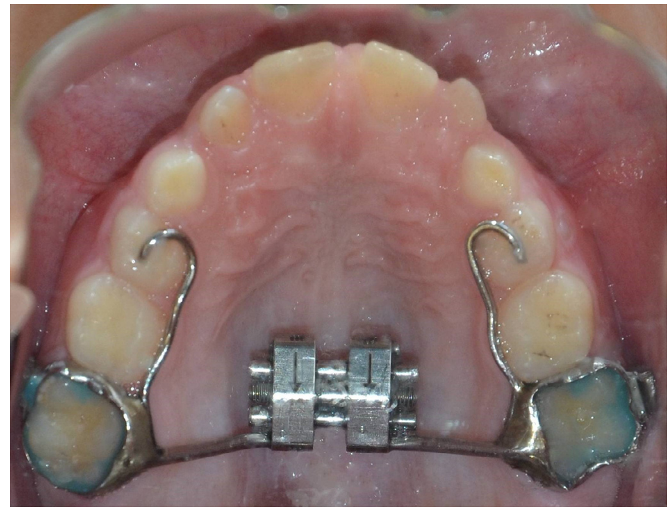

Fig. 1. Maxillary Expander (hyrax type).

2.2. Fractal calculation for alveolar bone and midpalatal suture thickness

For the fractal calculation, we used the box-counting method (Fig. 2). In this method, the fractal size is calculated as a function of distance of interest [16]. In the box-counting method, a guide with boxes is placed on the structure of the bone of interest. The created box has a size from 2 to 64 pixels and the number of boxes is counted in the guide. The total number of boxes depends on the dimensions of the box enclosed by the guidelines. A graph of these two dependent variables (the number and the count of boxes) is drawn in logarithmic scale [17]. The slope of the line corresponding to the points in the graph provides the fractal dimensions. Smaller fractal dimensions indicate that the pores inside the bone are higher and more porous. Higher fractal dimensions show that bone the architecture is more complex and intense, and the pores inside the bone are fewer [18].

The procedures for all analyses were performed on the computer by the same person following the method developed by White and Rudolph [19]. The box-counting method was performed on ImageJ 1.52b, an image analysis program, which is a version of National Institute from Health Image and can be downloaded and used for free at "https://imagej.nih.gov." The procedures required for the analysis were performed in the following order:

1 CBCT images, coronal of the individuals from the patient were opened in the ImageJ program, and the image area to be examined was chosen to be 20 × 180 pixels.
2 The region of Interest (ROI) obtained from original radiograms was duplicated.
3 Gaussian filter (sigma=35 pixels) was applied to the duplicated image, and the image was blurred, which ensured the appearance of significant density differences on the image by removing the high and moderate details in the image that appeared depending on the superficial tissue covering the bone and the varying thickness of the bone.
4 The image blurred by the Gaussian filter was extracted on the original image by the "subtraction" procedure.
5 For each pixel, the 128 gray tones were added. The zones in different brightness levels of the image obtained as the 128-gray tone on average help to distinguish bone marrow and trabecular structure; 128 was set as threshold regardless of the initial brightness level.
6 The image was converted to an 8-byte format using the "Type" option.

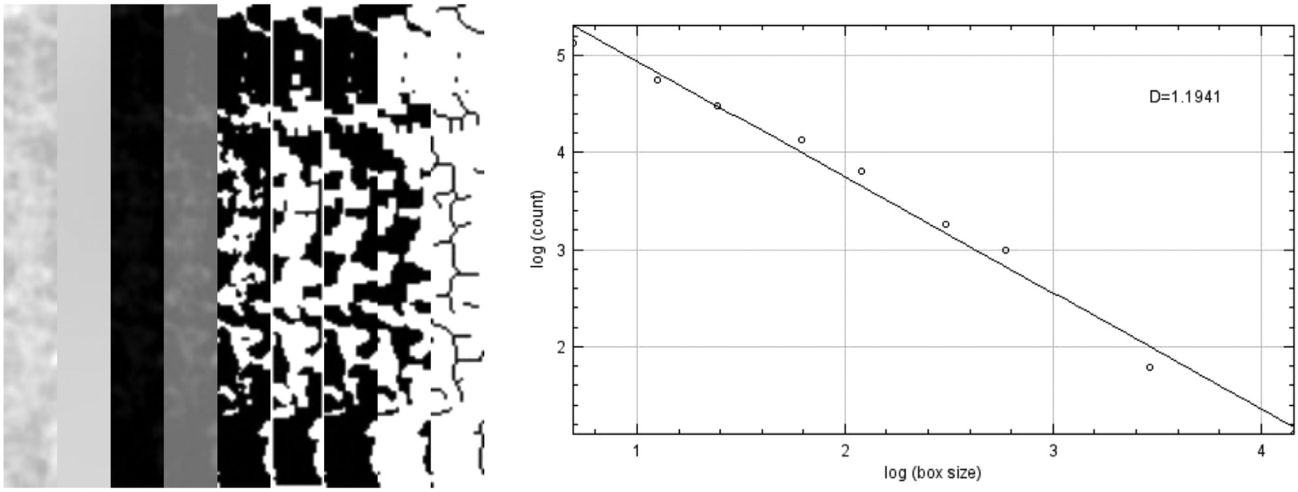

Fig. 2. The FD calculation process, Gaussian method using the box-counting method.

7. The image was then converted to a two-color image in black and white, ensuring to differentiate the main what?
8. To reduce the noise in image, the “Erode” option was used, and then existing areas were enlarged and highlighted using the “Dilate” option.
9. The “Invert” option was used to convert white areas to black and black areas to white to what? And why?
10. The “Skeletonize” option was used to outline the skeleton of the trabeculation and make it ready for fractal analysis.

After orientation, six landmarks were digitized to measure the length of the apical root. Then mesiopalatal, mesial, and distal cusps were pointed in coronal view (Fig. 3). To find and digitize the most occlusal point of each cusp, the coronal plane was moved forward and backward sagittal view. Each root apex was identified and digitized on the slice by moving the axial plane apically, just before the disappearance of the root. Each root apex were also examined on the sagittal view. The axial view was rotated until the buccal bone was parallel to the sagittal line and eight points were digitally marked on the buccal furcation level of the first maxillary molar (Fig. 4A). Sutural assessment was made using the most axial central cross-sectional slices (Fig. 4B). From the average gray density values, midpalatal suture density (MPS) ratio was calculated according to the following criteria: The distances of eight points were calculated using X, Y, and Z coordinates of 14 landmarks. To eliminate bias, all landmarks were recorded twice on different days by two independent orientations (Fig. 5). The right and left sides of the patients were imaged in the same session using one independent orientation. Multiple digitized images were averaged to obtain the true value.

The following parameters were measured and analyzed after and before RME treatment: Values Fractal dimension: Midpalatal suture density (MPS), Distobuccal (DB), Mesiobuccal (MB), Palatal (P), Total distance, Cortical bone. The variables of Total distance, Cortical bone, DB, MB, and P were measured for both right and left sides. We also measured the distance between External maxilla, Internal maxilla, Palatal roots, Central inter fossa, 16, and 26 tipping angles (Table 2). A previously published method was used to measure dental expansion at the level of the pulp chamber of the maxillary permanent first molars [20]. Written informed consent was obtained from the patients to participate in this study. All analyzes were performed using SPSS version 25 at an error level of 0.05.

2.3. Statistically analyses

We used Spearman’s non-parametric test for non-normal variables to examine the correlation between changes in the fractal and other variables. In this test, a p-value below 0.05 means that there is a significant correlation between the two variables, and above 0.05 means that there is no statistically significant correlation between the two variables.

Our objective was to test whether there was a statistically significant difference between the variables measured before and after RME treatment. Therefore, the samples were dependent on each other. Since the variables were normal, we used a paired t-test to test for the presence or absence of a difference before and after RME.

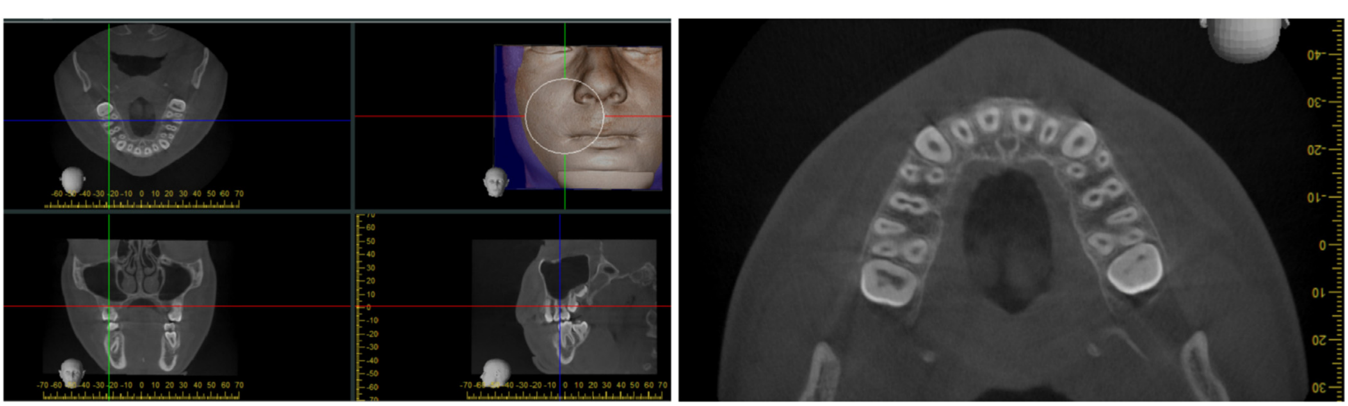

Fig. 3. (A) CBCT image, (B) orientation using the axial section.

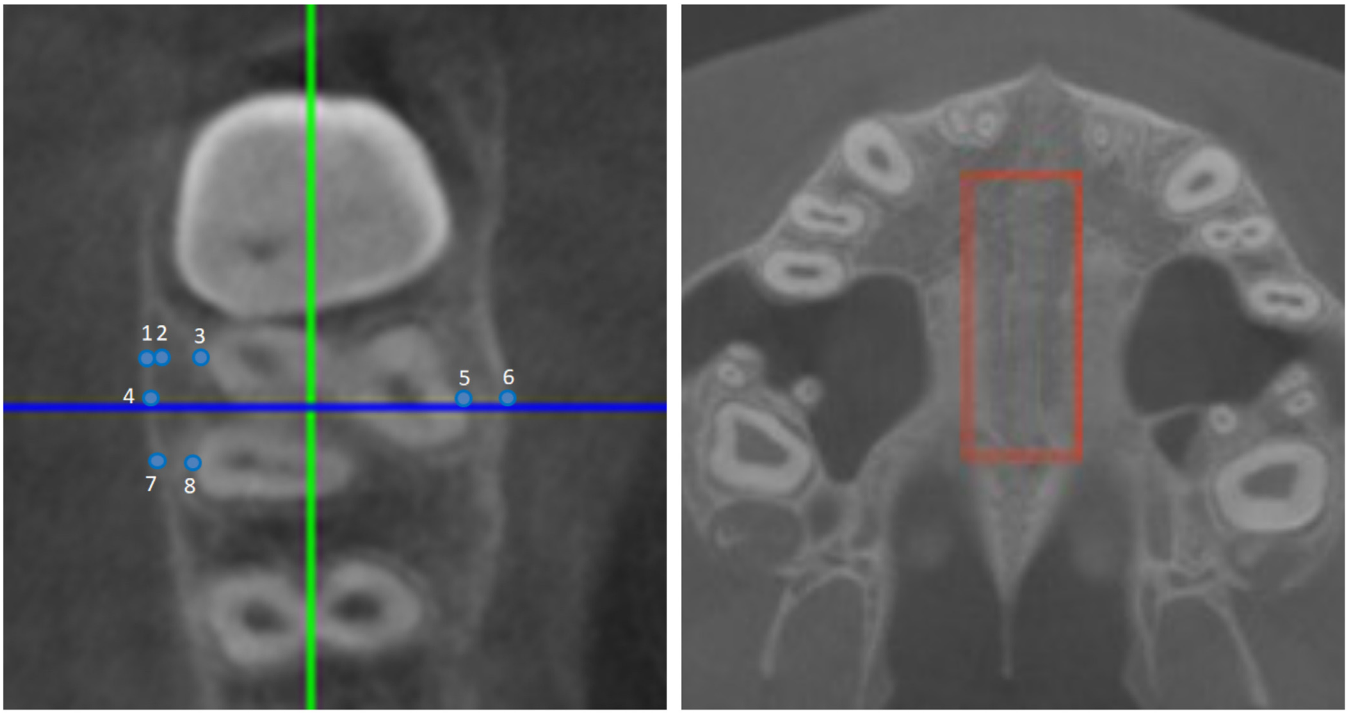

Fig. 4. (A) Axial view at furcation of the first maxillary molar, for linear distances: (1–2) Cortical bone thickness,(1–3) DB Root, (4–6) Total distance, (5–6) P Root, (7–8) MB Root, B) the gray density of the MPS from the distal of the incisive foramen to the distal of the first molar.

2.4. Results

In this study, the effect of Maxillary Expanders on bone architecture was measured by analyzing CBTC images of the patients, before and after RME treatment. The variables measured are shown in Table 2.

As shown in Table 3, the correlation of the variations of the MPS fractal variables with the variables Right MB (positive with 0.34), Left MB (positive with 0.59), and external maxilla (negative with −0.53), variables were significant ($p<0.05$). The correlation coefficient between the MPS and the external maxilla variables was −0.53 indicating a strong inverse correlation between the two variables.

Variables for which MPS reduced their measurement value (T0-T1>0) were Right DB, Right MB, Right Cortical Bone, Left DB, Left MB, and Left Cortical Bone.

Other variables for which MPS increased their measurement value (T0-T1 <0) were Right P, Right Total Distance, Left P, Left Total Distance, external Maxilla, Internal Maxilla, Palatal roots, Central Inter Fossa, 16, and 26. This means that RME affected the MPS fractal values, Right MB, Left MB, and External Maxilla and caused statistically significant changes.

For the null hypothesis, each relationship between variables was analyzed. The p values for these analyze are shown in Table 3. Statistically significant positive correlations were found for the relationships between the MPS ratio and both skeletally and dental effects of expander, the null hypotheses for these variables were accepted.

3. Discussion

In this study, we investigated the changes in the thickness of mid-palatal suture and the maxillary alveolar buccal bone after RME treatment. This study was first to investigate the effect of Maxillary Expanders on buccal bone plate thicknesses and the results showed statically significant changes after RME treatment. Several methods have been proposed to evaluate skeletal changes after RME

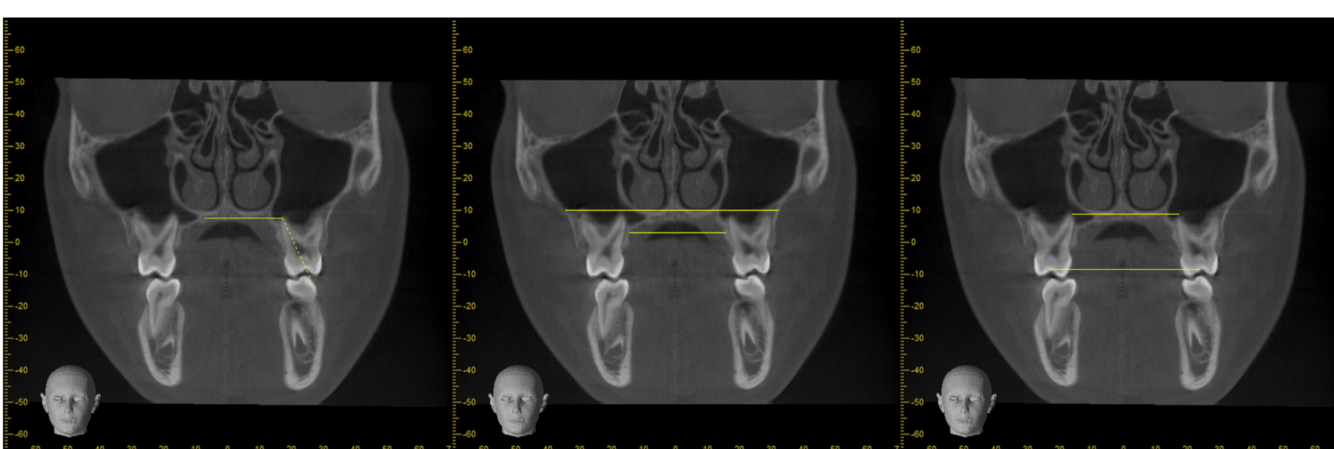

Fig. 5. Coronal view of the CBCT for linear measurements (A) tipping angles of 16 and 26, (B) External and internal maxillary distance and (C) Palatal root and Central fossa distance.

Table 2
Description of the variables.

Variable	Description
MPS	midpalatal suture from the distal aspect of the incisive foramen to the distal aspect of the first molar crown
MB Root	distance from the mesiobuccal root to the surface of alveolar buccal bone
DB Root	distance from the distobuccal root to the surface of alveolar buccal bone
P Root	distance from the palatal root to the surface of palatal alveolar bone
Total distance	(Alveolar plate thickness) defined as the distance between the outer and inner borders of the alveolar cortical plate in the area of the buccolingual direction of the maxillary first molar
Cortical bone thickness	the shortest distance between the outer buccal alveolar cortical plate and the mesial root area
External maxillary distance	measured from the outer limits of the buccal cortical plates, passing through the center of the maxillary first molar furcation
Internal maxillary distance	measured from the outer limits of the palatal cortical plates, passing through the center of the maxillary first molar furcation
Palatal root distance	the shortest distance between the left and right the first molars' palatal roots
Central fossa	the shortest distance between the left and right the first molars' central fossas
16 and 26 tipping angles	values of tipping of upper first molar after RME

treatment, one of which is high-resolution CBCTs [21-24]. Although some studies have used computed tomographic (CT) analysis to investigate the potential effects of RME [25, 26]. The CBCT method provides a better set of diagnostic parameters as well as high accuracy, due to its isotropic voxel resolution of 0.4 mm to 0.125 mm [27].. This method performs better than other methods in terms of the accuracy and quantity of diagnostic parameters and has become a widely used method for analyzing the effects of RME. Moreover, the activation protocol has been standardized for all subjects.

For Midpalatal Suture, we performed fractal calculation for Distobuccal (DB), Mesiobuccal (MB), Palatal (P), Total Distance and Cortical Bone. Of these, only MB showed significant change in response to RME treatment. In addition, linear measurements were made for External maxilla, Internal maxilla, Palatal roots and Inter Central fossa. In these measurements, only External maxilla showed a significant difference after RME. Therefore, we suggest that fractal analysis of MB and linear measurement of the External maxilla could be used to detect changes in the thickness of midpalatal suture and alveolar bone after RME. There are some previous studies showing the application of fractal analysis to bone changes. For example, some studies have suggested that fractal dimensions can be used to measure bone marrow density [28] and osteoporosis [29]. Their results showed that fractal dimensions reflect differences in bone density between different individuals and suggested that this method could be used directly to compare values between individuals.

In fractal computation, manual analysis of an image may contain operator-induced errors or inaccuracies that affect the final result. Therefore, developing automated methods or methods with fewer steps can help make the process of computing fractal dimensions easier and more reliable. Fractal analysis has been used in many different research areas, one of which is field of the dentistry [29]. Our results suggest that fractal analysis can be used as an indicator for the evaluating the dental and skeletal effects of RME treatment. In a similar study by Kowal et al. [30]., they used fractal analysis to detect midpalatal suture maturation. Their results showed a strong negative correlation between fractal dimension and maturation stage.

Incidences of dehiscence at the permanent first molars have been reported between 2.5% and 55% after RME [9, 31]. Before RME treatment, decreased buccal alveolar bone supporting the teeth could be a predisposing factor for patient to dehiscence. [32] Reduction in the thickness of buccal bone plate on permanent teeth has been demonstrated in several studies. For example, the results of these studies show that the buccal bone thickness on maxillary permanent first molars decreased from 0.86 to 0.78 fractal values on the left and from 0.82 to 0.79 fractal values on the right [26].

Garib et al. [27] conducted a short term study where a follow-up CT was performed at 30 days after the activation period to observe the changes midpalatal suture without considering data from the retention period. In addition, the evaluated time interval in previous studies was shorter than in our study [6, 26, 27]. However, Haas has suggested that, during the retention period, residual forces from the MPS could move the bone through the teeth and if there is a stuck by the appliance extension on permanent first molars, this could result in a loss of bone thickness on the buccal side [33].

Table 3
Descriptive statistics of quantitative variables before RME (T0) and after RME (T1).

		N: 42	T0	T1	*ΔT (T1-T0)*	Paired T-test** *(T1-T0)*	Spearman correlation ***	*p*****
Fractal measurement	Midpalatal Suture	1.15 (0.07)*	1.09 (0.13)*	−0.06	**0.002**		0.001	
	Distobuccal	Right	2.64 (0.55)	1.47 (0.65)	−1.13	**0.000**	−0.30	0.053
		Left	2.49 (0.48)	1.54 (0.57)	−0.95	**0.000**	−0.08	0.609
	Mesiobuccal	Right	1.94 (0.61)	1.00 (0.60)	−0.94	**0.000**	0.34	**0.027**
		Left	1.96 (0.61)	0.90 (0.49)	−1.06	**0.000**	0.59	**0.000**
	Palatal	Right	1.72 (0.54)	2.83 (0.87)	1.11	**0.000**	0.14	0.367
		Left	1.99 (0.52)	2.94 (1.06)	0.95	**0.000**	−0.38	**0.012**
	Total Distance	Right	15.19 (1.41)	15.37 (1.13)	0.18	**0.008**	0.21	0.166
		Left	15.28 (1.26)	15.48 (1.35)	0.20	**0.000**	−0.17	0.284
	Cortical Bone	Right	0.86 (0.16)	0.78 (0.16)	−0.08	**0.007**	0.19	0.227
		Left	0.82 (0.18)	0.79 (0.18)	−**0.03**	**0.017**	0.04	0.796
Linear Measurement	External maxilla	63.78 (4.12)	66.42 (0.42)	2.64	**0.000**	−0.53	0.000	
	Internal maxilla	27.82 (3.13)	29.40 (3.00)	1.58	**0.000**	−0.06	0.698	
	Palatal roots	31.54 (3.09)	35.18 (3.85)	3.64	**0.000**	0.30	0.051	
	Inter Central fossa	44.32 (3.14)	49.54 (3.41)	5.22	**0.000**	−0.21	0.166	
Angular measurement	Upper first molars	16	111.39 (4.88)	115.42 (5.93)	4.03	**0.000**	0.17	0.271
		26	111.72 (3.98)	116.99 (5.16)	5.27	**0.000**	−0.17	0.271

* standard deviation values are shown in parenthesis.
** Paired T-test results to compare mean variables before and after RME (p>0.05).
*** Spearman correlation coefficient test results to investigate the correlation between changes of fractal variable and other variables.
**** Spearman correlation coefficient test results p values (p>0.05).

In a previous study, periodontal tissue changes were evaluated after orthodontic tooth movement with fixed appliances. Then, vertical loss, bone thickness and angulation changes were measured for each tooth using CBCT [34]. In our study, angulation changes and vertical bone loss were not considered, but angulation changes of first molars after RME were reported with the similar appliances. In addition, it was reported that after RME treatment, the maxillary permanent first molars had a palatal inclination of approximately 3.5° relative to the deciduous teeth, as scanned by CBCT.

To reduce skeletal discrepancy, buccal tipping may occur on maxillary first molars when maxillary expansion is required with or without cross-bite [35]. When expansion is required at permanent molars, buccal tipping undesirably increases by approximately 3 to 4° toward the buccally [36]. We did not include vertical measurements and inclination changes in the study, which could be the subject of future research.

A recent systematic review suggests that although the loss of alveolar thickness of bone has been well documented in the literature when RME was performed with permanent first molars as anchors, its clinical results are not still clear [37]. Statistical comparison was made with bone loss of MPS, but the clinical significance of the reported bone loss may be questionable. It is important to investigate other factors for RME treatment that could play a relevant clinical role. Soft tissue could cover the alveolar bone defect, which is more common in the bone ridge as dehiscence or fenestration [38].

The MPS ratio was determined from CBCT scans. In the before maturation period, the suture is filled with connective tissue and is a wide gap between the maxillary bones [39]. Since this connective tissue is not completely calcified, thus, the suture region is radiolucent and equivalent in gray scale value to close to 0. In the maturation progress, connective tissue begin to form at the margins of the suture, becoming in a mixture of non-calcified tissue and calcified bone. As a result, the MPS density ratio increases during the maturation. During the adolescent period, suture area becomes calcified to an extent that resembles cortical bone, the bony spicules become increasingly interdigitated, and resulting in a MPS density close to 1.

The MPS density ratio could be useful for clinical applications. The priority usage is to determine for adolescents and young adults whether surgically assisted or conventional expansion. The second usage is to predict the skeletal effects prior to treatment. To obtain sufficient skeletal correction, patients with MPS density close to 1 will require more overall expansion, since the anchor teeth will have more tipping in these patients. Uprighting these teeth commonly lead to partial loss of the increased intermolar distance.

On the other hand, patients with MPS density close to 0 will require less expansion force to obtain the similar skeletal correction since, the molar teeth are tipless and can be held close to their post expansion position. These FD evaluation of the MPS density ratio make it a diagnostic parameter that helps adjust RME treatment for minimizing undesirable effects. If a CBCT scan image before treatment is available, deciding the ratio of the MPS density should be preferred in as much as it is a more meaningful way of understanding the response to expansion treatment. The changes in density after expansion suggest that RME may induce a decrease in MPS density.

4. Conclusion

The aim of this study was to investigate bone density using fractal analysis to evaluate the skeletal and dental effects of RME treatment in patients. The results obtained in this study are as follows:

1 There was a strong positive correlation between the number of MPS fractal dimensions and the left and right MB variables, which means that as the fractal value increased, the value of this variable increased. There was a negative correlation between the value of the fractal dimensions of the MPS and P and External Maxilla variables, which was moderate for P and strong for External Maxilla. The results suggest that the MPS has a significant negative correlation with the extent of skeletal expansion achieved by RME at the maxillary expansion level.

2 The results indicate that MPS fractal analysis can be used as a quantitative and objective method to evaluate the skeletal and dental effects of RME in patients.

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Conflict of interest

No conflict of interest for all authors.

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