ORIGINAL ARTICLE

Medical Journal of Western Black Sea
Batı Karadeniz Tıp Dergisi

Med J West Black Sea 2024;8(1): 43-51
DOI: 10.29058/mjwbs.1426984

Evaluation of Trabecular Changes Using Fractal Analysis After Orthodontic Treatment for Congenital Maxillary Lateral Incisor Missing with Space Opening and Closure Methods

Konjenital Maksiller Lateral Kesici Eksikliğinin Boşluk Açma ve Kapama Yöntemleriyle Ortodontik Tedavisi Sonrası Trabeküler Değişikliklerin Fraktal Analiz Yöntemiyle Değerlendirilmesi

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Cite this article as: Çiçek O et al. Evaluation of trabecular changes using fractal analysis after orthodontic treatment for congenital maxillary lateral incisor missing with space opening and closure methods. Med J West Black Sea. 2024;8(1):43-51.

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Received
28.01.2024

Revision
29.03.2024-12.04.2024

Accepted
13.04.2024

ABSTRACT

Aim: The aim of the study was to compare the trabecular changes in alveolar bone structure after the treatment of congenital maxillary lateral incisor missing (CMLIM) with space-opening and -closure methods by fractal dimension (FD) analysis.

Material and Methods: The study included 48 patients and three groups were formed: control (Group 1), space-opening (Group 2), and space-closure groups (Group 3). FD analysis was performed on panoramic images taken before (T0) and after (T1) treatment in the area of interest of trabecular alveolar bone determined in the distal apical region of the maxillary central incisor. For inter-group comparisons, the Kruskal-Wallis test was employed, while the Wilcoxon test was utilized for intra-group comparisons. The statistical significance was determined as $p<0.05$.

Results: No statistically significant differences were observed in the FD values of all groups at both T0 and T1 ($p>0.05$). In Group 2, a significant decrease in FD values was observed during the T1 period compared to T0, whereas Group 3 showed a significant increase ($p<0.05$).

Conclusion: It was observed that the alveolar bone trabeculation after orthodontic treatment for CMLIM was similar to the bone structure in patients who did not receive orthodontic treatment with both methods. It has also been concluded that in order to increase stability in space-opening cases, a consolidation period is needed for the mineralization of the alveolar structures before implant surgery, or, if possible, a space-closure method that eliminates the need for these should be preferred.

Keywords: Orthodontics, malocclusion, space closure, fractals, cancellous bone

ÖZ

Amaç: Çalışmanın amacı, konjenital maksiller lateral kesici eksikliğinin (KMLKE) boşluk açma ve kapama yöntemleri ile tedavisi sonrası alveoler kemik yapısında meydana gelen trabeküler değişiklikleri fraktal boyut (FD) analizi ile karşılaştırmaktır.

Gereç ve Yöntemler: Çalışmaya 48 hasta dahil edildi ve üç grup oluşturuldu: kontrol grubu (Grup 1), boşluk açma grubu (Grup 2) ve boşluk kapama grubu (Grup 3). Maksiller santral kesici dişin distal apikal bölgesinde belirlenen trabeküler alveolar kemiğin ilgi alanında tedavi öncesi (T0) ve sonrası (T1) alınan panoramik görüntüler üzerinde FD analizi uygulanmıştır. Gruplar arası karşılaştırmalarda Kruskal-Wallis testi kullanılırken grup içi karşılaştırmalarda Wilcoxon testi kullanıldı. İstatistiksel olarak anlamlılık düzeyi p<0.05 olarak belirlenmiştir.

Bulgular: Hem T0 hem de T1'de, tüm grupların FD değerleri arasında istatistiksel olarak anlamlı bir fark bulunmamıştır (p>0.05). Grup 2'de T0'a kıyasla T1 döneminde FD değerlerinde anlamlı bir düşüş gözlenirken, Grup 3'te anlamlı bir artış görülmüştür (p<0.05).

Sonuç: KMLKE için ortodontik tedavi sonrası alveoler kemik trabekülasyonunun her iki yöntemle de ortodontik tedavi görmeyen bireylerdeki kemik yapısına benzer olduğu görüldü. Ayrıca, boşluk açılan vakalarda stabiliteyi arttırmak amacıyla implant cerrahisi öncesinde alveolar yapıların mineralizasyonu için bir konsolidasyon periyodunun gerekli olduğuna veya mümkünse bunlara ihtiyacı ortadan kaldıran boşluk kapatma yönteminin tercih edilmesi sonucuna varılmıştır.

Anahtar Sözcükler: Ortodonti, maloklüzyon, boşluk kapama, fraktal, kansellöz kemik

INTRODUCTION

The congenital missing permanent teeth, excluding third molars, affects 3-10% of individuals, or almost one in 10-12 of the population (1-3). Congenital maxillary lateral incisor missing (CMLIM) has an important place in this percentage; in fact, according to many studies, the maxillary lateral incisors represent the teeth most frequently missing congenitally following the third molars (4-9). In permanent dentition, congenitally missing two or one of the maxillary lateral incisors causes a discrepancy in the maxillary dentition and, consequently, in the mandibular dentition and presents serious aesthetic problems, especially in the anterior region (10). Due to the significant effect of this condition on both dental and facial aesthetics, patients show a high demand for orthodontic treatment.

There are several treatment options for the management of CMLIMs. Treatment options include maintaining and accepting the space, reshaping canines as lateral incisors, space-closure or space-opening, preserving or redistributing the space to fit the size of the final restoration with orthodontic treatment in preparation for future prosthetic treatment (11). However, as each patient is unique, the necessary treatment plan should be prepared for each patient with careful diagnosis and a comprehensive multidisciplinary study (12).

It is important to be aware of the aesthetic and functional needs of the patient and to determine how the desired tooth movements will affect the alveolar bone structure when deciding on the treatment procedure. In addition to the clinical examination, radiographic evaluation is also necessary to select the treatment procedure that will provide the most effective and optimal dentofacial outcome for the patient. For this purpose, radiographic diagnostic tools, such as dental panoramic radiographs (DPRs), are frequently used routinely in addition to the clinical examination (13-15).

The advantages of DPRs include their widespread use and frequent preference in routine care (16). Studies have shown that the morphology of the jaw bones can be analysed on DPRs and alterations in the alveolar bone's trabecular pattern can be detected with periodically taken DPRs (17,18) and many researchers have used fractal dimension (FD) analysis to convert these changes in bone structure into numerical data (18-22). FD analysis has also been used in the medical field to assess the progression, course and severity of disease, or to detect disease that has not yet occurred, due to its advantages such as the lack of invasiveness, ease of application and independence from projection geometry (23-25).

The fractal concept describes complex and compound structures that cannot be identified by common shapes such as square, circle or round and that cannot be determined in terms of morphology and dimensions (22). Trabecular bone shows a "fractal" characteristic due to its similarity and branched structure. Fractal dimension analysis is also one of those methods that can help to identify or numerically express the complex shapes and is used to evaluate the complex alveolar bone tissue (20). Numerous studies in the dentistry literature have evaluated the use of FD analysis as a method to detect the effect of orthodontic functional appliance treatment using standardized DPR on alveolar bone trabeculation, to provide qualitative/quantitative bone analysis during and after implant preparation, or detect osteoporotic changes in bone tissue that might be caused on by a metabolic disease (13,17,24,26,27). However, there are no studies on trabecular bone changes in the orthodontic treatment of CMLIMs.

Therefore, in this study, the bone trabeculation before orthodontic treatment in patients with CMLIM and the trabeculation of the remodeled alveolar bone after treatment in those areas where space-opening and -closure methods were applied with orthodontic tooth movements were evaluated by FD analysis on panoramic images. The study's first null hypothesis (H0) posits that the FD values within groups show no significant difference following treatment. The study's second null hypothesis contends that the FD values among the groups do not differ significantly after treatment.

MATERIAL and METHODS

This retrospective study was performed by analyzing panoramic images from clinical archival records. Prior to the study, ethical approval was granted by the Zonguldak Bülent Ecevit University Non-Interventional Clinical Research Ethics Committee, with the approval dated 22 November 2023 and bearing the decision number 2023/22-4. The sample size of the study was calculated using the G*Power program(version 3.1.9.7; Franz Faul, University of Kiel, Kiel, Germany), based on a similar previous study by Amuk et al. (28). Accordingly, α error probability (α error probe) was taken as 0.05, the power of the study (1 – β error probability) as 0.95 and effect size as 1.141. Thus, if at least 18 samples in total were included, the actual power of the study was calculated as 98%. In order to further increase the power of the study, a total of 48 patients (10 males, 38 females) who had completed treatment at the Orthodontics Department were recruited and divided into three groups: the control group (n=16, Group 1), which did not undergo orthodontic treatment, and the study groups for space-opening (n=16, Group 2) and space-closure (n=16, Group 3).

The inclusion criteria for the study groups were defined as follows: presence of congenital bilateral missing maxillary lateral incisor, no history of trauma, completed fixed orthodontic treatment, no having systemically bone disease, and not having good quality panoramic radiographs with high resolution. The control group was selected among systemically healthy patients with no previous orthodontic treatment and no congenitally missing teeth. To ensure standardization, patients in all groups were selected from those with normal vertical and sagittal skeletal values (Table 1). Patients lacking even one of these criteria were excluded from the study. Demographic (gender, age, and treatment duration) and cephalometric (SNA, ANB, and SN/GoGn angles) data of the patients are shown in Table 1.

For the study, measurements were made in the defined region of interest on panoramic radiographs taken by an X-ray machine (Veraview IC5 HD, J Morita Mfg. Corp., Kyoto, Japan) before (T0) and after (T1) treatment. The panoramic radiographs were captured with the Frankfurt horizontal plane and the bite bar accurately positioned to ensure standardization.

Angular measurements for all patients were conducted using lateral cephalometric radiographs obtained from a cephalometric X-ray machine (Veraviewepocs 2D, J Morita Mfg. Corp., Kyoto, Japan). The SNA, ANB, and SN/GoGn angles were measured on these radiographs employing the NemoCeph digital analysis program (Nemotec, 2006, Madrid, Spain), and their definitions are detailed in Table 2.

Orthodontic Treatment Protocol

All patients received fixed orthodontic treatment involving metal brackets, adhering to a 0.022 × 0.028 inch slot MBT prescription. Following the application of 0.012 inch, 0.014 inch, 0.016 inch heat-activated round NiTi wire and 0.016 inch round stainless steel wire, respectively, 0.019 × 0.025 inch square heat-activated NiTi wire and 0.019 × 0.025 inch square stainless steel wire (American Orthodontics, Sheboygan, WI, USA) were placed (29).

Table 1: Demographic and cephalometric characteristics of the patients.

		Group 1	Group 2	Group 3
Age	(Year±SD)	18.6 ± 4.01	15.4 ± 2.8	15.1 ± 2.8
Gender, n (%)	Female	13 (81.2)	14 (87.5)	13 (81.2)
	Male	3 (18.8)	2 (12.5)	3 (18.8)
Treatment duration (Year±SD)			2.28 ±0.87	3.33±1.34
SNA angle		81.56 ± 1.5	81.6 ± 4.2	79.7 ± 2.6
ANB angle		2.3 ± 1.0	2.0 ± 1.3	2.1 ± 1.2
SN/GoGn angle		33.5 ± 3.1	32.5 ± 3.4	34.1 ± 3.9

SD: Standard deviation, **n:** sample size, **%:** percentage

Table 2: Cephalometric angles and definitions.

Parameters	Description
SNA	The angle between the Sella-Nasion and the Nasion-A point lines. It determines the position of the maxilla in the anterior-posterior direction relative to the cranium.
ANB	The angle between the Nasion-A point and Nasion-B point lines. It determines the position of the maxilla and mandible relative to each other in the anterior-posterior direction.
SN/GoGn	The angle at the intersection of Sella-Nasion and Gonion-Gnathion lines. It is used to determine the vertical direction of the facial skeleton.

In the space-opening group, the mechanics were applied using open coil springs on 0.019 × 0.025 inch square stainless steel wireIn the space closure group, a 0.019 × 0.025 inch square stainless steel wire was installed in one session, followed by the placement of a 1.6 mm × 8 mm temporary anchorage device (Aarhus System, American Orthodontics) in the alveolar region between the roots of the maxillary central incisors at the middle third of the root level under local anesthesia. The spaces were closed with minimum anchorage by applying tie-back mechanics with indirect anchorage from the miniscrew (29).

Fractal Analysis

FD analysis procedures were conducted on the same computer by the same investigator using the box counting method developed by White and Rudolph (30) with ImageJ (version 1.53), an image analysis program from the National Institute of Health Image (30).

The procedural steps required for FD analysis were performed separately at T0 and T1 periods, respectively, as follows: For each patient, a 20x20 pixel trabecular bone area of interest was detected in the region corresponding to the distal apical triad of the maxillary central tooth 8-10 mm distal and 7-8 mm inferior to the Spina Nasalis Anterior point, taking care to avoid any pathology, lamina dura, maxillary sinus and tooth root in the selected regions (Figure 1 and 2).

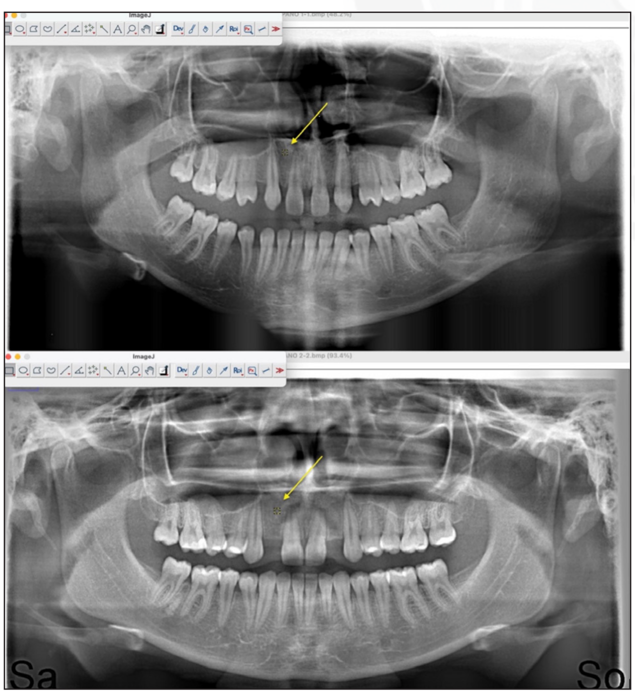

Figure 1: Selection of a 20x20 pixel area of interest on a panoramic radiograph before (panoramic radiograph above) and after (panoramic radiograph below) space-opening treatment. The yellow arrow indicates the selected area of interest.

The area was selected in the image and then duplicated and saved in 8-bit format. The Gaussian filter (sigma= 35 pixels) was used on the duplicated image for blurring, and 'subtraction' was applied to subtract it from the origin image. The image was transformed into a 'binary' format by adding a grey pixel value of 128 to each pixel position. Respectively, erosion and dilation processes were applied to the image for remove noise. Then 'Invert' option was used to invert the image and then skeletonize it. This process made sure that the trabeculae were only determined by their outlines. Using the 'box counting' method in ImageJ, FD analysis was performed on the skeletonized image (Figure 3).

Statistical Analysis

Statistical Package for Social Sciences (SPSS, version 26, IBM Corporation, NY, USA) program was used for statistical analysis of the data obtained in the study. Normality distribution of the data was examined by Shapiro-Wilk test. Since the data were not normally distributed, the Kruskal-Wallis (Mann-Whitney U) test was used for inter-group comparisons and the Wilcoxon sign rank test for intra-group. The reliability test of the measurements was evaluated with Spearman's rho correlation coefficient. The level of statistical significance was set at $p<0.05$.

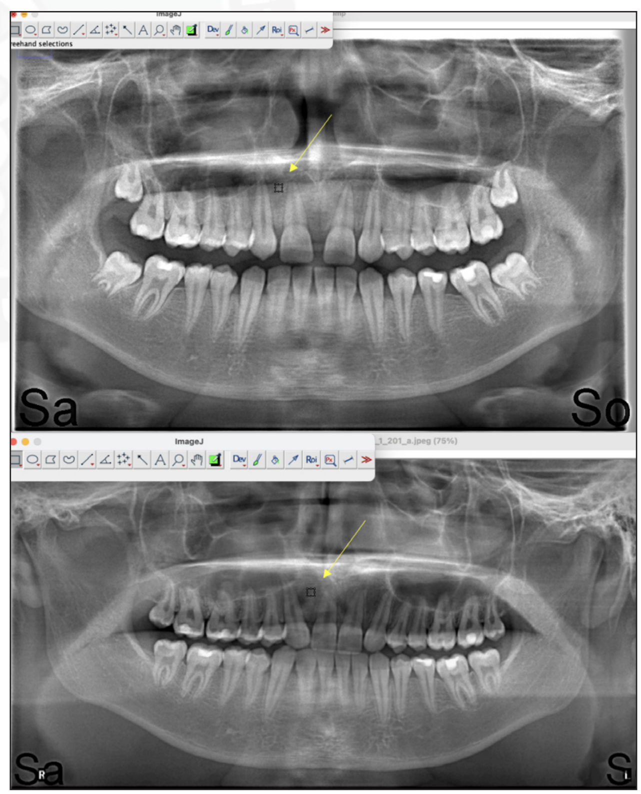

Figure 2: Selection of a 20x20 pixel area of interest on a panoramic radiograph before (panoramic radiograph above) and after (panoramic radiograph below) space-closure treatment. The yellow arrow indicates the selected area of interest.

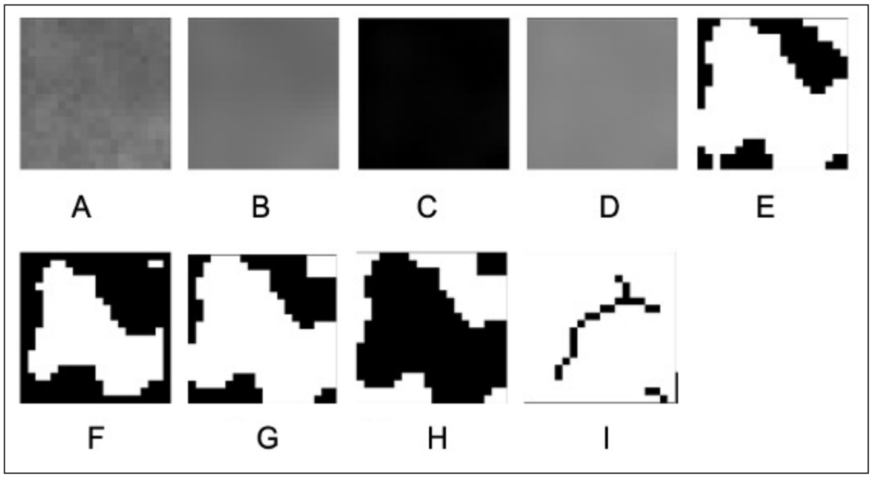

Figure 3: The procedure steps for Fractal Dimension analysis. A) Duplicated image, B) Blurred image with Gaussian filter, C) Subtraction of the blurred image from the original, D) 128 gray addition, E) Binarization process, F) Erosion process, G) Dilation, H) Inverted image, I) Skeletonization.

Table 3: Statistical analysis results for intra- and inter-groups.

		Group 1[a]	Group 2[b]	Group 3[c]	p
T0	(Mean±SD)	1.44 ± 0.13	1.43 ± 0.11	1.42 ± 0.15	0.232 [K]
	(Median)	1.43	1.44	1.43	
T1	(Mean±SD)	1.44 ± 0.13	1.42 ± 0.15	1.43 ± 0.15	0.123 [K]
	(Median)	1.43	1.41	1.43	
T0/T1 difference	(Mean±SD)		0.009 ± 0.014	0.01 ± 0.012	0.001 * [M]
	(Median)		0.001[c]	0.007[b]	
Intra-group difference	p		0.037 * [W]	0.008 * [W]	

[K]: Kruskal-wallis / [M]: Mann-Whitney U test / [W]: Wilcoxon test
[a]: Difference with Group 1 in the same row p< 0.05 / [b]: Difference with Group 2 in the same row p< 0.05 / [c]: Difference with Group 3 in the same row p< 0.05

RESULTS

In order to evaluate the diagnostic reproducibility of intra-observer measurement reliability, a sample of 16 randomly selected patients was analyzed to identify the level of observer reliability. The results were remarkable, showing excellent observer reliability with a Spearman's rho correlation coefficient of 0.936 between measurements taken four weeks apart.

The mean FD value of the control group was 1.44 ± 0.13. At T0, the mean FD value of the space-opening group was 1.43 ± 0.11, while the space-closure group was 1.42 ± 0.15. At T1, the mean FD values of the space-opening and -closure groups were 1.42 ± 0.15 and 1.43 ± 0.15, respectively.

During the T0 period, there were no statistically significant differences in the FD values across all groups. (p>0.05). Similarly, at T1, no statistically significant differences were found in the FD values measured across all groups (p>0.05). According to Wilcoxon test, it was found that the FD values at T1 in the space-opening group showed a statistically significant decrease compared to T0 (p<0.05). On the other hand, the FD values at T1 in the space-closure group were statistically significantly higher than T0 (p<0.05). It was observed that the amount of T0/T1 change was statistically significantly higher in Group 3 than in Group 2 (p<0.05). The results of the intra- and inter-group statistical analyses are presented in Table 3.

DISCUSSION

In our study, the trabecular changes in the alveolar bone structure after treatment of CMLIM with space-opening and -closure methods were evaluated using fractal dimension analysis on DPRs. At T1, compared to T0, there was a significant decrease in FD values in the space-opening group and an increase in the space-closing. In addition, no significant differences in FD values were found between groups at T1. Based on our findings, the first null hypothesis of the study was rejected, while the second null hypothesis was accepted .

Fractal dimension analysis has recently become a widely preferred method in dentistry due to it is applicable and easily accessible, and unaffected by parameters such as radiation dose and projection angle, and provides objective information about trabecular bone structure (31). It has been reported that FD, which can be defined on radiographic images, reflects the mineral change in trabecular alveolar bone (23,25,32) and studies have shown a correlation between trabecular bone morphology and FD (33,34).

The literature in orthodontics shows that FD analysis has been performed in many studies to explore the impact of functional appliance treatment and malocclusion on mandibular condyles and to evaluate the effect of orthodontic treatment on the mandibular bone (15,28,35-38). In addition, Ok and Kaya, in their study investigating the connection between dental effects of RME (rapid maxillary expansion) treatment and the patency of the midpalatal suture suggested that fractal analysis can also applied to determine the modifications of midpalatal suture and alveolar bone following RME treatment (15). In this study, FD analysis was employed to examine trabecular changes in remodeled alveolar bone following fixed orthodontic treatment of patients with congenitally missing maxillary lateral incisors, using both space-opening and space-closure techniques.

Fractal dimension analysis is a method that identifies physiological and morphological characteristics of biological tissues with the help of clinical diagnostic materials (39). It has been reported that fractal analysis is unaffected by variables such as projection angle, which can vary between -10 and +30, and radiodensity but is affected by parameters such as the shape and size of the region of interest (ROI) selected as reference (16,23,25,33). Heo et al. identified ROIs of 200x200 pixels from the operative fields on the DPRs of bilateral sagittal splint ramus osteotomy patients diagnosed with mandibular prognathism and evaluated the bone trabeculation changes in the relevant regions with FD analysis and stated that fractal analysis can be used to examine the bone repair process following orthognathic surgery (40). In the present study, after determining a 20x20 pixel ROI from the same region in each patient for standardization, changes in alveolar bone structure were evaluated separately at T0 and T1 by using FD analysis. The fractal dimensions of alveolar bone after orthodontic treatment in the space-opening and space-closure treatment groups compared to beginning showed significant differences.

Tooth displacement in the alveolar bone, even if controlled by orthodontic treatment, alters the surrounding tissues supporting the tooth. The purpose of orthodontic treatment is to provide the desired tooth movement while minimizing adverse effects on the quality of the alveolar trabecular bone (41) and maintaining a stable post-treatment status (36). Instead of using the more common panoramic radiographs, Otis et al. evaluated the relationship between apical external root resorption and alveolar bone density using FD analysis (37). Their research indicated that there was no correlation between the extent of root resorption and fractal dimension (FD) in patients undergoing fixed orthodontic treatment, given the consistent FD values before and after treatment. Rothe et al. focused their study on analyzing the trabecular structure of the alveolar bone from regions of interest (ROI) located solely at the apices of mandibular incisors, which are recognized as a risk factor for the orthodontic relapse of these teeth (36). According to them, the FDs of the relapse group and the stable group were found to be not significantly different. Similarly, in our study, since structures such as periodontal ligaments and tooth roots are involved in the relevant area and further reduction of the selection area may lead to misleading results, the middle and coronal thirds of the space-opening and -closure areas were not preferred and the selection area was limited to the distal apical region in order to reach the correct result. Statistically significant differences were not observed in the FD values between the control and study groups at both T0 and T1. Amuk et al., in a study of class II patients treated with Herbst appliance reported that FD values increased in the central condyle during functional treatment but decreased in the superoposterior region and increased in the angulus mandible during fixed orthodontic treatment after Herbst (28). In another study, Bolat Gümüş et al. determined the changes in mandibular bone trabeculations in patients with class II malocclusions after functional orthodontic treatment using monoblock or twin-block appliances (22). They concluded that FD values of mandibular condyle were not significantly different before and after treatment. They reported that the FD values of mandibular corpus area had greatest values before treatment and there was a significant decrease with treatment. In the present study, we observed a significant decrease at post-treatment FD values of patients treated with space-opening method, whereas the FD values of patients treated with the space-closure method showed a significant increase. Additionally, no significant difference was observed in the FD values among the groups at T1. During the tooth movement that occurs with orthodontic treatment, the alveolar bone undergoes a remodelling process and some osteopenia, i.e. a decrease in bone density, occurs (41). The long-term durability of mini- and endosseous implants is critically dependent on the trabecular bone structure (42). This is especially important in cases where the implant site has been created orthodontically.

Various techniques are available for assessing trabecular bone structure. Haghnegahdar et al. in 2016, examined changes in bone trabeculation afterorthodontic treatment in children, young adults, adults and both genders with using FD analysis on panoramic images (39).Following fixed orthodontic treatment, they observed that the trabecular structure in the interdental regions of the mandible of children had become more dense. In contrast, the trabeculation of young adult patients had become less dense. They concluded that after fixed orthodontic treatment, a certain follow-up period would be necessary before endosseous implants could be placed. In this study, patients treated with the space-closure method had significantly higher FD values compared to beginning of the study, while patients treated with the space-opening method had statistically significantly lower FD values. It was discovered that the space-closure group had a significantly higher T0/T1 change than the space-opening group.

Köse et al., investigated whether there was a relation between total orthodontic treatment period and value of FD in patients of different ages (38). They found that total treatment period had a significant effect on fractal dimension and concluded that the physiological characteristics of alveolar trabecular bone and the estimation of tooth movement in orthodontics could be determined by fractal dimension values. In this study, it was observed that physiologic characteristics of the alveolar bone may change according to the space-opening and -closure methods, but the amount of this change was maintained within normal limits.

Tooth loss or congenital tooth missing may cause the loss of the buccolingual width and vertical height of the alveolar ridge (43). Several studies have reported a reduced buccolingual width following the space-opening treatment of CMLIM (44,45). In fact, some researchers have recommended that implant placement should be more palatal or delayed until there is sufficient bone thickness at the implant site, even though alveolar bone loss is more consistentduring the retention phase (43,46). In this study, a significant reduction in the FD values of the trabecular structure was observed in the space-opening group, which is believed to result from a decrease in buccolingual bone thickness.

Studies have also reported changes in sagittal and vertical angles after orthodontic treatment of CMLIM (10). In addition, differences in FD values in the alveolar bone of different skeletal malocclusions have been reported (47,48). Therefore, our study was standardized by adding patients with normal skeletal angles in order to eliminate the potential altering effect of different skeletal components on the FDs of the trabecular alveolar structure.

In addition, some studies have shown that early preprosthetic space-opening with orthodontic appliances for future implant treatment reduces the bone density in the alveolar crest and therefore orthodontic space-opening should be postponed as long as possible (44,49). In our study, the initial ages of the study participants were 15.4±2.8 years for group 2 and 15.1±2.8 years for group 3, and the duration of treatment was 2.28±0.87 for group 2 and 3.33±1.34 for group 3, respectively. This allowed the patients to be prepared for prosthetic implant treatment without delay.

It has been reported that selecting a larger region of interest in the fractal analysis method may provide more information about the trabecular structure (38). The limitations of this study are that the maximum size of the region of interest was 20 x 20 pixels to exclude the surrounding anatomical structures and that trabecular changes were not evaluated after dental implant placement in patients with space-opening. The inclusion of the only skeletal class I individuals with CMLIM in this study is another limitation. Future studies could investigate the effect of orthodontic treatment of CMLIM patients with different skeletal values on the alveolar bone structure with space-opening and -closure methods. However, previous studies have reported that the results of FD analysis on two-dimensional DPRs routinely taken for orthodontic diagnosis are reliable and reproducible (50-52).

Fractal dimension analysis can be an essential tool for the orthodontist to have an idea about the physiological changes that occur in the alveolar bone structure after treatment and to quantitatively evaluate the bone before the implant placement stage, especially in cases where the implant spaces will be created with orthodontic treatment for CMLIMs.

CONCLUSIONS

The alveolar bone trabeculation after treatment with the space-opening method showed a less mineralized and more porous structure with a significant decrease in the FD values compared to beginning, while the alveolar bone trabeculation after treatment with the space-closure method showed a more complex and dense structure with a significant increase in FD values compared to the beginning. It was concluded that the trabecular changes in remodeled alveolar bone after treatment of CMLIMs with space-opening or space-closure methods were not different from a bone structure in patients who did not receive orthodontic treatment. In addition, due to the decrease in mineralization observed with the decrease in FDs of trabecular bone in the space-opening method, it is concluded to wait for consolidation, which may last up to 6 months, before implant surgery for prosthetic rehabilitation. Furthermore, it was recommended that the space-closure method be preferred, as it addresses the anatomical disadvantages in the alveolar area where space has been opened, thus eliminating the need for implant surgery.

Acknowledgment

None.

Author Contributions

Conceptualization and methodology: **Orhan Çiçek, Samet Özden,** Software: **Orhan Çiçek, Samet Özden, Deniz Arslan,** Validation: **Orhan Çiçek, Samet Özden, Deniz Arslan,** Formal analysis: **Orhan Çiçek, Samet Özden, Deniz Arslan,** Investigation: **Orhan Çiçek, Samet Özden, Deniz Arslan,** Resources: **Orhan Çiçek, Samet Özden, Deniz Arslan,** Data curation: **Orhan Çiçek, Samet Özden, Deniz Arslan,** Writing and original draft preparation: **Orhan Çiçek, Samet Özden, Deniz Arslan,** Writing, review and editing: **Orhan Çiçek, Samet Özden,** Visualization and supervision: **Orhan Çiçek, Samet Özden,** Approval: **Orhan Çiçek, Samet Özden.** All authors have read and agreed to the published version of the article.

Conflicts of Interest

The authors declare no conflicts of interest.

Financial Support

This study received no external funding.

Ethical Approval

The study was conducted in accordance with the Declaration of Helsinki. Ethical approval for the study was given by Zonguldak Bülent Ecevit University Non-Interventional Clinical Research Ethics Committee dated 22 November 2023 and decision number 2023/22-4.

Review Process

Extremely and externally peer-reviewed.

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