IDR International Dental Research

Int Dent Res 2023; 13(S1): 38-43
https://doi.org/10.5577/idr.2023.vol13.s1.6

Original Article Open Access

Evaluation of the effect of class II fixed orthodontic treatment on the periradicular bone structure of endodontically treated mandibular molar teeth using fractal dimension analysis

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Received: 28 June 2023
Revised: 19 August 2023
Accepted: 30 August 2023

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How to cite this article:

Küçükkaraca E, Sarıçam E. Evaluation of the effect of class II fixed orthodontic treatment on the periradicular bone structure of endodontically treated mandibular molar teeth using fractal dimension analysis. Int Dent Res 2023;13(S1):38-43.
https://doi.org/10.5577/idr.2023.vol13.s1.6

Abstract

Aim: The aim of this study was to investigate whether changes in periradicular tissues with orthodontic movement of root canal-treated teeth differ from those without root canal treatment using fractal dimension analysis (FA).

Methodology: A retrospective archive study was performed using panoramic radiographs taken before (T1) and after (T2) fixed orthodontic treatment. Panoramic radiographs of a total of 32 mandibular 1st and 2nd molar teeth were divided into groups: Group 1 (n:17), the control group, comprised radiographs of mandibular 1st or 2nd teeth without root canal treatment, and Group 2 (n:15) comprised radiographs of 1st or 2nd mandibular molars with root canal treatment. Fractal analyses were performed in four different regions—the periapical, bifurcation, mesial periapical, and distal periapical regions—of the mandibular molar teeth included in the study for a total of 128 analyses.

Results: In the control group, orthodontic treatment did not make a statistically significant difference to the fractal dimension values in the four regions of the tooth ($p > 0.05$). In the endodontically treated group, the fractal dimension values of the mesial periapical regions increased statistically significantly after orthodontic treatment ($p < 0.05$).

Conclusion: The FA values of this study showed that more biological interaction occurred in the root canal treatment group and in the mesial periapical region. Thus, it is important to keep orthodontic force within the tooth's physiological limits to avoid damaging the tooth in the periapical areas where stress accumulates during orthodontic treatment.

Keywords: Fractal analysis, orthodontic tooth movement, endodontically treated teeth, class II orthodontic treatment, molar teeth

Introduction

With advancements in technology and materials science and increasing aesthetic awareness, orthodontic treatment has become popular among adolescents and an increasing number of adults. With the rise in adult patients requesting orthodontic treatment, the presence of problems such as caries, apical lesions has similarly increased, requiring the cooperation of endodontic and orthodontic specialties (1, 2).

Orthodontic forces used to move teeth have been reported to cause vacuolization, bleeding, congestion, circulatory changes, and fibrinolysis effects on the dental pulp. Orthodontic tooth movement can cause biological reactions in the dental pulp and periodontal ligament, including neurovascular disturbances, triggers of inflammatory responses, degenerative changes, increased neural activity and /or altered sensitivity, and decreased pulpal blood flow (1, 3-5).

The alveolar bone is remodeled by forcing resorption on the compressive side and apposition (formation) on the tensile side of the periodontal ligament using mechanical stimuli generated during orthodontic tooth movement. This causes the tooth to move in the socket in response to orthodontic force. However, since this movement is controlled by cellular mechanisms, areas of pressure and tension can form on either side of the periodontal ligament depending on the type of force applied (5).

In a study by Wickwire et al. endodontically treated teeth were found to move similarly to untreated teeth, while endodontically treated teeth showed more root resorption (6). However, Spurrier et al. discovered that teeth that had undergone endodontic treatment exhibited less external apical root resorption those that had not (7). Few studies have examined the effects of endodontic treatment on teeth with apical lesions or apical periodontitis or on teeth with a history of periradicular surgery (8, 9).

Fractal dimension analysis (FA) is a statistical texture analysis that uses mathematics to describe complicated forms and structures. FA expresses the roughness of a texture and shows the complexity of a form by indicating the self-similarity of texture variations at different scales. The complexity of the structure is represented by the value of the fractal dimension (FD) (10-12).

The most widely used method in FA implementation is the box count method, which was first described by Russell et al (13). Box counting algorithms are often used to evaluate the structure of trabecular bone by analyzing the bone and marrow regions. This method evaluates the boundaries of the trabecular bone and bone marrow, with a higher value indicating a more complex structure. FD values are related to changes in bone density and reflect bone mineral loss (10, 14, 15).

In examination of the bone and marrow regions of the trabecular cortex, the box-counting algorithm is frequently used to quantify the trabecular structure, made up of the trabecular bone and bone marrow boundaries, with a higher score suggesting more complicated structures. FD values represent variations in bone density and are related to changes in bone mineral levels (10, 14, 15). In the box counting method algorithm, the trabecular bone is covered by a box grid, and the boxes containing trabecular bone are counted by the computer program in the grids created by boxes with diameters ranging from 2–64 pixels. The FD value is determined by the total number of boxes with trabecular bone, which is determined by the box size of the grid and the slope of the line that fits the points on the graph of these variables drawn on a logarithmic scale (13, 16, 17).

The analysis of bone structure to determine bone health has important applications in many areas of medicine. Using images obtained using digital imaging systems, mathematical image analysis methods can benefit qualitative and quantitative research into bone density and alveolar bone structure (13, 16, 17). FA has been reported to be a valuable diagnostic tool for objectively analyzing alveolar bone (18). The biological responses that occur in the teeth and periradicular tissues as a result of the mechanical force applied during orthodontic treatment have always been a topic of interest (3-5). Although there are many studies on functional orthodontic treatments and their effects on periradicular tissues (19-22), there are not many studies on the effects of fixed orthodontic treatments on surrounding tissues (6, 7, 23).

The purpose of this study was to use FA to investigate whether changes in periradicular tissue during the orthodontic movement of root canal-treated teeth are different from those of untreated teeth. The null hypothesis of this study was that there would be no change in the periradicular tissues after orthodontic treatment of 1st and 2nd molars with and without a history of root canal.

Materials and Methods

This is a retrospective study employing radiographs. The project was approved by the ethics committee of Ankara Yıldırım Beyazıt University (2023-228/05)

The power analysis of the study was performed using G*Power (version 3.1, Heinrich Heine Universität, Düsseldorf, Germany) and reference information from similar previous studies (22). As a result of the power analysis, the total sample size was found to be 28 (a = 0.05, effect size [dz]: 0,6384695, critical t: 1,7032884, non-centrality parameter: 3.3784630, and power (1-b) = 0.95.]

In this study, panoramic radiographs of 52 patients who underwent fixed orthodontic treatment at Ufuk University Ridvan Ege Hospital Oral and Dental Health Center between 2016 and 2019 were scanned at the beginning (T1) and end of treatment (T2).

Based on these radiographs, patients who met the following inclusion criteria were included in the study:

- Good-quality panoramic radiographs at the beginning and end of orthodontic treatment
- Well-filled root canal-treated mandibular first and second molars without periapical lesions prior to orthodontic treatment
- Individuals with class II malocclusion who underwent fixed orthodontic treatment by mesialization of the mandibular molar with class II intermaxillar elastics

The exclusion criteria were as follows:

- Panoramic radiographs at the beginning and end of orthodontic treatment with poor acquisition quality
- Mandibular first and second molars that underwent root canal treatment following orthodontic treatment
- Mandibular first and second molars that underwent root canal treatment and had periapical lesions before or after orthodontic treatment

Figure 1. Selected ROIs for fractal analysis of mandibular molar teeth.

A total of 32 mandibular teeth (first and second molars) on radiographs that met the inclusion criteria were divided into the following groups:

- **Group 1 (n=17):** mandibular first and second molars without any root canal **treatment (control)**
- **Group 2 (n=15):** mandibular first or second molars with root canal treatment

Fractal analyses were performed in four different regions (periapical, bifurcation, mesial, and distal) of each tooth included in the study, resulting in a total of 128 regions.

Fractal analyses

The regions of interest (ROIs) were determined in the bone tissue in the area to be analyzed on panoramic radiographs of patients before and after orthodontic treatment. All ROIs chosen for the analysis had the same size and position (30×30 pixels) and position; therefore, the chosen ROIs were standardized and repeatable. ROIs for the before and after radiographs were placed on the periapical, distal, and mesial regions of the periapical bone and bifurcation regions of the tooth (Fig. 1). Each radiograph was analyzed with FD using ImageJ v1.52 software (National Institutes of Health, Bethesda, USA) and the box counting method suggested by White and Rudolph (14). The high-resolution JPEG format periapical radiographs were all converted to tagged image file format (TIFF). Each ROI was duplicated (Fig. 2a), and the resulting image was blurred with a Gaussian blur (sigma (Σ) = 35 pixels) (Fig. 2b). The blurred image was subtracted from the original image (Fig. 2c). Then, the bone marrow cavity of the trabeculae was distinguished by adding 128 Gy values for each pixel location (Fig. 2d). Each image was converted into 8-bit using the “Type” format and into a black-and-white format with the “Binary” option to define the boundaries of the trabecular and bone marrow boundaries (Fig. 2e). By using “Erode,” the noise was minimized (Fig. 2f). The image was then subjected to “Dilate” for enhancement (Fig. 2g). The outline of the trabecular bone was revealed by selecting “Invert,” which changed the white areas to black and the black areas to white. “Skeletonize” showed the borders of the trabecular system, which were required for fractal analyses (Fig. 2h). The “Fractal box count” displayed in the “Analyse” section was used to calculate FD.

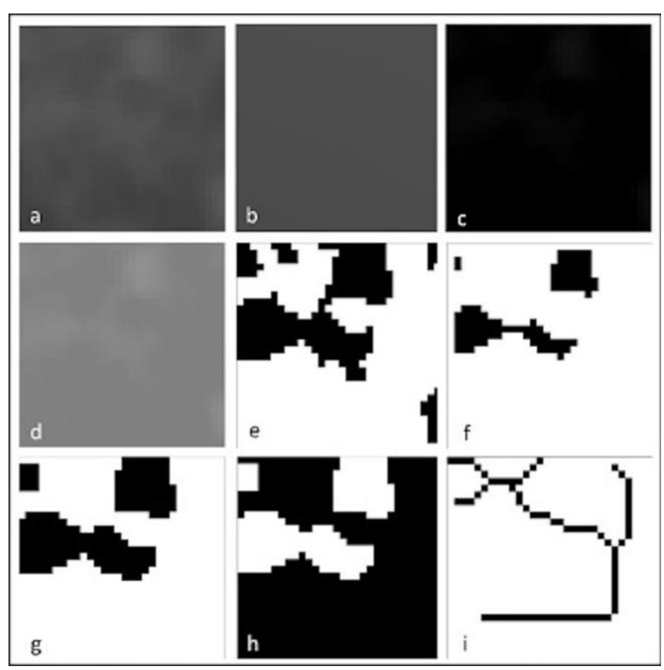

Figure 2. Stages of fractal dimension analysis: (a) cropped ROI, (b) Gaussian blur filter, (c) subtract blurred ROI, (d) addition of a gray value of 128 to each pixel location, (e) binarization, (f) erosion, (g) dilatation, (h) inversion, and (i) skeletonization.

Statistical analysis

The data were analyzed using IBM SPSS Statistics software for Windows (Ver. 22.0; IBM Corp., Armonk, NY, USA), and the significance level was established at $p < 0.05$.

The Kolmogorov-Smirnov test was used to evaluate the assumption of normality. Data for periapical before, bifurcation before, bifurcation after, and mesial periapical before from the control group were distributed non-normally ($p < 0.05$). Data from the other regions of the control group and all regions of the endodontically treated teeth were normally distributed ($p > 0.05$). Comparisons of repeated measurements were made using the Student's paired t-test in normally distributed data. The Wilcoxon t-test was used for nonnormally distributed data.

Results

The demographic characteristics of the participants are provided in Table 1.

In the control group, there was no statistically significant difference due to orthodontic treatment in the values of the fractal dimension of the periapical, mesial, distal, and bifurcation regions of the analyzed teeth ($p > 0.05$) (Table 1).

In the endodontically treated group, the fractal dimension values of the periapical, distal, and bifurcation regions of the teeth were not statistically significant before and after orthodontic treatment ($p > 0.05$) (Table 2). However, the fractal dimension values of the mesial regions of the endodontically treated teeth increased statistically significantly after orthodontic treatment ($p < 0.05$) (Table 3).

Table 1. Demographic characteristics of the patients.

		Group 1 n:17	Group 2 n:15	Total n: 32
Age		18.21 ± 2.41	19.16 ± 1.82	18.68 ± 2.11
Gender	Female	13	9	24
	Male	4	6	10
Number of teeth	36	14	6	20
	37	-	-	-
	46	3	7	10
	47	-	2	2
Region	Periapical	17	15	32
	Bifurcation	17	15	32
	Mesial	17	15	32
	Distal	17	15	32

Table 2. Comparison of the fractal dimension values obtained from the periapical, bifurcation, mesial, and distal regions of the control teeth before and after orthodontic treatment.

Control		Mean±SD	Median-IQR	Min-Max	p
Periapical	T1	1.255±0.093	1.282-0.154	1.092-1.389	0.298[b]
	T2	1.284±0.089	1.320-0.125	1.094-1.376	
Bifurcation	T1	1.182±0.112	1.220-0.157	0.931-1.292	0.177[b]
	T2	1.154±0.096	1.205-0.171	1.001-1.298	
Mesial	T1	1.267±0.084	1.288-0.121	1.064-1.358	0.642[b]
	T2	1.258±0.059	1.269-0.074	1.142-1.391	
Distal	T1	1.252±0.084	1.251-0.103	1.028-1.376	0.240[a]
	T2	1.216±0.096	1.209-0.133	1.026-1.370	

[a] Student's paired t-test, [b] Wilcoxon t-test. SD: Standard deviation, IQR: interquartile range. Min: Minimum value, Max: Maximum value, T1: Before treatment, T2: After treatment

Table 3. Comparison of the fractal dimension values obtained in the periapical, bifurcation, mesial and distal periapical regions of endodontically treated teeth.

Root canal treatment		Mean±SD	Median-IQR	Min-Max	p
Periapical	T1	1.237±0.097	1.253-0.161	1.059-1.389	0.126[a]
	T2	1.201±0.107	1.235-0.192	1.036-1.374	
Bifurcation	T1	1.137±0.143	1.118-0.231	0.889-1.391	0.918[a]
	T2	1.135±0.130	1.111-0.211	0.966-1.377	
Mesial	T1	1.088±0.181	1.106-0.283	0.799-1.328	0.002[a]
	T2	1.206±0.106	1.231-0.130	0.976-1.331	
Distal	T1	1.175±0.141	1.208-0.212	0.881-1.341	0.167[a]
	T2	1.208±0.120	1.210-.0.180	1.027-1.390	

[a] Student's t-paired test. SD: Standard deviation, IQR: Interquartile range. Min: Minimum value, Max: maximum value. T1: Before treatment, T2: After treatment.

Discussion

FA is used to evaluate various aspects of bone health, structure, and healing, involving both quantitative and qualitative assessments. FA has been widely used to evaluate different topics, such as investigating changes in trabecular bone structure, analyzing dental materials, identifying systemic disorders, and detecting caries (24-26). The 3D structure of the trabecular bone is revealed by the fractal dimension (FD) computed from two-dimensional radiographs. Despite having significant limitations, FA is a straightforward, non-invasive approach that offers objective data unaffected by factors such as projection geometry or radiation dosage. As a result, it is used frequently in medicine and dentistry when evaluating the trabecular bone structure (27). The limitations of this study are the small sample size and the generalization of fixed treatment techniques. In future studies, it may be useful to have a larger sample size and to group fixed orthodontic treatment variations (e.g., extraction, non-extraction, distalization, mesialization movements).

This study assessed the clinical applicability of FA data from the midpalatal suture to predict the pubertal growth spurt. Cone-beam computed tomography (CBCT) images were used to study the relation between FD value, skeletal maturation index, and chronological age. Results indicated that skeletal maturation increased with age whereas FD value decreases (19). In investigations using FA, functional orthopedic forces have been found to reduce the trabecular structure of the condylar area (20).

Fractal analysis studies conducted after functional orthopedic treatment in patients with class II div 1 reported that FD value increased in the condyle neck and apposition and decreased in the coronoid process and resorption. Furthermore, remodeling of the coronoid process, condylar expansion, and dentoalveolar osteogenesis were found to promote healing in Twin Block-treated patients (21, 22).

Thus far, no recent studies have linked fractal dimensional change at the teeth-bone interface to mechanical loading. Chen et al. examined periapical radiographs of premolar and molar teeth with necrotic pulp and radiographically visible periapical osteolytic lesions before and 3, 6, and 12 months after endodontic treatment. They also examined changes in periradicular bone structure using fractal analysis. Accordingly, fractal analysis using mathematical morphology and the box-counting method can detect changes in the periapical trabecular pattern in the early period after root canal treatment (28).

Wagle et al. reported that the fractal dimension in the root apices of the maxillary molars increased with orthodontic force in their rat study (23). They also reported that there were different variations in FD values in the root length from the apex to the cemento-enamel junction. In this study, varying FD values were found in different regions around the root, supporting the study of Wagle et al. (23), but the hypothesis of this study is rejected. The different fractal-dimensional responses between the apical, bifurcation, mesial, and distal apical regions with mechanical loading may also help explain the pattern of force distribution along the periradicular bone around the root of tooth movement.

A low FD value indicates a higher rate of voids in the bone, and bone tissue has a more porous structure. A high FD value indicates that bone architecture is more complex and denser, with fewer voids (16). However, the increased stress due to mechanical loading creates a more complex structural morphology. In this study, we believe that the FD values in the mesial apical region of the root may have increased due to the mesial directional mechanical force generated in the mandibular molars with class II elastics. Consequently, the fractal dimension values formed in the bone as a result of orthodontic forces can be used as a parameter in determining the physiological limits of biomechanical loads.

Conclusion

The mechanical loads produced by fixed orthodontic treatment change the FD values through a biological mechanism in the periradicular tissues around the tooth. FD values in the mesial apical region of the mandibular molar roots may increase due to the mesial directional mechanical force with class II elastics.

This study showed that differences may arise in the force distribution of periradicular tissues around the tooth. The FD values in this study show that the the highest level of interaction occurs in the group that received root canal treatment and the mesial periapical region.

The results of this study reveal the importance of applying orthodontic force within physiological limits to avoid tooth damage in periapical areas, where significant stress accumulates during orthodontic treatment.

Disclosures

Ethical Approval: Ethics committee approval was received for this study from Ankara Yıldırım Beyazıt University, Research Ethics Committee, in accordance with the World Medical Association Declaration of Helsinki, with the approval number: 2023/228-05.

Peer-review: Externally peer-reviewed.

Author Contributions: Conception – E.K.; Design – E.K., E.S.; Supervision – E.S.; Materials – E.K., E.S.; Data Collection and/or Processing – E.K., E.S.; Analysis and/or Interpretation – E.K.; Literature Review – E.K., E.S.; Writer – E.K.; Critical Review – E.K., E.S.

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

Funding: The authors declared that this study has received no financial support.

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