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Research Article

EVALUATION OF FRACTAL ANALYSES OF THE TRABECULAR BONE REGION IN LESIONED AND HEALTHY MANDIBULAR FIRST PERMANENT MOLARS ACCORDING TO AGE AND GENDER ON PANORAMIC RADIOGRAPHS

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ABSTRACT

Objective: This study aimed to investigate the fractal dimension values of trabecular bone in periapical lesions and healthy mandibular first permanent molars, based on age and gender, using panoramic radiographs.

Material and Methods: The panoramic radiographs of a total of 216 patients aged 6-16 years who applied to Dicle University Faculty of Dentistry Department of Pedodontics in 2022 were retrospectively examined. The patients were equally distributed by gender into three age groups: 6-9, 10-12, and 13-16 years. Fractal analysis was applied using the ImageJ program to the regions of interest (ROI's) of 25x25 pixels determined from two different regions on each digital panoramic radiograph, and fractal dimension calculations were performed. The data were analyzed using the Shapiro-Wilk and/or Kolmogorov-Smirnov tests, as well as the Mann-Whitney U and Kruskal-Wallis H tests. The confidence interval for all statistical tests was set at 95%, and the significance level was accepted as $p<0.05$.

Results: According to the results of the study, the average fractal dimension value of the lesioned region was 1.106, while the average fractal dimension value of the healthy region was 1.116. No statistically significant difference was found in the fractal dimension values between both the lesioned and healthy groups, as well as between the age and gender groups ($p>0.05$).

Conclusion: Fractal dimension (FD) calculation is a reliable method for detecting early-stage periapical lesions. However, to achieve more comprehensive evaluations, future studies should integrate histological and clinical parameters and compare 2D and 3D imaging techniques with larger sample sizes.

Keywords: Periapical Lesion, Panoramic Radiography, Fractal Analysis, ImageJ, ROI

INTRODUCTION

The radiographic diagnosis of periapical pathologies is the first step in determining the treatment strategy. For periapical pathologies to be diagnosed using conventional radiographs, there must be approximately %30-50 mineral loss in the bone (1). This can lead to the inability to detect lesion formation in the early stages with conventional radiographs. Trabecular bone is often preferred for evaluating bone health because it is metabolically more active than cortical bone and has a significantly higher renewal rate (2). Considering these factors, the combined examination of the bone structure of the jaws using radiographs and analyses has gained importance in dentistry in recent years. For this purpose, the "Fractal Analysis" method, which is a non-invasive diagnostic tool capable of detecting bone loss at an early stage and providing objective data, has been developed (3). The word "fractal" is derived from the Latin word "fractus," meaning "broken" or "fragmented" (4). Fractal Analysis (FA) is a mathematical method that allows for the quantitative description of complex structures and shapes that cannot be expressed by integral dimensions. It is numerically expressed as fractal dimension (FD). FD describes the complexity of a structure. Generally, a high FD indicates a more complex structure, while a low FD indicates a simpler internal order (5). Fractal analysis is used in medicine for the detection and monitoring of diseases and has gradually found a wide range of applications in dentistry (6).

This study aims to evaluate the fractal dimensions of trabecular bone in the apical regions of both lesioned and healthy mandibular first permanent molars using panoramic radiographs, with the goal of exploring the potential of fractal analysis for radiographic diagnosis and investigating the relationship between fractal dimension and factors such as gender and age.

MATERIALS AND METHODS

Power Analysis of the Study

The patients were equally distributed by gender into three age groups: 6-9, 10-12, and 13-16 years. A theoretical power value of 81% was calculated with a 5% margin of error and a 95% confidence level, based on gender distinction and an effect size of 0.25. The study aimed to include at least 216 observations. The power calculation was performed using the GPower 3.1 software package.

Study Sample

The panoramic radiographs of a total of 216 patients aged 6-16 years who applied to Dicle University Faculty of Dentistry Department of Pedodontics in 2022 were retrospectively examined. This is a monocentric, cross-sectional study aimed at evaluating and comparing fractal dimension analyses of trabecular bone in specific regions of the lesioned and healthy lower permanent first molars, based on age and gender. The analysis was performed using ImageJ software on panoramic radiographs saved in TIFF format. Inclusion criteria for the panoramic radiographs involved ensuring the clear visibility of the mandibular anterior, premolar, molar, ramus, angle, TMJ region, and inferior mandibular cortex, the absence of ghost images, and the use of the same device and consistent exposure parameters for capturing the radiographs.

Study groups were formed for three different age groups: 6-9 years, 10-12 years, and 13-16 years, considering gender distribution. A total of 72 patients, 36 boys and 36 girls from each age group, were selected to meet the inclusion criteria, totaling 216 patients (Table 1).

Table 1. Inclusion and exclusion criterias.

Inclusion	Being in the mixed and/or permanent dentition period.
	Having erupted mandibular first permanent molars.
	Having a lesion at the apex of either the 36 or 46 tooth.
	Having either the 36 or 46 tooth without decay.
	No extraction performed on the 36 and 46 teeth.
	Patients with diagnostic panoramic radiographs without various artifacts or positioning errors.
Exclusion	Presence of cysts and tumors involving the 36 and/or 46 teeth.
	Prior restorative treatment and/or root canal treatment on the 36 and/or 46 teeth.
	Presence of a fracture in the relevant bone region.

Data Collection

All panoramic radiographs were taken with a Progeny (Midmark Company, USA) X-ray device using the following exposure parameters: 0.5 mm focal spot, 3.2 mm filtration, 70 kVp, 10 mA, and 15.9 seconds.

Application of Fractal Analysis

In our study, the ImageJ 1.54d image analysis program, which can be downloaded for free from "https://imagej.nih.gov," was used for FD measurement. The analysis was conducted by E.B. using the box counting method by White and Rudolph (7). High-resolution images of patients included in the study were obtained in Tagged Image File Format (TIFF) from the database for processing panoramic images. Using the ImageJ 1.54d program, the images belonging to the patients were opened and the relevant regions (ROI - Region of Interest) were selected (Figure 1). On each panoramic radiograph, one ROI was determined from the apical region of the healthy mandibular first permanent molar (caries-free and without a lesion at the apex) and its symmetric mandibular first permanent molar with a lesion at the apex. The selected ROI’s were 25x25 pixels in size, with a total of 2 ROI’s per patient (Figure 1).

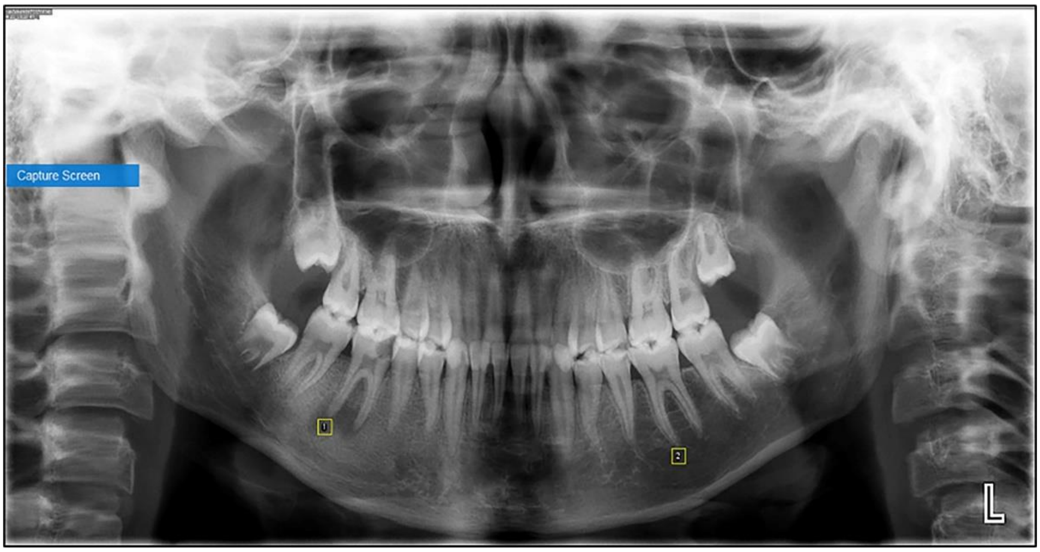

Figure 1. Selected regions of interest (ROI’s) on panoramic radiograph; ROI 1 is determined at the apex of the lesioned right mandibular first permanent molar, and ROI 2 is determined at the apex of the healthy left mandibular first permanent molar.

The steps followed in the method designed by White and Rudolph for fractal dimension analysis were used (7) (Figure 2).

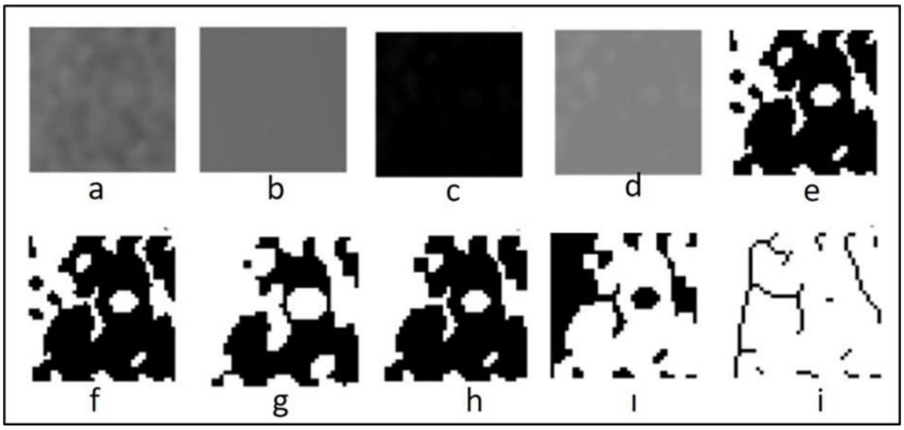

Figure 2. Steps of the box counting method; a. Cropped image of the relevant region, b. Duplicated image, c. Application of Gaussian filter, d. Image subtracted from the original, e. Addition of gray tones, f. Creation of a binary (two-color) image, g. Erosion, h. Dilation, ı. Inversion of colors, i. Skeletonization.

Initially, panoramic radiographic images saved in TIFF format were transferred to the ImageJ program, and the square-shaped relevant region (ROI) of 25x25 pixels selected on the radiograph (Figure 1) was cropped using the "crop" feature. The cropped ROI was duplicated using the "duplicate" feature. The duplicated image was blurred using the "Gaussian Blur" filter with a sigma value of 35 pixels. The purpose of this step is to remove density differences on the image caused by soft tissue covering the bone surface and changes in bone thickness, making sharper differences more pronounced. Next, the blurred image was subtracted from the original image using the "Subtract" feature, and 128 gray tones were added to each pixel using the "Add" feature. The various brightness areas in the resulting image distinguish the trabecular structure from the bone marrow. The "Binary" process was applied to convert the image to black and white, creating a two-color image, making the outlines of the trabecular structure and bone marrow clearly visible. The noise in the image was eroded and reduced using the "Erode" feature, and the existing areas were enlarged and clarified using the "Dilate" feature. The image was inverted using the "Invert" feature, making the black areas white and the white areas black, revealing the outlines of the trabecular bone. The outlines of the trabecular bone were converted into a skeletal structure with lines using the "Skeletonize" feature, making them ready for fractal analysis. As the final step, the fractal dimension calculation for the trabecular outlines was performed using the "Analyze" feature. The image was divided into squares of 2, 3, 4, 6, 8, 12, 16, 32, and 64 pixels in size using the "Fractal Box Count" option (Figure 3).

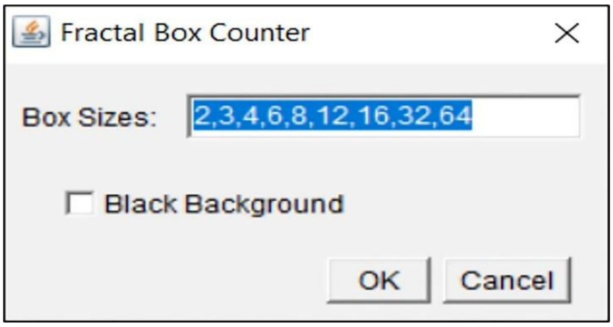

Figure 3. Box counting algorithm in fractal analysis.

The number of squares containing trabeculae and the total number of squares in the image were calculated for each pixel of various sizes. A logarithmic scale graph of the obtained values was plotted. The slope of the line obtained by connecting the points on the graph provided the fractal dimension value, indicating the complexity of the structure (7) (Figure 4).

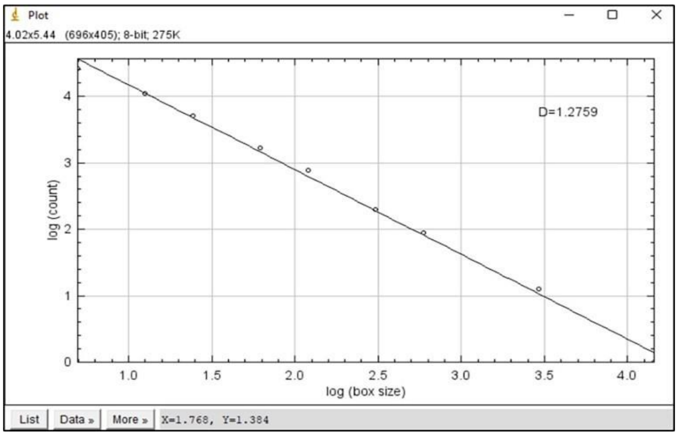

Figure 4. Plotting of values on a logarithmic scale. The slope of the line represents the fractal dimension value and is indicated by "D" in the figure. FD = D

Statistical Analysis

The data obtained in this study were analyzed using the licensed IBM SPSS V 21 software package. The Shapiro-Wilk and/or Kolmogorov-Smirnov tests were performed to assess the normality of the variables, considering the number of units. Since the variables did not follow a normal distribution, the Mann-Whitney U and Kruskal-Wallis H tests were employed to examine the differences between groups. In cases where significant differences were observed in the Kruskal-Wallis H test, the Post-Hoc Multiple Comparison Test was applied to identify the groups exhibiting differences. The confidence interval for all statistical tests was set at 95%, and the significance level was accepted as p<0.05.

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RESULTS

A total of 216 patients, comprising 108 girls and 108 boys aged 6-16 years, who met the inclusion criteria for this retrospective study, were selected as the sample. Fractal dimension measurements of the trabecular bone in the apical region of lesioned and healthy right or left mandibular first permanent molars were performed using panoramic radiographs. The measurement results were then compared based on gender and age.

Demographic Results

Of the participants included in the study, 50% were girls and 50% were boys. The participants were divided into three equal age groups: 6-9 years, 10-12 years, and 13-16 years (Table 2).

Table 2. Demographic data.

		Sample Size	%
Gender	Boy	108	50
	Girl	108	50
	Total	216	100
Age	6-9 years	72	33.33
	10-12 years	72	33.33
	13-16 years	72	33.33
	Total	216	100

FD Measurements

The average fractal dimension (FD) measurement value of the lesioned group among the participants is 1.106, while the average FD measurement value of the healthy group is 1.116 (Table 3).

Table 3. Distributions of measurement values.

	n	Mean	Median	Min	Max	Sd
Lesioned fractal analysis measurement value	216	1.106	1.139	0.051	1.346	0.156
Healty fractal analysis measurement value	216	1.116	1.154	0.104	1.314	0.182

n: Sample size; Sd: Standard deviation.

Although no statistically significant difference was found between the groups in terms of fractal dimension measurements for lesioned and healthy areas, the FD value measured from the radiographs of the lesioned group was found to be lower (p>0.05) (Table 4).

Table 4. Analysis results regarding the difference between groups in terms of lesioned and healthy fractal analysis measurement values.

	Group							Mann Whitney U Test		
		n	Mean	Median	Min	Max	Sd	Mean Rank	z	p
Fractal Analysis Measurement Value	**Lesioned**	216	1.106	1.139	0.051	1.346	0.156	205.16	-1.887	0.059
	Healty	216	1.116	1.154	0.104	1.314	0.182	227.84		
	Total	432	1.111	1.144	0.051	1.346	0.17			

Although no statistically significant difference was found between genders in terms of fractal dimension measurements for lesioned and healthy areas, the FD values measured from the radiographs of boys were found to be higher (p>0.05) (Table 5).

Table 5. Analysis results regarding the difference between genders in terms of lesioned and healthy fractal analysis measurement values.

	Gender							Mann Whitney U Test		
		n	Mean	Median	Min	Max	Sd	Mean Rank	z	p
Lesioned fractal analysis measurement value	**Boy**	108	1.11	1.131	0.563	1.346	0.136	107.65	-0.2	0.841
	Girl	108	1.102	1.14	0.051	1.305	0.174	109.35		
	Total	216	1.106	1.139	0.051	1.346	0.156			
Healthy fractal analysis measurement value	**Boy**	108	1.136	1.152	0.384	1.312	0.13	110.39	-0.444	0.657
	Girl	108	1.096	1.154	0.104	1.314	0.222	106.61		
	Total	216	1.116	1.154	0.104	1.314	0.182			

n: Sample size; Significant at p ≤ 0.05; Sd: Standard deviation; z: Mann Whitney U Test Statistic.

No statistically significant difference was found between the age groups regarding the fractal dimension measurement values for both lesioned and healthy areas (p>0.05) (Table 6).

Table 6. Analysis results regarding the difference between age groups in terms of lesioned and healthy fractal analysis measurement values.

	Age							Kruskal Wallis H Test		
	Years	**n**	**Mean**	**Median**	**Min**	**Max**	**Sd**	**Mean Rank**	**H**	**p**
Lesioned fractal analysis measurement value	**6-9**	72	1.116	1.15	0.673	1.305	0.138	113.79	1.393	0.498
	10-12	72	1.079	1.132	0.051	1.326	0.201	101.76		
	13-16	72	1.122	1.126	0.834	1.346	0.114	109.95		
	Total	216	1.106	1.139	0.051	1.346	0.156			
Healthy fractal analysis measurement value	**6-9**	72	1.132	1.147	0.538	1.312	0.131	108.65	0.299	0.861
	10-12	72	1.126	1.148	0.538	1.314	0.131	105.58		
	13-16	72	1.089	1.172	0.104	1.305	0.256	111.27		
	Total	216	1.116	1.154	0.104	1.314	0.182			

n: Sample size; Significant at p ≤ 0.05; Sd: Standard deviation; H: Kruskal Wallis H Test Statistic.

DISCUSSION

Periapical pathologies provide general information about the need for endodontic treatment. Additionally, in the pediatric patient group, tooth extraction may be preferred over endodontic treatments in the presence of periapical lesions, especially in teeth with open apices. The diagnosis of periapical pathologies is the first step in determining the treatment strategy to be applied (8).

It is not possible to monitor early-stage bone destruction with radiographic examination. It has been reported that mineral loss in the bone must be between %30-50 to be diagnosed with conventional radiographs (9). This situation poses the risk of failing to detect lesion formation at an early stage with conventional radiographs. Changes in the trabecular and cortical structure of the bone can be an early indication of certain pathologies, local or systemic diseases; therefore, the combined examination of the bone structure of the jaws using radiographs and analyses has become quite important in dentistry (3).

In recent years, "fractal analysis," a radiographic analysis method that can detect bone loss at an early stage, is not affected by adversities that can hinder the accurate evaluation of radiographs, and provides completely objective data by eliminating practitioner-dependent factors, has been frequently used (10). It is a mathematical analysis method that can evaluate irregular and complex body structures. Some researchers have shown that the complex structure of trabecular bone can be examined on radiographs using this method (7, 11). When applied to trabecular bone images on radiographs, this method is considered a reflection of the trabecular bone microarchitecture and provides information about changes in mineral content and density in the alveolar bone over time (12, 13). It is thought that the fractal analysis method will contribute to radiographic examination by examining details in the bone structure that are not visible to the naked eye (14, 15).

Considering this information, the use of fractal analysis as a non-invasive diagnostic tool based on objective and quantitative data was preferred in our study for diagnosing periapical pathologies. This method was selected due to its superior ability to reflect the metabolic activity of trabecular bone and its potential to offer valuable diagnostic insights in detecting changes in bone structure.

Since it is free to use and easily accessible, fractal analysis in our study was performed using the box counting method with the ImageJ 1.54d (ImageJ®, National Institute of Mental Health, Bethesda, MD, US) software.

In a study by Demirbaş et al., where they examined the trabecular structure of the mandible using fractal analysis on panoramic radiographs of patients with sickle cell anemia, they found lower FD values compared to healthy individuals. The FD values were lower in the anemia group (1.68±0.08) compared to the control group (1.71±0.04) (16). These findings support the results of Gümüşsoy et al., who found lower FD values in patients with chronic kidney failure compared to healthy individuals (17). Demiralp et al. found the average FD values in patients using bisphosphonates (1.39 ± 0.14) to be higher than those of the healthy control group (1.38 ± 0.07). They suggested that this result might be related to the reduced bone resorption in patients using bisphosphonates (18). Southard et al., in a study conducted on 10 cadaver maxillae, created artificial bone lesions and found that the average FD value decreased from 1.26 to 1.1 with ongoing mineral loss in the calculations they performed on the periapical radiographs they obtained (12). Chen et al., in a study where they measured FD in periapical radiographs taken for follow-up at 3, 6, and 12 months after root canal treatments of premolar and molar teeth with periapical lesions larger than 2 mm, observed a significant increase in fractal dimension 3 months after the root canal treatment ($p<0.05$). They concluded that fractal analysis could be used to detect changes in periapical trabecular bone at an early stage after root canal treatment (19). In a study by Aktuna Belgin et al., where they evaluated the mesial and distal interdental regions of mandibular first molars in periodontitis and healthy individuals using fractal analysis on periapical radiographs, the average FD value was found to be 1.04 in the healthy group and 0.97 in the periodontitis group. The average FD value was significantly lower in the periodontitis group compared to the healthy group ($p<0.05$) (20).

In a study by Shrout et al., cadaver mandibles were divided sagittally into two halves, and trabecular bone was gradually removed in 4 stages. Fractal analysis was applied to the periapical radiographs taken after each stage. They reported an increase in fractal dimension over time as the stages progressed (21). In a study by Ruttiman et al., trabecular bone decalcification was performed on cadaver mandibles using 10% formic acid, and fractal analysis was then performed on the periapical radiographs taken afterward. They reported that the FD values calculated after decalcification were greater than the FD values calculated before decalcification (22).

According to the literature, there is no consensus on the relationship between FD and the complexity of trabecular bone. In some cases, a decrease in FD value can be observed in radiographs due to reduced bone density. In one study, this was explained by the fact that demineralization makes the bone more porous and simple, increasing the spaces within the bone due to the decreased complexity of the trabecular structure (23). In some cases, despite a decrease in bone density in radiographs, an increase in FD value can be observed. In one study, it was stated that the loss of thin trabecular structure due to demineralization could cause abrupt density changes in radiographic images, leading to changes in fractal dimension. In other words, the increase in FD was expressed as a reflection of the increase in image roughness due to the architectural irregularity of the trabecular network through demineralization (24). These results regarding the observation of FD increase are similar to the studies by Shrout et al. (21) and Ruttiman et al. (22).

In our study, the average FD value of healthy teeth was found to be 1.116, and the average FD value of lesioned teeth was found to be 1.106. No statistically significant difference was found between the FD values ($p>0.05$). Our findings are consistent with the studies of Demirbaş et al. (16), Gümüşsoy et al. (17), Chen et al. (19), Southard et al. (12), and Aktuna Belgin et al. (20), which report that the FD value in the diseased or lesioned group is lower compared to the healthy group.

In some studies examining the effect of gender on FD, it has been reported that women have lower FD values than men. In a study by Güleç et al., which investigated the effect of gender on FD in systemically healthy individuals, a significant difference was found between the FD values of the right angulus and left condyle according to gender, and it was reported that FD values were generally lower in women (25). In a study by Alman et al. examining FD values in patients with osteopenia according to gender, it was found that women had lower FD values than men (26). Higher FD values in men are associated with a higher and more complex trabecular structure. In contrast, the trabecular structure in women is more porous and contains fewer trabeculae (27).

There are also studies in the literature that report no relationship between gender and FD. In a study by Updike et al., which examined the effect of chronic periodontitis on FD, no relationship was found between gender and FD (3). In a study by Gümüşsoy et al., which used fractal analysis to examine changes in the trabecular structure of the mandible caused by chronic kidney failure, no relationship was found between gender and FD (17).

In this study, the sample consisted of an equal number of boys and girls, with 36 boys and 36 girls in each age group (6-9, 10-12, and 13-16 years), totaling 216 individuals. No statistically significant difference was found between the fractal dimension (FD) values of lesioned and healthy teeth according to gender ($p>0.05$). The observation that boys had higher FD values, although not statistically significant, is consistent with the findings of Güleç et al. (25) and Alman et al. (26). Our results also align with the studies by Updike et al. (3) and Gümüşsoy et al. (17), which report no association between gender and FD. We suggest that the variability in results from studies investigating the relationship between gender and FD may be attributed to differences in sample sizes and gender distribution inequalities.

In a study by Demirbaş et al. examining the relationship between changes in the trabecular structure of the mandible and fractal dimension (FD) on panoramic radiographs of patients with sickle cell anemia, it was found that the average FD values of patients under 20 years old were significantly lower than those of patients over 20 years old (16). In a study by Demiralp et al. involving patients using bisphosphonates, no significant relationship was found between FD values and age (18). Similarly, in a study by Güleç et al. measuring FD values on panoramic radiographs of children aged 5-11 years with sleep bruxism, no significant relationship was observed between age and FD values. The researchers attributed these findings in children to developmental changes occurring with age (28).

In our study, no statistically significant difference was found between the fractal dimension (FD) values of lesioned and healthy teeth based on age (p>0.05). Our findings are consistent with those of Demiralp et al. (18) and Güleç et al. (28), who also reported no relationship between age and FD in the literature.

Factors such as anatomical variations, the variety of radiographic methods used to obtain 2D bone images, radiographic errors such as artifacts, lack of calibration in radiographic devices, differences in sample sizes, the profiles of patients included in the samples, the techniques used for FD measurement, and the varied selection of regions of interest (ROIs) in terms of size, location, and shape are believed to contribute to the inability to standardize the results found in the literature (29).

Due to the retrospective nature of this study, potential effects of systemic diseases present in the sample group on FD values, as well as challenges in maintaining consistent panoramic radiograph standards in pediatric patients, can be considered limitations of our study.

CONCLUSION

Based on the findings and insights from our study, FD calculation can be recommended as a quantitative and objective method for detecting early-stage periapical lesions that are clinically suspected but not visible to the naked eye. Although fractal analysis is a reliable technique, it is crucial to incorporate histological and clinical parameters in future studies to reach consensus among researchers. While 2D imaging methods are frequently employed in evaluating fractal dimension, further comprehensive studies comparing these methods with 3D imaging techniques and including larger sample sizes are needed.

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Authorship contributions

E.B. and E.C.T. designed the research study; performed the research; analyzed the data; wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

Data availibity statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declaration of competing interest

The authors have no conflicts of interest to declare.

Ethics

This study, approved by the Local Ethics Committee of the Faculty of Dentistry, Dicle University, under protocol number 2022-45 on December 28, 2022, was conducted in accordance with the ethical principles of the World Medical Association's Declaration of Helsinki.

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