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Comparison of trabecular bone structure in individuals with healthy periodontium and stage III/IV, grade C periodontitis by fractal analysis

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Objective. The aim was to perform fractal analysis (FA) to compare differences in trabecular microarchitecture in interdental and antegonial regions on panoramic radiographs in periodontally healthy patients and those with stage III/IV, grade C periodontitis, and to compare the effects of patient age and sex on FA results.

Study Design. Clinical and radiographic records from 33 periodontally healthy individuals and 28 individuals with aggressive periodontitis were obtained from the faculty archives. Three regions of interest (ROIs) were chosen bilaterally from interdental bone around the mandibular first molar and canine and the antegonial region. The mean fractal dimension (FD) values of the ROIs were calculated. Significance of differences was established at $P < .05$.

Results. FD values of all 3 ROIs in the periodontitis group were significantly lower than values in the control group ($P \leq .004$). FD was not affected by patient age ($P = .357$) or sex ($P = .216$). There were no significant correlations between FD and age in either group ($P \geq .093$). FD values differed significantly between sexes in only one ROI.

Conclusions. FA can effectively detect trabecular microarchitectural differences in patients with aggressive periodontitis compared to periodontally healthy individuals. This technique might be useful in predicting the susceptibility of patients to periodontal disease. (Oral Surg Oral Med Oral Pathol Oral Radiol 2023;135:427−432)

Periodontitis is a highly prevalent, multifactorial, host-mediated, inflammatory disease characterized by destruction of the tissues supporting the teeth. Because it is a chronic progressive disease, its local manifestations range from bleeding periodontal pockets to eventual tooth loss.[1,2] The primary etiologic factor of periodontitis is the pathogenic microbial biofilm, but the clinical character and course of the disease are defined by the host response, which is regulated by different factors including genetics and other individual characteristics.[3-6]

"Aggressive periodontitis" was the name given in the 1999 classification of periodontal diseases by the American Academy of Periodontology to the highly destructive form of periodontitis characterized by onset at an early age, rapid rate of progression, and a distinct pattern of destruction in response to a relatively small amount of plaque in some individuals.[7,8] According to the 2017 classification of periodontal and periımplant diseases and conditions, this form of periodontal disease is now termed "stage III/IV, grade C periodontitis."[9] The reasons and mechanisms behind the susceptibility of some individuals to this destructive form of the disease at a young age are not yet fully understood. Emphasis is generally placed on microbiology and genetically determined immune factors.[6,10] To reach a better understanding of the pathogenesis of this aggressive form of periodontitis, other individual factors, including bone quality, should also be taken into account.

Radiographs are often used for evaluation of alveolar bone support, which is essential for accurate assessment of the severity and extent of periodontitis.[11-13] Radiographs are valuable for periodontal evaluation, but due to technical limitations, they are not regarded as a substitute for clinical examination but as an adjunct. Bone resorption is predictably detectible in conventional radiographs only after 30% to 50% loss of mineral density has occurred. Although conventional radiographs are a useful tool for examination of previous alveolar bone destruction, they are insufficient in the detection of early changes and assessment of current disease activity.[12,14] In this context, novel qualitative and quantitative trabecular bone analysis methods may be valuable for timely diagnosis and personalized

Statement of Clinical Relevance

Abnormal trabecular bone patterns may explain the susceptibility of some individuals to rapid, early-onset periodontitis. Fractal analysis can detect these changes and may have value in evaluating young people with a familial history of aggressive periodontitis and diagnosing the disease.

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follow-up of periodontitis cases characterized by progressive bone destruction at young ages.

The system of fractal geometry was developed by Benoit Mandelbrot in the 1970s and since then has been applied in different areas of science, including biology.[15,16] Fractal analysis (FA) is based on the fact that when magnified, complex natural structures that are not measurable by the classical geometric system present the same level of complexity on their borders; in other words, they feature self-similarity. FA is a simple and low-cost choice for mathematical graphic analysis,[17,18] most commonly performed with the box-counting method.[18,19] Fractal analysis, represented by the fractal dimension (FD), is a quantitative mathematical method for identifying complex patterns. FD exhibits an object's self-similarity and the ways it fills space.

To our knowledge, only a few studies[20-22] have employed FA to comparatively evaluate trabecular structures in the alveolar bone of individuals with a healthy periodontium vs patients with periodontitis. There is a need for research on trabecular bone structure in patients with severe periodontal bone destruction compared with healthy individuals from the same age group.

The present study was therefore designed to compare FD values in the trabecular bone at 3 regions of interest (ROIs) in a control population to values in patients with stage III/IV, grade C periodontitis, calculate the correlation of FD values with patient age in both populations, and compare FD values in males and females. The null hypotheses stated that there would be no statistically significant differences in FD in any ROI between the 2 groups, no significant correlations of FD and age in both groups, and no significant differences in FD between males and females.

MATERIALS AND METHODS

This retrospective study was carried out in accordance with the Declaration of Helsinki and approved by the Recep Tayyip Erdoğan University Ethics Committee (2020/38). Written informed consent was obtained from all participants.

After approval, panoramic radiographs acquired as part of the oral examination and periodontal records from the archives of the Periodontology Department of the university were retrospectively reviewed. Panoramic radiographs of 144 patients were selected. The exclusion criteria consisted of a history of a disease, condition, or drug that affects bone metabolism; nonperiodontal/endodontic lesions; fractures; and root canal treatment in the ROIs. As a result, 83 patients were excluded, leaving 61 individuals in the study.

The patients were divided into 2 groups. The control group consisted of 33 individuals (17 males and 16 females) confirmed as periodontally healthy by dental history, clinical records, and radiographic examination. The periodontitis group included 28 patients (10 males and 18 females) who were diagnosed with stage III/IV, grade C periodontitis on the basis of dental history, patient symptoms, clinical records, and radiographic examination.

All clinical measurements were performed by a single periodontist with 20 years of experience. Measurements of probing depth (PD) and clinical attachment level (CAL) were performed with a periodontal probe at 6 sites on each tooth (mesiobuccal, mid-buccal, distobuccal, mesiolingual, mid-lingual, and distolingual). In accordance with the 2017 World Workshop,[9,23] stage III/IV included patients who had PD and CAL $\geq$5mm on at least 2 nonadjacent teeth, radiographic bone loss extending to the middle or apical third of the root, and at least one tooth lost due to periodontal disease. Those who presented with a rapid rate of progression with incisor-molar destruction patterns were classified in grade C periodontitis.

Panoramic radiographs were acquired using a Planmeca Promax 2D S2 device (Planmeca Oy, Helsinki, Finland) operating at 66 kVp, 8 mA, and 16.6 s exposure time. FA was performed with ImageJ software version 1.52 (National Institutes of Health, Bethesda, MD, USA) by a dentomaxillofacial radiologist with $>$8 years of experience. Three square ROIs of 15 $\times$ 15 pixels were chosen bilaterally in the interdental bone mesial or distal to the first mandibular molar (FDm), in the interdental bone mesial or distal to the mandibular canine (FDc), and in the supracortical bone above the antegonial notch (FDa; Figure 1).[22,24,25]

Image processing and FA using the box-counting method, as proposed by White and Rudolph[19] and other researchers,[26] were performed on each ROI. The chosen ROI was cropped and duplicated. Gaussian blur was then applied to eliminate large-scale variations in brightness caused by the thickness of the object or soft tissue. The blurred image was subtracted from the original cropped image, and 128 gray values were added to each pixel location, resulting in a new image with a mean pixel value of 128. The resulting image was made binary with the threshold tool of the software at a brightness value of 128. Areas $\leq$128-pixel values were converted to black, whereas the other areas were converted to white. Erosion and dilation steps were used to reduce noise. The image was then inverted and skeletonized. FD values were calculated with the box-counting function of the Image J software. The resulting FD values ranged from 1 to 2 and were used in the statistical comparison of the groups to represent the trabecular structure. FD values of the 3 ROIs were calculated by taking the mean of the right side and left side measurements for each region. To permit calculation of intraexaminer reliability, 20 images were randomly reevaluated 2 weeks later by the same examiner.

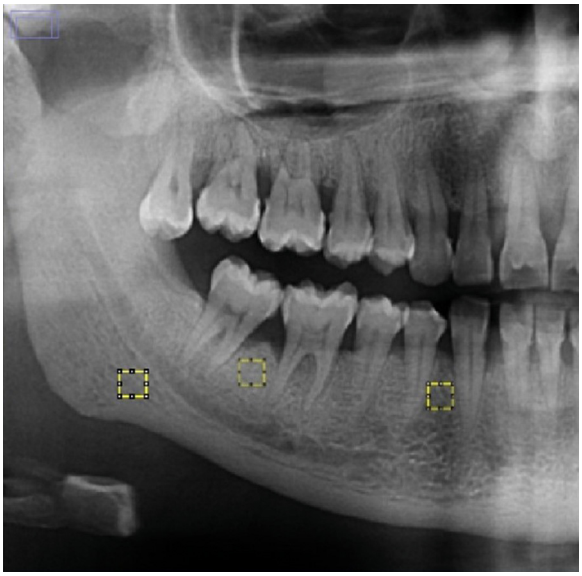

Fig. 1. Regions of interest for fractal dimension measurement on panoramic radiographs. Six regions of interest were selected mesial or distal to the right and left first mandibular molar, mesial or distal to the right and left mandibular canine, and in the trabecular bone in the supracortical area of the right and left antegonial notch.

Statistical analysis of the data was performed with SPSS for Windows SPSS 8 version 23.0 (IBM SPSS Inc., Armonk, NY, USA). Mean and SDs were calculated for the quantitative data of FD values and patient age in each group, and the distributions of data were evaluated for normality with the Shapiro-Wilk Test. FDm values and age were not distributed normally and were analyzed for the significance of differences between the 2 groups with the Mann-Whitney U test. FDc and FDa were found to have normal distributions, and the significance of differences between the groups in these parameters was computed with the Student *t* test. The distribution of control and periodontitis patients by sex was analyzed with the Pearson chi-square test.

Correlations of FD and patient age were examined with the Spearman nonparametric correlation test. FD values did not follow a normal distribution when stratified by patient sex, so the difference in all FD levels between sexes was calculated with the Mann-Whitney U test. Intraexaminer reliability was calculated with the kappa test based on data from the first examination and the subsequent re-evaluation of 20 images. $P < .05$ represented statistically significant differences for all parameters.

RESULTS

The FD values of all 3 ROIs in the periodontitis group were significantly lower than in the control group ($P \leq .004$), as indicated in Table I and Figure 2. The mean ages (with SDs) of the control and periodontitis patients were 28.5 ± 4.0 and 28.9 ± 5.9, respectively. The difference between groups was not significant ($P = .357$). There was no significant difference in sex distribution between control and periodontitis populations ($P = .216$).

When the effect of patient age on FD was examined, no significant correlations were found between the mean FD values of all ROIs and age in the control group ($P \geq .093$) or periodontitis group ($P \geq .650$), as listed in Table II. Analysis of the effect of sex on FD values showed that the mean FDc was significantly higher in females than males ($P = .007$), but there were no significant differences between mean FDm and FDa values by sex ($P \geq .059$), as shown in Table III. The kappa value for intraexaminer agreement for analysis of FD was 0.992, which represented almost perfect agreement.[27]

DISCUSSION

This study indicated that a degraded trabecular pattern of mandibular bone is associated with the rapid progression of periodontitis. To the best of our knowledge, this was the first investigation distinguishing the differences between the trabecular microarchitecture of healthy alveolar bone and stage III/IV, grade C periodontitis with FA.

Sener et al[22] discovered that FD values in patients with moderate periodontitis were significantly lower than in healthy individuals. Similarly, Belgin and Serindere[21] evaluated the trabecular changes in patients with periodontitis and suggested that FD values were significantly lower in the periodontitis group. They concluded that FD can be used as a quantitative method for detecting periodontal destruction. In a study by Updike and Nowzari,[20] the mean FD values calculated on periapical radiographs of both moderate and severe

Table I. Distribution of FD values and patient age of the control and periodontitis groups

	Control	*Periodontitis*	*P value*
FD levels			
FDm	1.51 ± 0.07	1.37 ± 0.13	< .001*
FDc	1.50 ± 0.07	1.40 ± 0.14	.004‡
FDa	1.50 ± 0.08	1.39 ± 0.14	< .001‡
Age (mean ± SD)	28.5 ± 4.0	28.9 ± 5.9	.357*
Sex (n,%)			.216†
Male	16 (48.5)	18 (64.3)	
Female	17 (51.5)	10 (35.7)	

*Mann-Whitney U test.
†Pearson chi-square test.
‡Student *t* test.*FD*, fractal dimension; *FDm*, mandibular molar; *FDc*, mandibular canine; *FDa*, antegonial notch.

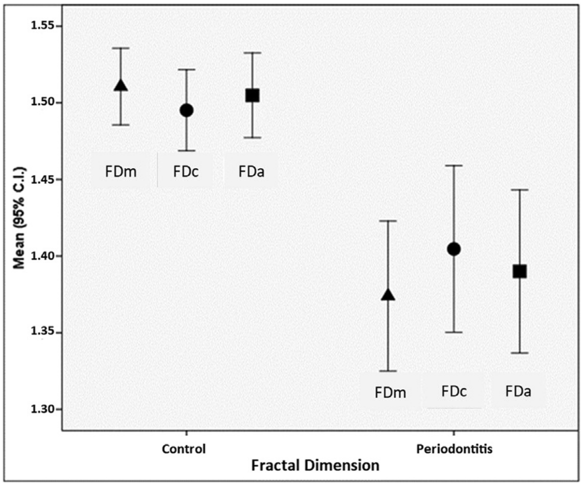

Fig. 2. Distribution of fractal dimension values of control and periodontitis groups. The triangle, circle, and square represent the mean fractal dimension of the mandibular molar, mandibular canine, and the antegonial notch, respectively. The vertical lines represent 95% CIs. *FDm*, mandibular molar; *FDc*, mandibular canine; *FDa*, antegonial notch.

periodontitis patients were lower compared with those in healthy individuals. Furthermore, Niramitchainon et al[28] evaluated the association between systemic bone loss and periodontitis by using trabecular bone scores. They suggested that degraded trabecular bone is associated with severe periodontitis and has a synergistic effect with poor oral hygiene. The present research supports these studies and also extends their findings by including patients with stage III/IV, grade C periodontitis.

The statistically significant differences in FD values between control and periodontitis cases in the antegonial bone that were revealed in this investigation show that the trabecular pattern may vary even in regions that are not affected by periodontitis. The association of antegonial FD values and periodontal destruction may lead to a better understanding of the apparent susceptibility of some individuals to aggressive forms of periodontitis. Comparative FA of other nonperiodontal trabecular regions should also be conducted for this reason. The results of our investigation may also support the use of FA as a predictive and prognostic tool that can guide the management of patients with periodontitis. Future studies with larger patient populations comparing various stages and grades of periodontal health and disease are required to test this hypothesis.

Table II. Correlations of FD values and age within control and periodontitis groups

	Control (Rs, P value)	*Periodontitis (Rs, P value)*
FDm	.281, .113	.090, .650
FDc	−.297, .093	.044, .823
FDa	.104, .563	−.021, .917

FD, fractal dimension; *FDm*, mandibular molar; *FDc*, mandibular canine; *FDa*, antegonial notch; *Rs*: Spearman correlation coefficient.

Table III. Distribution of FD values by sex

	Male	*Female*	*P value**
FD levels			
FDm	1.42 ± .12	1.48 ± .11	.059
FDc	1.42 ± .12	1.50 ± .10	.007
FDa	1.44 ± .11	1.47 ± .14	.161

FD, fractal dimension; *FDm*, mandibular molar; *FDc*, mandibular canine; *FDa*, antegonial notch.
*Mann-Whitney U test

A timely and accurate diagnosis is essential for appropriate treatment regarding the early and rapid destructive characteristics of this form of periodontitis. Periodontal diagnosis is derived from the combination of the patient's medical and dental histories and clinical and radiologic findings.[28] Assessment of alveolar bone status can be important for diagnosis, treatment planning, and estimation of the prognosis of periodontal disease. However, early detection of trabecular changes is limited in conventional 2-dimensional radiography because of magnification, superposition, and distortion.[11,14,22]

Therefore, one of the aims of this study was to establish a practical and low-cost method for the diagnosis of periodontitis with FD analysis. Shrout et al[29] compared patients with healthy gingiva to those with periodontitis and concluded that FD could be calculated from standardized clinical radiographs and might be useful in distinguishing these 2 groups. Cha et al[30] also suggested that FD might be used for the diagnosis of periodontitis. Similarly, Updike and Nowzari[20] indicated that dental radiographs might be used for screening the onset of trabecular changes.

The present research was one of a few studies that have compared periodontally healthy and diseased samples on digital panoramic images through FA. FD values of periodontitis patients were significantly lower compared with periodontally healthy individuals. The results of this study are valuable because panoramic radiography is commonly used by dentists to screen new patients, and conventional 2-dimensional radiographic assessment made on panoramic radiographs is insufficient to detect periodontal destruction.[14,31] If the use of FA becomes widespread and studies are conducted on large populations, a threshold value may be established, and fractal measurements can be used for diagnosis and prognosis. Similar to other research,[20,21,22] the present study showed that age and sex are not significantly associated with FD values. This may imply that FD itself, independent from age or sex, could be an indicator for the risk of periodontal destruction. In order to thoroughly evaluate the relationship between FD and these demographic features, more comprehensive investigations with larger populations are required.

This study had some limitations. The evaluations were made retrospectively on archival diagnostic data, so there was no chance to repeat periodontal charting for the evaluation of intraexaminer reliability of clinical diagnosis. Additionally, it was impossible to make an absolute inference about the whole population based only on the present study with a limited sample of patients. Although similar results were found in other research, further comprehensive investigations with larger sample sizes and longitudinal observation are required to more completely understand the relationship between trabeculation and periodontal disease.

CONCLUSIONS

The results of the present study demonstrated that fractal analysis of the trabecular bone on panoramic radiographs can detect the trabecular microarchitectural changes that distinguish aggressive periodontitis from health. If the hypothesis that a low-quality trabecular pattern increases susceptibility to stage III/IV, grade C periodontitis is valid, and if this deficiency can be detected via FA, early supportive interventions with respect to bone metabolism may be a useful adjunct to periodontal treatment. This method showed potential benefits in the routine periodontal evaluation of young individuals with a familial history of destructive periodontal disease and other risk factors.

DECLARATION OF INTEREST

None.

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