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Anatomical assessment of the trabecular structure of the alveolar bone in periodontal disease by fractal analysis method

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Background: *Early diagnosis and treatment of periodontitis, which can cause loss of bone support of the teeth, is of great importance. The use of fractal analysis method is being investigated in order to differentiate periodontal disease radiographically. Fractal analysis presents the degree of complexity in the structure of fractal objects as a numerical data, and has been used to measure changes in trabecular bone. The aim of this study was to compare the trabecular bone fractal dimension (FD) values of patients with periodontitis and gingivitis using panoramic radiographs, and to evaluate the possible relationship between age and gender with fractal dimension.*

Materials and methods: *Panoramic radiographs of 64 patients with gingivitis and 64 patients with periodontitis were evaluated retrospectively in the study. Using the radiographs of the patients, FD values measured from the trabecular bone were calculated with the box-counting method in the Image J programme. The FD values of both groups were compared. In addition, the relationship between age and gender parameters and FD values was evaluated within the groups.*

Results: *According to the results of the study, the calculated average FD value of the patients in the gingivitis group was 1.195, while the calculated average FD value of the patients in the periodontitis group was 1.196. No statistically significant difference was observed between the FD values of the gingivitis group and the periodontitis group ($p > 0.05$). No statistically significant correlation was observed between FD values and age and gender ($p > 0.05$).*

Conclusions: *No statistically significant results were obtained for the calculated mean FD values of the patients in the gingivitis and periodontitis groups.* (Folia Morphol 2024; 83, 1: 157–167)

Keywords: fractal analysis, periodontitis, gingivitis, panoramic radiography

INTRODUCTION

Periodontitis is a disease of the periodontium and therefore of many structures including the gums. It concerns the tissues lying around the periodontium. And the periodontium also includes the cementum of the tooth root and, therefore, the tooth tissue. Periodontal diseases, which are inflammatory lesions of the tissues surrounding the teeth, are among the

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most common oral diseases in adults [39]. Gingivitis is a disease of the gums characterized by hyperaemia, oedema, and bleeding symptoms. It is also characterized by loss of attachment and alveolar bone loss [33]. Plaque tartar, periodontal pocket, inflammation, and reduced bone level are the findings that can be seen at this level. However, periodontal pocket depth differs between clinically healthy patients and patients with gingival disease. This depth detection with a periodontal probe is also important in determining the staging of periodontitis (Fig. 1) [8]. The stages of gingival disorders can start as gingivitis and progress to advanced periodontitis (Fig. 2) [4, 25, 35]. Periodontitis and osteoporosis are known to be common inflammation-related skeletal system disorders. Aging, accumulation of oxidative stress and cellular aging, vitamin D deficiency, smoking have been reported to be factors affecting the progression of osteoporosis and the formation of periodontitis [51]. Particularly, the increasing relationship between aging and periodontist has been included in the studies. Diep et al. [10] reported that there is an important need for dental care associated with endodontic conditions in the future elderly.

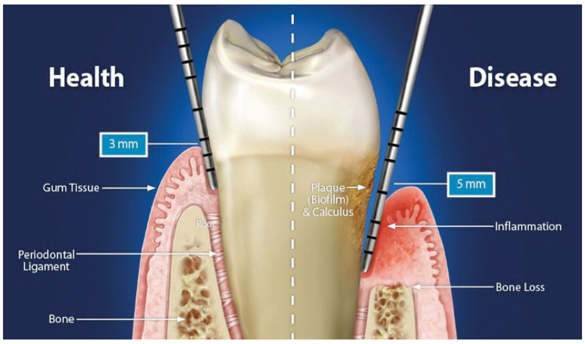

Figure 1. Morphological differences between healthy and diseased teeth and their appearance in terms of depth detection with a periodontal probe staging of periodontitis.

Alveolar bones of the upper and lower jaws consist of cortical (compact) and cancellous (trabecular) bone parts. Trabecular bone is surrounded by cortical bone like an outer sheath. Cortical bone in our skeletal system is protected against external factors, and trabecular bone has undertaken the task of actively maintaining metabolic functions [6].

Radiographs are essential tools for the diagnosis and follow-up of periodontal diseases. It has been stated that the destruction in the bone can only be detected with conventional radiographs when it reaches 30–50% [32]. This may cause the initial stage of periodontitis to be overlooked. Nowadays, technology and artificial intelligence applications have been developed, and a non-invasive diagnostic method containing objective and quantitative data is tried to be developed in the radiographic analysis [38]).

Mandelbrot described the shapes of objects that can be found outside of the geometric shapes known in nature, different from the typical geometries taught in schools and complex, with the term ‘fractal’. Fractal analysis has been used in the measurement of many objects existing in nature. The complexity of fractals comes from the endless repetition of details within details. Two features that characterize fractal geometry are the self-similarity property of each part of the figure viewed from separate scales, that is, the resemblance to the whole object, and the vari-

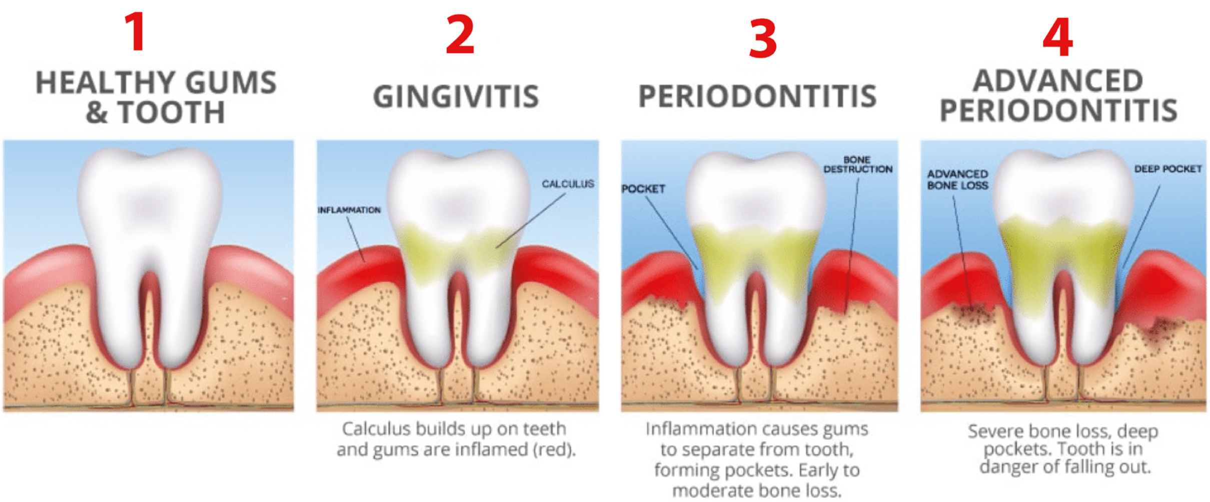

Figure 2. Stages of gum disease; 1— healthy gums and tooth; 2 — gingivitis; 3 — periodontitis; 4 — advanced periodontitis.

ation of a defined scale. That is when the examined area is enlarged or reduced by scale change; there is a similarity to the whole shape in each scale dimension [30]. An increase in the fractal dimension (FD) value is observed when the patterns have a more complex structure, while lower values indicate a simpler structure.

A special computer algorithm developed by White and Rudolph generates a number that gives the FD value representing the morphological features of the architecture, and this value gives us information about the complexity of the structure [49]. In addition to this programme called Image J, other software types that calculate fractal size such as NRecon, Scion Image CTAn, and TAS Plus have been produced.

When the trabecular structure of the cancellous bone was examined, it was observed that it showed fractal characteristics [15, 34, 50]. As a result of the studies, it was concluded that the fractal size of the bone and its biomechanical properties are related to predictors of the Young's modulus of equine cancellous bone [14]. It was found that the loss of minerals in the bone and the decrease in density decreased the FD value; likewise, a high FD has been shown to indicate fewer cavities in the more complex bone architecture [49].

It was investigated how the fractal dimensions of trabecular bone of the periapical bone showed a prospective morphological change after two different apexification treatments in teeth with apical periodontitis. The lesion area of the case was evaluated with the fractal analysis method on the periapical radiographs obtained before the treatment and 1 year after the treatment with the Image-J programme [17]. In addition, Tosun et al. [45] calculated the fractal size of abnormal tissue areas around the root apex on periapical radiographs taken before and after treatment in a retrospective study of 50 patients. And they mentioned a statistically significant difference in FD in the comparison of treated and untreated patient groups [45]. In another study, using the fractal analysis method, it was investigated whether it could distinguish the trabecular bone in this region between healthy peri-implant mucosa and individuals with peri-implant disease on periapical radiographs. They reported that the method used did not have any distinguishing features in terms of FD, but it could be useful in terms of probing depth, the presence or absence of bleeding on probing, and clinical attachment level [26].

The invisible details in the structure of the trabecular bone, which has been proven to have fractal properties, can be evaluated by the fractal analysis method [36]. Studies are reporting that the trabecular morphology of the alveolar bone and changes in the trabeculae in case of disease can be detected by this method [21]. There are limited studies in the literature investigating the use of fractal analysis to support the radiographic diagnosis of periodontal disease.

We aimed to evaluate the fractal size of patients with periodontitis and gingivitis using panoramic radiographs, and to evaluate the possible contribution of fractal analysis method to radiographic diagnosis, as well as to evaluate the possible relationship of fractal size with gender and age.

MATERIALS AND METHODS

Patient selection

Our study was carried out retrospectively using the records of Dicle University Faculty of Dentistry, Department of Periodontology. This study, which was approved by Dicle University Clinical Research Ethics Committee on 24.02.2021 with protocol number 2021-15, was conducted by the ethical principles of the World Medical Association Declaration of Helsinki. The records of 562 patients who had periodontal treatments in the Dicle University Periodontology Department between 01.10.2017 and 31.12.2018 were scanned and the patients were selected by the inclusion criteria. Among the patients whose existing periodontal index records and radiographic records were evaluated together, a total of 128 patients, 64 patients with gingivitis and 64 patients with periodontitis, were included in the study.

Inclusion criteria

The inclusion criteria were as follows having been diagnosed with gingivitis or periodontitis according to the records of the Department of Periodontology and to have a panoramic radiograph that is registered in the system and has diagnostic value.

Exclusion criteria

The exclusion criteria were as follows: presence of any systemic disease affecting bone metabolism, use of drugs that affect bone metabolism, the number of existing teeth is less than 20, presence of overflow filling, root canal treatment, cyst, tumour, lesion in the relevant area, presence of bone fracture in the relevant region, extraction of tooth numbers 5, 6 or 7 in the relevant region, to have had periodontal treatment in the last 6 months, patients with panoramic

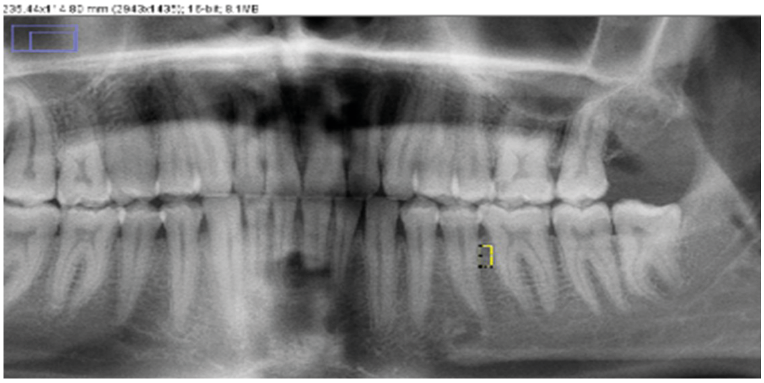

Figure 3. Region of interest selection in the Image J programme.

radiographs of no diagnostic value due to various artifacts or positioning errors.

Radiological evaluation

All the panoramic radiographs were taken with the Planmeca ProMax 2D panoramic X-ray device at Dicle University Faculty of Dentistry, Department of Oral and Maxillofacial Radiology, and the irradiation parameters were determined as 64 kVp, 7mA.

Radiographic images included in the study were opened and analysed in Meta Soft Pacs imaging system and saved in Digital Imaging and Communications in Medicine (DICOM) format, which has high image quality.

Fractal analysis

The panoramic image was opened in the Image J programme and the area to be examined, called region of interest (ROI), was selected (Fig. 3). The relevant area was selected to include first the mesial and then the distal of tooth 36, and two separate FDs were calculated and the average of the two measurements was taken. If tooth 36 was out of consideration, tooth 46 was used in the calculation. The ROI was chosen in a rectangular shape with a size of 23 × 51 pixels. Narrow interproximal areas that do not allow ROI selection at this site are adjusted to be in the closest pixel to it.

The image was rotated in the desired direction with the 'rotate' option and the relevant region was enlarged with the 'magnifying' feature so that the ROI selected in the posterior of the mandible can be selected in a rectangular shape and at the specified pixel.

- The ROI selected to include the interdental trabecular bone was clipped with the 'crop' feature.
- The cropped ROI was copied with the 'duplicate' feature.
- A 'Gaussian filter' set to 35 pixels was used to remove the density differences created by the soft tissue in the image and to make sharper differences more evident.
- The image filtered by the 'Subtraction' feature has been extracted from the original.
- It was set to 128 values with the 'add' property to reveal the density differences in the image.
- With the 'Binary' feature, the image was made black and white. Thus, the trabeculae became evident.
- The 'erode' and then 'dilate' features were used to eliminate noise and highlight the main lines.
- With the 'invert' feature, the image was inverted, and the desired features are brought into view.
- Using the 'skeletonized' feature, the trabecular structure in the bone was transformed into complex lines.

With the 'Box-counting' feature, the image was divided into squares of 2, 3, 4, 6, 8, 12, 16, 32, and 64 pixels (Fig. 4). Squares containing these complex lines representing trabeculae were counted. This calculation was done separately for each pixel size and the total number of frames was calculated. The number of counted plates was plotted against the total number of plates on a logarithmic scale. A line is drawn through the data points in the graph. The slope of the drawn line gives the FD value, which expresses the complexity of the analysed image (Fig. 3).

Statistical analysis

In this study, Shapiro Wilk's and/or Kolmogorov-Smirnov tests were used due to the number of units while investigating the normal distribution of the variables. While evaluating the results, 0.05 was used as the significance level. Chi-square analysis was applied while examining the relationships between groups of nominal variables.

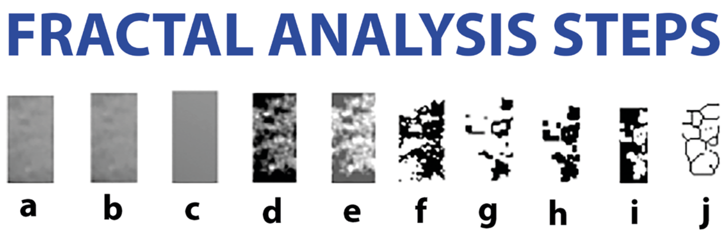

Figure 4. Fractal analysis steps; a — cropped view of the relevant area; b — duplicated image; c — applying a Gaussian filter; d — image extracted from the original; e — grayscale adjustment; f — binarization; g — eroding; h — dilatation; i — reversal; j — skeletonization.

Table 1. Relationship between groups in terms of gender

Gender	Groups							
	Periodontitis		Gingivitis		Total			
	N	%	N	%	N	%	Chi-square	P-value
Male	31	48.44	32	50	63	49.22		
Female	33	51.56	32	50	65	50.78	0.031	0.86
Total	64	100	64	100	128	100		

Table 2. Differences between groups in terms of age

Groups	Age							
	N	Mean	Median	Minimum	Maximum	Standard deviation	Mean rank	z	P-value
Periodontitis	64	34.05	33	18	54	9.91	65.09		
Gingivitis	64	33.91	32	22	65	9.32	63.91	–0.181	0.856
Total	128	33.98	32.5	18	65	9.58			

Table 3. Differences between groups in terms of fractal dimension values

Groups	Fractal dimension value								
	N	Mean	Median	Minimum	Maximum	Standard deviation	Mean rank	z	P-value
Periodontitis	64	1.196	1.214	0.813	1.395	0.141	67.23		
Gingivitis	64	1.195	1.185	0.957	1.429	0.121	61.77	–0.832	0.406
Total	128	1.195	1.206	0.813	1.429	0.131			

Spearman's correlation coefficient was used while examining the relationships between variables that did not come from the normal distribution. While examining the differences between groups, if the variables did not come from a normal distribution, the Mann-Whitney U test was used for comparisons between groups.

RESULTS

Demographic findings

There was no statistically significant relationship between the groups in terms of gender ($p > 0.05$); 51.6% of the periodontitis group and 50% of the gingivitis group were women. Table 1 shows the gender distribution and statistical relationship in the groups.

There was no statistically significant difference between the groups in terms of age ($p > 0.05$). The mean age of the periodontitis group was higher than the mean age of the gingivitis group, but the difference was not statistically significant. Table 2 shows the age and statistical relationship of the groups.

FD measurements

There was no statistically significant difference between the groups in terms of FD values ($p > 0.05$). Table 3 shows the FD values of the gin-

Table 4. Differences between genders in terms of fractal dimension values

		Fractal dimension value								
		N	**Mean**	**Median**	**Minimum**	**Maximum**	**Standard deviation**	**Mean rank**	**z**	**P-value**
Periodontitis	Male	31	1.201	1.199	0.885	1.395	0.109	30.68	–0.759	0.448
	Female	33	1.191	1.227	0.813	1.39	0.168	34.21		
	Total	64	1.196	1.214	0.813	1.395	0.141			
Gingivitis	Male	32	1.208	1.18	1.026	1.429	0.132	34.38	–0.806	0.42
	Female	32	1.181	1.193	0.957	1.367	0.108	30.63		
	Total	64	1.195	1.185	0.957	1.429	0.121			
Total	Male	63	1.204	1.192	0.885	1.429	0.12	65.16	–0.198	0.843
	Female	65	1.186	1.213	0.813	1.39	0.141	63.86		
	Total	128	1.195	1.206	0.813	1.429	0.131			

Table 5. The relationship between fractal dimension values and age

			Age
Periodontitis	Fractal dimension	r	0.055
		p	0.665
		n	64
Gingivitis	Fractal dimension	r	0.089
		p	0.483
		n	64
Total	Fractal dimension	r	0.08
		p	0.367
		n	128

givitis and periodontitis groups and their statistical relationship.

Although there was no statistically significant difference between the genders in terms of FD values measured from the radiographs of the patients in the periodontitis and gingivitis groups, the FD value measured from the radiographs of the men was higher ($p > 0.05$). Table 4 shows the relationship between FD and gender.

Although there was no statistically significant difference between the genders in terms of FD values measured from the radiographs of the individuals regardless of the group, the FD value calculated from the radiographs of the men was higher ($p > 0.05$; Table 4).

Although there was no statistically significant relationship between the FD values measured from the radiographs of the patients both gingivitis and periodontitis groups and the age values, the FD value increased as the age increased ($p > 0.05$). Table 5 shows the relationship between FD and age.

Regardless of the group, there was no statistically significant relationship between the FD values measured from the radiographs of the individuals and the age values, but the FD value increased as the age increased ($p > 0.05$; Table 5).

DISCUSSION

The clinical significance of the relationship between periodontitis and genetic factors is known. Based on recent research data, it has been reported that genetic and ethnic factors are considered the leading susceptibility or severity factors for devastating periodontitis. A family history of early-onset aggressive periodontitis has been known for a long time. Hereditary syndromes have often been associated with severe periodontitis. They reported that periodontal disease associated with systemic inherited syndromes mainly indicates Mendelian inheritance [12]. Shungin et al. [41] presented as a meta-analysis a genome-wide association study by identifying clinical findings, self-reported dental disease proxies with similar underlying genetic contributions, and then identifying 47 novel and conditionally independent risk loci for dental caries. Similarly, they reviewed the literature for gene polymorphisms associated with periodontitis and peri-implantitis susceptibility in the Iranian population[20]. In a study investigating epigenetic factors in periodontitis, these epigenetic changes have been reported to be associated with excess inflammatory cytokines, chemokines and matrix-degrading enzymes that can be suppressed by certain histone deacetylases (small molecule inhibitors of certain histone deacetylases) or by small molecule inhibitors of DNA methyltransferases. They noted the importance of providing critical information about the therapeutic and diagnostic potential of epigenetics in periodontal disease [19]. For all that, they stated that periodontitis may be an individual risk factor for the development of oral cancer. They suggested that individuals with periodontal problems, especially those with severe periodontitis and coexisting lifestyle risk factors, should be followed closely. They concluded that maintaining periodontal health in at-risk patients can minimise their cancer risk [22]. In a genetic microbiological study, they reported that the correlation of mir155 with periodontal parameters and periodontal pathogens further strengthens the evidence for periodontal inflammation as a risk of preeclampsia in pregnant women, especially when associated with chronic periodontitis. They suggested that mir155 can be considered as one of the genetic biomarkers and is an important criterion for the early diagnosis of periodontitis [29].

The fractal analysis method, which is thought to contribute to the radiographic examination by examining the invisible details in the bone structure, has been used to understand objects in many fields such as astrophysics, genetic, economy, agriculture, medicine, and dentistry [11, 16, 27, 31].

It has been reported that the FD value calculated by the studies is not affected by variables such as irradiation time (mAs), kilovolt peak acceleration voltage (kVp), and projection angle, therefore fractal analysis can be performed with non-standardized radiographs during the filming of [7, 18, 46].

Considering this information, our study aimed to use fractal analysis to evaluate the trabecular bone morphology of patients with periodontitis and gingivitis, as well as to evaluate the possible relationship between fractal dimension, age, and gender.

There are a limited number of studies in the literature regarding the use of fractal analysis to support the radiographic diagnosis of periodontitis. Current studies used cone beam computed tomography (CBCT) and periapical radiography technique [1, 9, 37, 38, 40, 48]. Although there are many studies on FD calculation using panoramic radiographs in different fields in dentistry [15, 21, 42], no study has yet been conducted using panoramic radiographs in the evaluation of periodontal disease.

Periapical and bite-wing radiographs are imaging modalities with better resolution than panoramic radiographs. However, the disadvantages are that the number of films to be taken is higher when the whole mouth is evaluated and the radiation dose that the patient will receive is higher than the dose that will be taken with panoramic radiographs [43].

The fact that panoramic radiographs are in widespread use with increasing frequency, the advantageous situation in their application and patient tolerance, and the fact that they allow imaging of larger areas with a lower radiation dose have prompted us to use panoramic radiography in this study.

It has been reported that the box-counting method is widely used and is currently in fractal analysis [21]. In this method, the process steps suggested by White and Rudolph are applied. For this purpose, the Image J image analysis programme was developed.

In our study, ROI was chosen within the borders of trabecular bone, not including cortical bone, tooth, or periodontal space. Like other studies [1, 38], In our study, two separate ROIs were selected from the mesial and distal interdental region of the mandible number 6 tooth, which is frequently affected by periodontitis, FD was calculated from these regions, and the average of the two values was taken.

In our study in which trabecular bone FD measurements of 64 gingivitis and 64 periodontitis patients were compared, it was observed that there was no statistically significant difference between the calculated FD values of the patients in the two groups.

In the study of Shrout et al. in 1998 [40], the FD values calculated from the periapical radiographs of the group with periodontitis and the healthy or another patient group with gingivitis were compared. As a result of this study, it was found that the FD value of the group with periodontitis was significantly lower [5]. In our study, digital panoramic radiographs were recorded and used in DICOM format with high image quality. We believe that this situation may have caused the difference between the results.

In the study of Şener et al. [38], in which they measured FD using the periapical radiographs of healthy and moderately severe periodontitis patients, a significant difference was found between the FD values of both groups. In the study of Bollen et al.[5], in which they compared periapical and panoramic radiographs, it was reported that FD values measured from periapical radiographs of the same patients were higher. This situation causes us to consider the possibility of different details and resolutions in imaging methods to change the results in diseases that cause local bone loss such as periodontitis.

Coşgunarslan et al. [9] calculated FD from CBCT images of healthy and periodontitis patients and reported that there was no statistically significant difference between FD measurements of the two groups, like our study. They reported that the inconsistency of this result with some studies in the literature may be due to the difference in imaging methods [9]. In addition, Magat et al. suggested that CBCT has low image resolution for fractal analysis of trabecular bone [28]. Based on this, it can be thought that the results may vary when FD measurement is performed using periapical, panoramic, or CBCT imaging.

In the study of Updike and Nowzari [48], the FD values of healthy, moderate/severe, and severe periodontitis patients were compared. As a result of the study, there was a significant difference between the FD values of the periodontitis groups and the healthy group, but no significant difference was found between the FD values of the moderate/severe periodontitis and severe periodontitis groups [48]. We believe that the fact that the result of our study is not fully compatible with this study may be due to the difference in ROI position.

Region of interest selection is done manually. This leads to practitioner error and the inability to standardize the ROI position [28]. It is impossible to select an ROI from the same area in every patient, which may lead to differences in measurements. In the study by Shrout et al. [40], which compared the FD values of the periodontitis and healthy/gingivitis group, ROIs were determined in different sizes according to the shape and size of the interproximal bone. As a result of the study, it was reported that there was a significant difference between the FD values of the two groups. We think that the non-parallelism of our results may be due to the variation in the selected ROI sizes. For our study results to be of optimum accuracy, the gender and age distribution of the groups were determined to be homogeneous.

Studies have reported that there was no significant relationship between gender and FD [1, 47, 48]. The results of these studies support the findings of our study. Researchers reported that there was a significant difference between FD values in their studies [1, 48]. We think that the inconsistency of these results with our study may be due to the difference in age values between groups. Age distribution was determined to be homogeneous in the periodontitis and gingivitis groups so that our study results were not affected by age-related variability. Amer et al. [2] reported that fractal size of trabecular bone was not associated with age.

Geraets and van der Stelt [13] mentioned that the conflicting results may be due to the anatomical differences of the examined region and the methods used to obtain the image. When utilizing the fractal analysis to study bone, it should be noted that all the steps in the analytical chain have an impact on the results.

It has been suggested that retrospective evaluation of the bone microstructure surrounding unerupted/impacted canines can provide analytical information on treatment prognosis and anchorage considerations. Bone surface area and bone marrow surface area can be measured by FD analysis of CBCT images, and bone density has been reported to be reliably estimated [3]. In addition, Köse et al. [23] observed a negative relationship between FDs in the mandibular mental region and total orthodontic treatment time. FD analysis has drawn attention to its importance for understanding the physiological properties of alveolar bone and predicting orthodontic tooth movement [23]. In a study of fractal analysis of periapical bone, it was stated that high resolution showed the least variation in FD values at all compression levels, making it the most reliable and consistent resolution for measuring FD values [44]. In a study in which implant evaluation was evaluated in terms of FD, they found that FD values of trabecular bone around the implants were significantly lower than the initial values 6 months after prosthetic loading. However, they reported that no significant decrease or increase was observed at 12 months, with results comparable to peri-implant alveolar bone at 6 months [52]. On the other hand, it has been suggested that fractal size of alveolar bone measured from intraoral digital radiographs alone may be an insufficient parameter to determine initial implant stability [24].

Many factors are likely to have an impact on the results, from patient selection in the study to imaging methods, the quality of these methods, sample size, gender and especially age distributions between groups, changes in ROI location and size, personal variations in ROI selection, and patients' anatomical variations. To standardize these variables as much as possible, the limitations of the method need to be developed and more studies with a larger sample size are needed.

CONCLUSIONS

In this study, trabecular bone fractal dimension values were compared using panoramic radiographs of patients with periodontitis and gingivitis, and the following results were obtained:

— there was no statistically significant difference between the groups in terms of FD values of trabecular bone calculated using panoramic radiographs of the patients in the periodontitis and gingivitis groups;

— in the periodontitis and gingivitis groups, there was no statistically significant difference between FD values, gender, and age values, according to the comparisons in the FD values of the trabecular bone, which were made within the group and without any group discrimination.

We believe that the inability to obtain a significant result is due to the wide age range of the population in this study. It is obvious that there is a need for prospective fractal analyses and follow-ups to be made between different age groups due to the degeneration of the anatomical structure in the trabecular structure with aging.

Conflict of interest: None declared

REFERENCES

1. Aktuna Belgin C, Serindere G. Evaluation of trabecular bone changes in patients with periodontitis using fractal analysis: A periapical radiography study. J Periodontol. 2020; 91(7): 933–937, doi: 10.1002/JPER.19-0452, indexed in Pubmed: 31850519.
2. Amer ME, Heo MS, Brooks SL, et al. Anatomical variations of trabecular bone structure in intraoral radiographs using fractal and particles count analyses. Imaging Sci Dent. 2012; 42(1): 5–12, doi: 10.5624/isd.2012.42.1.5, indexed in Pubmed: 22474642.
3. Arvind TR, Jain RK, Nagi R, et al. Evaluation of alveolar bone microstructure around impacted maxillary canines using fractal analysis in dravidian population: a retrospective CBCT study. J Contemp Dent Pract. 2022; 23(6): 593–600, indexed in Pubmed: 36259297.
4. Barsoum F, Prete BRJ, Ouanounou A. Drug-Induced gingival enlargement: a review of diagnosis and current treatment strategies. Compend Contin Educ Dent. 2022; 43(5): 276–286, indexed in Pubmed: 35589146.
5. Bollen AM, Taguchi A, Hujoel PP, et al. Fractal dimension on dental radiographs. Dentomaxillofac Radiol. 2001; 30(5): 270–275, doi: 10.1038/sj/dmfr/4600630, indexed in Pubmed: 11571547.
6. Bostrom M, Yang Xu, Koutras I. Biologics in bone healing. Curr Opin Orthop. 2000; 11(5): 403–412, doi: 10.1097/00001433-200010000-00013.
7. Buckland-Wright JC, Lynch JA, Rymer J, et al. Fractal signature analysis of macroradiographs measures trabecular organization in lumbar vertebrae of postmenopausal women. Calcif Tissue Int. 1994; 54(2): 106–112, doi: 10.1007/BF00296060, indexed in Pubmed: 8012865.
8. Citterio F, Gualini G, Chang M, et al. Pocket closure and residual pockets after non-surgical periodontal therapy: a systematic review and meta-analysis. J Clin Periodontol. 2022; 49(1): 2–14, doi: 10.1111/jcpe.13547, indexed in Pubmed: 34517433.
9. Coşgunarslan A, Aşantoğrol F, Canger EM, et al. Use of fractal analysis to detect trabecular changes related to periodontitis. Selçuk Dent J. 2019: 341–345.
10. Diep MT, Hove LH, Ørstavik D, et al. Periapical and endodontic status among 65-year-old Oslo-citizens. BMC Oral Health. 2022; 22(1): 371, doi: 10.1186/s12903-022-02406-9, indexed in Pubmed: 36050662.
11. Elblbesy MA, Attia M. Optimization of fractal dimension and shape analysis as discriminators of erythrocyte abnormalities. A new approach to a reproducible diagnostic tool. Math Biosci Eng. 2020; 17(5): 4706–4717, doi: 10.3934/mbe.2020258, indexed in Pubmed: 33120525.
12. Gera I, Vári M. [Genetic background of periodontitis. Part I. Basic principles and inherited syndromes. Literature review]. Fogorv Sz. 2009; 102(3): 87–95, indexed in Pubmed: 19618776.
13. Geraets WG, van der Stelt PF. Fractal properties of bone. Dentomaxillofac Radiol. 2000; 29(3): 144–153, doi: 10.1038/sj/dmfr/4600524, indexed in Pubmed: 10849540.
14. Haire TJ, Hodgskinson R, Ganney PS, et al. A comparison of porosity, fabric and fractal dimension as predictors of the Young's modulus of equine cancellous bone. Med Eng Phys. 1998; 20(8): 588–593, doi: 10.1016/s1350-4533(98)00063-0, indexed in Pubmed: 9888237.
15. Heo MS, Park KS, Lee SS, et al. Fractal analysis of mandibular bony healing after orthognathic surgery. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2002; 94(6): 763–767, doi: 10.1067/moe.2002.128972, indexed in Pubmed: 12464904.
16. Heymans O, Fissette J, Vico P, et al. Is fractal geometry useful in medicine and biomedical sciences? Med Hypotheses. 2000; 54(3): 360–366, doi: 10.1054/mehy.1999.0848, indexed in Pubmed: 10783467.
17. Ince Yusufoglu S, Ugur Aydin Z, Tulumbaci F, et al. Evaluation of different Apexification treatments of teeth with immature apices and apical periodontitis on the fractal dimensions of trabecular bone. Aust Endod J. 2021; 47(2): 163–169, doi: 10.1111/aej.12441, indexed in Pubmed: 32902092.
18. Jolley L, Majumdar S, Kapila S. Technical factors in fractal analysis of periapical radiographs. Dentomaxillofac Radiol. 2006; 35(6): 393–397, doi: 10.1259/dmfr/30969642, indexed in Pubmed: 17082328.
19. Jurdziński KT, Potempa J, Grabiec AM. Epigenetic regulation of inflammation in periodontitis: cellular mechanisms and therapeutic potential. Clin Epigenetics. 2020; 12(1): 186, doi: 10.1186/s13148-020-00982-7, indexed in Pubmed: 33256844.
20. Kadkhodazadeh M, Tabari ZA, Pourseyediyan T, et al. Relationship between Genetic Polymorphisms with Periodontitis and Peri-Implantitis in the Iranian Population: A Literature Review. J Long Term Eff Med Implants. 2016; 26(2): 183–190, doi: 10.1615/JLongTermEffMedImplants.2016015197, indexed in Pubmed: 28094743.

21. Kato CN, Barra SG, Tavares NPk, et al. Use of fractal analysis in dental images: a systematic review. Dentomaxillofac Radiol. 2020; 49(2): 20180457, doi: 10.1259/dmfr.20180457, indexed in Pubmed: 31429597.
22. Komlós G, Csurgay K, Horváth F, et al. Periodontitis as a risk for oral cancer: a case-control study. BMC Oral Health. 2021; 21(1): 640, doi: 10.1186/s12903-021-01998-y, indexed in Pubmed: 34911520.
23. Köse E, Ay Ünüvar Y, Uzun M. Assessment of the relationship between fractal analysis of mandibular bone and orthodontic treatment duration: a retrospective study. J Orofac Orthop. 2022; 83(Suppl 1): 102–110, doi: 10.1007/s00056-022-00406-6, indexed in Pubmed: 35776177.
24. Kulczyk T, Czajka-Jakubowska A, Przystańska A. A comparison between the implant stability quotient and the fractal dimension of alveolar bone at the implant site. Biomed Res Int. 2018; 2018: 4357627, doi: 10.1155/2018/4357627, indexed in Pubmed: 30410933.
25. Kuralt M, Cmok Kučič A, Gašperšič R, et al. Evaluation of gingival recessions with conventional versus digital methods. J Dent. 2022; 120: 104093, doi: 10.1016/j.jdent.2022.104093, indexed in Pubmed: 35301080.
26. Lang MS, Miyamoto T, Nunn ME. Validity of fractal analysis of implants in individuals with healthy and diseased peri-implant mucosa. Clin Oral Implants Res. 2020; 31(11): 1039–1046, doi: 10.1111/clr.13650, indexed in Pubmed: 32790884.
27. Lennon FE, Cianci GC, Cipriani NA, et al. Lung cancer-a fractal viewpoint. Nat Rev Clin Oncol. 2015; 12(11): 664–675, doi: 10.1038/nrclinonc.2015.108, indexed in Pubmed: 26169924.
28. Magat G, Ozcan Sener S. Evaluation of trabecular pattern of mandible using fractal dimension, bone area fraction, and gray scale value: comparison of cone-beam computed tomography and panoramic radiography. Oral Radiol. 2019; 35(1): 35–42, doi: 10.1007/s11282-018-0316-1, indexed in Pubmed: 30484179.
29. Mahendra J, Mahendra L, Mugri MH, et al. Role of periodontal bacteria, viruses, and placental mir155 in chronic periodontitis and preeclampsia: a genetic microbiological study. Curr Issues Mol Biol. 2021; 43(2): 831–844, doi: 10.3390/cimb43020060, indexed in Pubmed: 34449559.
30. Mandelbrot B. How long is the coast of britain? Statistical self-similarity and fractional dimension. Science. 1967; 156(3775): 636–638, doi: 10.1126/science.156.3775.636, indexed in Pubmed: 17837158.
31. Meyer HV, Dawes TJW, Serrani M, et al. Genetic and functional insights into the fractal structure of the heart. Nature. 2020; 584(7822): 589–594, doi: 10.1038/s41586-020-2635-8, indexed in Pubmed: 32814899.
32. Özer N, Baksı Şen BG. Third dimension in dental radiographic imaging: a literature update. J Dent Fac Atatürk Uni. 2021; 31(4): 652–661, doi: 10.17567/ataunidfd.821983.
33. Papapanou PN, Sanz M, Buduneli N, et al. Periodontitis: Consensus report of workgroup 2 of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions. J Periodontol. 2018; 89(Suppl 1): S173–S182, doi: 10.1002/JPER.17-0721, indexed in Pubmed: 29926951.
34. Prouteau S, Ducher G, Nanyan P, et al. Fractal analysis of bone texture: a screening tool for stress fracture risk? Eur J Clin Invest. 2004; 34(2): 137–142, doi: 10.1111/j.1365-2362.2004.01300.x, indexed in Pubmed: 14764077.
35. Revilla-León M, Gómez-Polo M, Barmak AB, et al. Artificial intelligence models for diagnosing gingivitis and periodontal disease: a systematic review. J Prosthet Dent. 2023; 130(6): 816–824, doi: 10.1016/j.prosdent.2022.01.026, indexed in Pubmed: 35300850.
36. Ruttimann UE, Webber RL, Hazelrig JB. Fractal dimension from radiographs of peridental alveolar bone. A possible diagnostic indicator of osteoporosis. Oral Surg Oral Med Oral Pathol. 1992; 74(1): 98–110, doi: 10.1016/0030-4220(92)90222-c, indexed in Pubmed: 1508517.
37. Sang-Yun C, Won Jeong H, Eun Kyung K. Usefulness of fractal analysis for the diagnosis of periodontitis. Korean J Oral Maxillofac Radiol. 2001; 31(1): 35–42.
38. Sener E, Cinarcik S, Baksi BG. Use of fractal analysis for the discrimination of trabecular changes between individuals with healthy gingiva or moderate periodontitis. J Periodontol. 2015; 86(12): 1364–1369, doi: 10.1902/jop.2015.150004, indexed in Pubmed: 26291294.
39. Ship JA, Crow HC. Diseases of periodontal tissues in the elderly. Description, epidemiology, aetiology and drug therapy. Drugs Aging. 1994; 5(5): 346–357, doi: 10.2165/00002512-199405050-00004, indexed in Pubmed: 7833588.
40. Shrout MK, Roberson B, Potter BJ, et al. A comparison of 2 patient populations using fractal analysis. J Periodontol. 1998; 69(1): 9–13, doi: 10.1902/jop.1998.69.1.9, indexed in Pubmed: 9527567.
41. Shungin D, Haworth S, Divaris K, et al. Genome-wide analysis of dental caries and periodontitis combining clinical and self-reported data. Nat Commun. 2019; 10(1): 2773, doi: 10.1038/s41467-019-10630-1, indexed in Pubmed: 31235808.
42. Suer BT, Yaman Z, Buyuksarac B. Correlation of fractal dimension values with implant insertion torque and resonance frequency values at implant recipient sites. Int J Oral Maxillofac Implants. 2016; 31(1): 55–62, doi: 10.11607/jomi.3965, indexed in Pubmed: 26478979.
43. Şener E, Baksı BG. Imaging Systems used for diagnosis of periodontal pathology. Part 1: Two or three dimensional imaging systems. EÜ Diş Hek Fak Derg. 2013; 34(2): 79–85.
44. Toghyani S, Nasseh I, Aoun G, et al. Effect of image resolution and compression on fractal analysis of the periapical bone. Acta Inform Med. 2019; 27(3): 167–170, doi: 10.5455/aim.2019.27.167-170, indexed in Pubmed: 31762572.
45. Tosun S, Karataslioglu E, Tulgar MM, et al. Fractal analysis and periapical index evaluation of multivisit nonsurgical endodontic retreatment: A retrospective study. Oral Surg Oral Med Oral Pathol Oral Radiol. 2022; 133(2): 245–251, doi: 10.1016/j.oooo.2021.08.016, indexed in Pubmed: 34556458.
46. Tosun S, Karataslioglu E, Tulgar MM, et al. Retrospective fractal analyses of one-year follow-up data obtained after single-visit nonsurgical endodontic retreatment on periapical radiographs. Clin Oral Investig. 2021; 25(11): 6465–6472, doi: 10.1007/s00784-021-04079-0, indexed in Pubmed: 34302217.

47. Uğur Aydın Z, Ocak MG, Bayrak S, et al. The effect of type 2 diabetes mellitus on changes in the fractal dimension of periapical lesion in teeth after root canal treatment: a fractal analysis study. Int Endod J. 2021; 54(2): 181–189, doi: 10.1111/iej.13409, indexed in Pubmed: 32931021.
48. Updike SX, Nowzari H. Fractal analysis of dental radiographs to detect periodontitis-induced trabecular changes. J Periodontal Res. 2008; 43(6): 658–664, doi: 10.1111/j.1600-0765.2007.01056.x, indexed in Pubmed: 18624949.
49. White SC, Rudolph DJ. Alterations of the trabecular pattern of the jaws in patients with osteoporosis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1999; 88(5): 628–635, doi: 10.1016/s1079-2104(99)70097-1, indexed in Pubmed: 10556761.
50. Yaşar F, Akgünlü F. The differences in panoramic mandibular indices and fractal dimension between patients with and without spinal osteoporosis. Dentomaxillofac Radiol. 2006; 35(1): 1–9, doi: 10.1259/dmfr/97652136, indexed in Pubmed: 16421256.
51. Yu Bo, Wang CY. Osteoporosis and periodontal diseases — An update on their association and mechanistic links. Periodontol 2000. 2022; 89(1): 99–113, doi: 10.1111/prd.12422, indexed in Pubmed: 35244945.
52. Zeytinoğlu M, İlhan B, Dündar N, et al. Fractal analysis for the assessment of trabecular peri-implant alveolar bone using panoramic radiographs. Clin Oral Investig. 2015; 19(2): 519–524, doi: 10.1007/s00784-014-1245-y, indexed in Pubmed: 24802628.