ASSESSMENT OF TRABECULAR CHANGES IN FURCATION INVOLVEMENT USING FRACTAL ANALYSIS

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ABSTRACT

Background and Aim: To evaluate the potential impact of the presence and extent of furcation involvement (FI) on trabecular bone changes, both on digital orthopantomography (OPG) and cone-beam computed tomography (CBCT) images, using fractal analysis.

Materials and Methods: In the present study, a total of 51 mandibular molars, of which 28 were determined as degree I FI (FI-I), and 23 were determined as degree II FI (FI-II) were included, while 43 mandibular molars without any evidence of FI (non-FI) served as the control group. Fractal dimensions (FD) were calculated using digital panoramic and CBCT images with Image J software. Receiver operating characteristic (ROC) analysis was used to compare the FD-FI diagnostic capacity of OPG and CBCT images.

Results: The FD values of digital panoramic and CBCT images were significantly higher in the control group than in the FI-I and FI-II groups ($p<0.05$). Also, the FD calculated on digital panoramic radiographs was markedly higher than the FDs of CBCT in all groups ($p<0.05$). The area under ROC curves for differentiating FI-I from the non-FI group were 0.752 and 0.828, and to diagnose FI-II were 0.877 and 0.902 for OPG_FD and CBCT_FD, respectively.

Conclusion: As fractal analysis has the potential to determine the presence, extent, and severity of FI in both panoramic and CBCT images, it can serve as a measure for a thorough analysis of cases with FI. When FI is considered a vital complexity factor in periodontal diseases/conditions, the benefit of reliable measures for early and accurate diagnosis of FI becomes more crucial.

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INTRODUCTION

Complexity is one of the major highlights of the recent classification entitled the Classification of Periodontal and Peri-Implant Diseases and Conditions, which is associated with the extent and severity of periodontal destruction, the treatment planning, prognosis, and long-term outcomes of periodontal treatment.[1]Complexity is such crucial that it has the potential to change the stage of periodontitis and the mode of treatment such as complex periodontal treatments and/or multidisciplinary treatment approaches.[1,2] Among the well-defined complexity factors, probing depths, pattern of bone loss, tooth mobility, missing teeth, bite collapse, and residual ridge defect size are listed, and furcation involvement (FI) is one of the crucial complexity factors.[2] The complexity is a new context that the Classification of Periodontal and Peri-Implant Diseases and Conditions brings to daily dental practice. Complexity is important because it is related to treatment, prognosis, long-term results, stage levels, and treatment options. As complexity increases, treatments become more multidisciplinary and complex, and since FI is an important complexity factor, early and accurate diagnosis of FI is crucial. [2,3]

Furcation involvement occurs when periodontal disease causes bone resorption in the bi- or trifurcation area of a multi-rooted tooth,[4] as alveolar bone destruction leads to bone defects around the teeth and in the inter-radicular region.[5] The anatomy of the furcation is known to facilitate the retention of bacterial deposits and complicate oral hygiene procedures and periodontal debridement.[6] Therefore, the successful treatment of FI is still challenging. Accurate diagnosis of FI plays a key role in selecting a specific treatment option among various proposed treatment models and approaches (e.g., conservative, resective, or regenerative therapy).[7] The clinical diagnosis, treatment decisions, and classification systems currently used for FI may be affected by an array of factors, including root morphology, the configuration of the residual inter- and peri-radicular bone, the length of the root trunk, and the degree of root separation.[8] It is crucial to detect FI early, as advanced stages of FI may make treatment difficult and negatively impact treatment success.[3] A meticulous radiographic examination often provides evidence in the early stages of furcation involvement and clinical diagnosis.[7]

Radiographic examination allows the assessment of anatomical features of tooth root, surrounding alveolar bone, and alveolar defects relating to the pattern and extent of bone resorption.[5] However, 2-dimensional imaging techniques routinely used to evaluate periodontal structures have inherent disadvantages, such as superimposition and blurring of anatomical structures that prevent precisely detecting intraosseous defects and furcation involvement.[9] On the other hand, these limitations can be overcome by three-dimensional (3D) imaging using cone-beam computed tomography (CBCT), which provides precise images with the potential to display small structures such as periodontal defects.[9] Although the benefits of various imaging modalities in periodontal evaluation are very evident, generally, the amount of bone destruction is underestimated on radiographs, mainly since bone changes can be seen on radiographs after 30% to 50% of the bone mineral structure is resorbed.[10–12] Therefore, advanced analysis of radiographic images is suggested to potentially increase the diagnostic capacity of radiographic examination in cases such as the early stages of periodontitis.[11,12]

Fractal analysis (FA) is a mathematical method to assess complex structures. It is defined quantitatively as the fractal dimension (FD), which represents the degree of complexity of a geometric structure.[13,14] Fractal analysis is primarily used in medicine and dentistry to determine the severity and progression of existing disease or to diagnose a potential disease. It is stated that FD detected on radiographs reflects the changes in trabecular bone density and mineral loss in the bone.[15–17] A higher degree of FD indicates that the bone architecture is more complex and the spaces within the bone are less, while a small FD suggests that the bone has a more porous structure.[15,18]

Radiological imaging techniques can detect alveolar bone level, pattern, and size of bone defects. The value of radiographs for diagnosing periodontal disease is based on their potential to predict disease severity and progression and evaluate treatment outcomes.[5] Trabecular changes caused by periodontitis and the severity of the disease can be determined quantitatively with fractal analysis.[19] Studies on the quantitative comparison of panoramic radiography and CBCT imaging methods in evaluating furcation involvement are limited in the literature. Therefore, the present study aimed to evaluate the trabecular changes caused by FI on panoramic radiographs and CBCT images with fractal analysis.

MATERIALS AND METHODS

Sample Selection

The study was approved by the Institutional Ethics Committee (GO 22/899) and conducted following the Helsinki Declaration of 1975, as revised in 2013. This study was performed on patients with both CBCT scans, including the mandible and digital panoramic images obtained for dental reasons. Written and verbal informed consents were obtained before radiologic imaging. All radiographic images were retrieved from the archive of the Dentomaxillofacial Radiology Department between August and December 2022. The inclusion criteria for all groups were those over 18 years of age and those with mandibular first or second molars. Exclusion criteria comprised poor diagnostic quality images (i.e., positioning, motion, or metal artifacts), large intraosseous lesions, mandibular fractures involving the region of interest, and periapical lesions extending towards the furcation area of mandibular molars. The relevant teeth with horizontal through-and-through furcation defects were also excluded. Degree I and II FI groups comprised 28 mandibular molars from 23 patients and 23 mandibular molars from 22 patients, respectively. Degree 0 FI consisting of 43 mandibular molars from 31 individuals were included in the study as a control group.

Image Acquisition

Digital panoramic images were obtained with a panoramic X-ray device (Morita Veraview IC5, J. Morita MFG Corp., Kyoto, Japan). The exposure parameters were 1-7.5 mA, 60-70 kVp, and 5.5-10 s. CBCT scans were performed by an i-Cat Next Generation device (Imaging Sciences International, Hatfield, PA, USA) with the parameters as follows: 3–8 mA, 120 kVp, 0.20 mm voxel, 16 × 6-13 cm field-of-view and 26 s scan time. All images were evaluated on a 24-inch LCD monitor with 1920 × 1080 resolution (Dell, Round Rock, TX, USA).

Radiographic Examination

Assessment of Furcation Involvement (FI)

The level of horizontal alveolar bone loss on the mandibular molars' furcation area was assessed by an experienced periodontist (BA) on CBCT images, with a slice thickness of 0.2 mm, by using i-CAT Vision software (Imaging Sciences International, Hatfield, PA, USA). The degree of FI was determined according to the section with the highest bone loss in the axial view. A line tangent to the adjacent roots was drawn on this section. The distance between this line and the deepest point of the bone defect was used to classify FI according to the Hamp et al.[20] classification system. Intra-class correlation coefficient (ICC) was used for calculating inter-rater agreement for the depth of furcation involvements, and accordingly, the repeatability of the measurements was found to be consistent (ICC: 0.97; 95% CI 0.91-0.99). Mandibular first and second molars with Degree I FI (FI-I) and Degree II FI (FI -II) were selected and included in the case group in the study, whereas the control group consisted of molar teeth with no evidence of FI (non-FI).

FD Analysis

All radiographic images were examined using Image J (Image J software, version 1.53, National Institutes of Health), a Java-based 64-bit software for Windows, available free of charge from https://imagej.nih.gov/ij/download.html. The rectangle tool of software was used to select region of interest (ROI). The ROI size was chosen carefully in the furcation region to consist of the maximum available field near the furcation entrance, excluding the surrounding structures such as the root lamina dura or periodontal ligament. Based on the prior training with the molar teeth with a narrow distance between roots, the largest possible rectangular ROI size for both imaging modalities was 4 x 20 pixels, avoiding anatomical structures such as dental root, lamina dura, or periodontal ligament space. It was standardized for each tooth (Figure 1). ROI was assessed on CBCT images in the sagittal section, which showed the most significant bone loss. Measurements were carried out by an experienced dentomaxillofacial radiologist (NK). All radiographic images were stored in a TIF (Tagged Image File) file format. Fractal analysis was performed according to the box-counting algorithm described in White and Rudolph's method.[17] Initially, the determined ROI was duplicated and blurred using a Gaussian blur filter (sigma=35 pixels). Following the subtraction of ROI from the main image, a grey value of 128 was added to each pixel location. After this step, the image was binarized with the software's threshold tool with a brightness value 128. Thereafter, the process was continued with this sequence of events: erosion, dilatation, inversion, and skeletonization of the image (Figure 2). Then, the fractal box count tool calculated the FD value of the skeletonized image.

Statistical Analysis

A statistical power analysis was conducted using G*Power 3.1, employing t-tests based on previous research data.[21] With an alpha of 0.05, 80% power, and a 0.60 effect size, a sample size of 36 was estimated for both case and control groups. Considering the possibility of missing data, 10% more than the estimated number of samples were included in the study. Descriptive statistics included count for data with categorical variables mean values ± standard deviations or median (IQR) for data with continuous variables. Data normality was assessed with the Kolmogorov–Smirnov test. The difference in measurements between the groups (non-FI and FI-I - FI-II) was determined with a chi-square test for sex, a one-way ANOVA test for age, and independent-samples Kruskal-Wallis test for OPG-FD and CBCT-FD. The significance values were adjusted using the Bonferroni correction to account for multiple tests. Related-samples Wilcoxon signed-rank test was performed to compare OPG-FD and CBCT-FD within the groups. Spearman's and Pearson's correlation coefficients were performed according to the normal distribution to assess the correlation between OPG-FD, CBCT-FD, and furcation depth measurements. Analysis of covariance (ANCOVA) test was performed to compare fractal dimensions between the groups, eliminating the effect of age as the covariate. Receiver operating characteristic (ROC) analysis was used to compare the FI diagnostic capacity of OPG and CBCT images, and ROC curves were used to find the optimal cut-off values. Optimal sensitivity and specificity thresholds for FI diagnosis were established using the Youden method. OPG_FD and CBCT_FD ROC curves of FI-I and FI-II were compared with ROC curves of the control group for pairwise comparisons of ROC curves. All statistical tests were carried out with SPSS (v.26, IBM Corp, NY, USA), and two-tailed $p<0.05$ was accepted as a significant difference.

RESULTS

In this study, 51 mandibular FI (FI degree I= (FI-I) F/M:14/14, mean age: 51.9±11.9. FI degree II (FI-II) F/M:11/12, mean age 49.9±12.2) and 43 mandibular molars without FI were included (F/M:22/21, mean age 41.3±13.4). Although it was comparable between the groups in terms of sex ($p>0.05$), the mean age of the control group was markedly lower than the case groups ($p<0.05$). The median values of fractal dimensions measured from both OPG and CBCT images were significantly higher in the control group than in the FI groups (FI-I and FI-II) ($p<0.05$). (Table 1). Furthermore, it was observed that fractal dimensions in CBCT and OPG were significantly associated with FI even when the impact of age was removed with ANCOVA analysis ($p<0.001$).

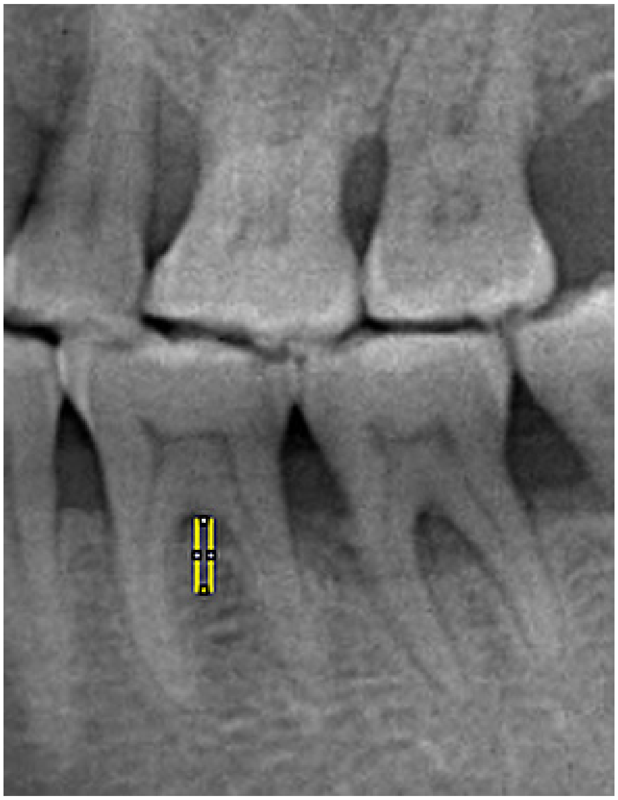

Figure 1. Cropped panoramic image showing the selection of ROI (4 x 20 pixels) in the left mandibular first molar with FI-I.

Table 2 displays the FD values of the different degrees of FI in OPG and CBCT images. OPG-FD values were higher than CBCT-FD values in all groups ($p<0.05$). The area under ROC curve (AUC) for the diagnosis of FI-I using OPG-FD measurement was 0.752 ($P<0.001$; 95% CI, 0.63-0.87) with optimal sensitivity and specificity of 54% and 91% at a cut-off value lower than 0.55 (Figure 3A). The ROC AUC for the diagnosis of FI-I using CBCT_FD values was 0.828 ($p<0.001$; 95%CI, 0.73-0.92) with optimal sensitivity and specificity of 82% and 77% at a cut-off value lower than 0.50 (Figure 3B). This indicated that CBCT-FD had a superior ability to diagnose FI-I defects than OPG-FD.

The AUC of OPG_FD and CBCT_FD between no FI and FI-II were 0.877 ($p<0.001$; 95%CI, 0.79-0.96) and 0.902 ($p<0.001$; 95%CI, 0.83-0.97), respectively. In distinguishing FI-II from no FI, the sensitivity and specificity for OPG_FD were 65% and 95%, respectively; for CBCT_FD, were 100% and 77%, respectively. For detecting FI-II, the cut-off values of OPG_FD and CBCT_FD were set at 0.54 and 0.51,

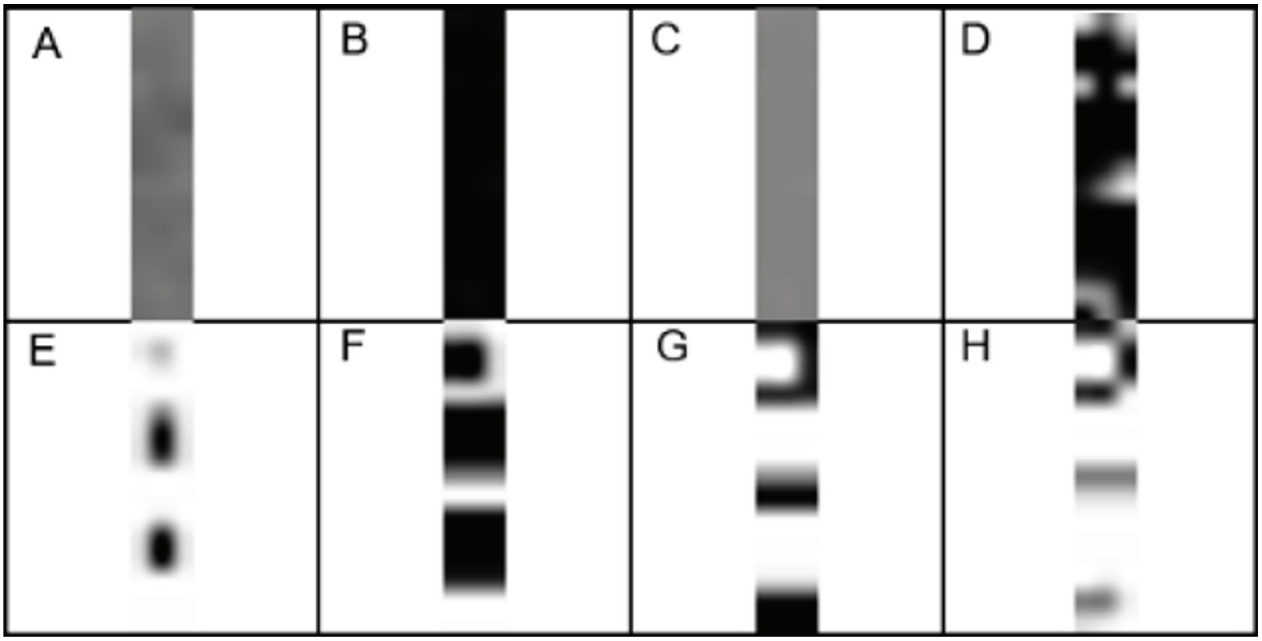

Figure 2. Steps of fractal dimension analysis. (A) Cropped and duplicated ROI. (B) The blurred image was then subtracted from the original image. (C) Addition of a gray value of 128 to each pixel location. (D) Application of 128 threshold value (E) Erosion. (F) Dilatation. (G) Inversion. (H) Skeletonization

Table 1. Comparison of the groups in terms of age, gender and fractal dimension measurements.

	Furcation Involvement (FI)			
	Degree 0 (N=43)	Degree I (N=28)	Degree II (N=23)	p*
Sex (F/M)	22/21	14/14	11/12	0.967
Age	41.3 ± 13.4	51.9 ± 11.9	49.9±12.2	0.002[1,2]
OPG_FD	0.66 (0.07)	0.55 (0.17)	0.46 (0.25)	<0.001[1,2]
CBCT_FD	0.57 (0.15)	0.41 (0.18)	0.34 (0.22)	<0.001[1,2]

OPG: orthopantomography, CBCT: Cone-beam computed tomography. FD: fractal dimension
* Significance between FI degree 0, 1 and 2 groups. Chi-square test for sex. One-way ANOVA test for age. Independent-Samples Kruskal-Wallis test for OPG-FD and CBCT-FD. Significance values have been adjusted by the Bonferroni correction for multiple tests.
1 Significance between FI degree 0 and degree 1 (p=0.003 for age; p=0.001 for OPG-FD; p<0.001 for CBCT-FD)
2 Significance between FI degree 0 and degree 2 (p=0.032 for age; p<0.001 for OPG-FD; p<0.001 for CBCT-FD)

Table 2. Differences between OPG_FD and CBCT_FD according to the groups.

Groups	OPG-FD	CBCT-FD	p*
Degree 0	0.66 (0.07)	0.57 (0.15)	<0.001
Degree I	0.54±0.14	0.39±0.12	<0.001
Degree II	0.48±0.13	0.33±0.12	<0.001

* Significance between OPG-FD and CBCT-FD within the groups. Related-samples Wilcoxon signed rank test for FI degree 0 group. Paired Samples T-Test for FI degree 1 and degree 2 groups.

respectively (Figure 3C-D). The AUC values in both imaging techniques were relatively high. By applying fractal analysis, FI-II could be distinguished from healthy alveolar bone with high success in both CBCT and OPG images. Comparing fractal dimension measurements for the capability to detect both FI-I and FI-II, no statistically significant difference

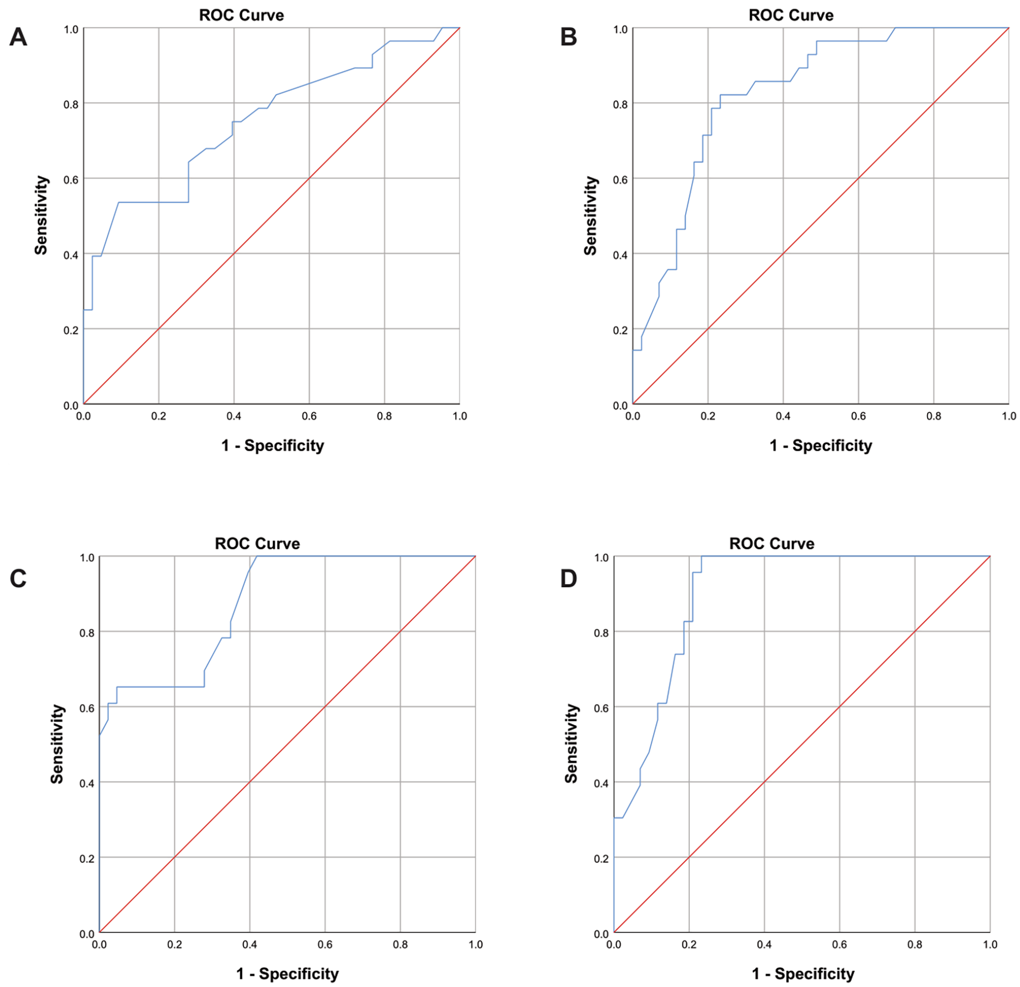

Figure 3. Graphs illustrating the ROC results for detection of FI-I using OPG_FD (A) and CBCT_FD (B) values; and FI-II using OPG_FD (C) and CBCT_FD (D) values.

was observed between the ROC curves of CBCT_FD and OPG_FD ($p=0.222$ for FI-I, $p=0.639$ for FI-II). No significant correlation was found between OPG-FD, CBCT-FD, and depth of the furcation measurements in the control and FI-I groups ($p>0.05$). Nevertheless, the FI-II group had a significant positive correlation between FD values of OPG and CBCT images and a significant negative correlation between fractal dimensions of CBCT images and furcation depth measurements ($p<0.05$).

DISCUSSION

The present study evaluated the efficiency of the fractal analysis method in detecting FI in mandibular molars. Although there are studies examining bone changes in periodontitis with fractal analysis, to our knowledge, this is the first study to evaluate FI with fractal analysis method on panoramic and CBCT images. According to the Classification of Periodontal and Peri-Implant Diseases and Conditions, periodontitis is defined based on the stage and grade levels of the disease. The stage of periodontitis is determined by disease severity, complexity, extent, and distribution.[1] Moreover, complexity factors such as FI may cause the stage of periodontitis to be elevated to a higher level.[1] FI also increases the complexity of periodontitis treatment, and an accurate evaluation of these defects is needed in treatment planning for optimal treatment outcomes.[2] However, the complex root morphology of molars and the anatomical and topographic relationship between the roots may make identifying the furcation defects on 2-D radiographic images difficult.[7] CBCT imaging allows detailed examination of furcation involvement and improves diagnosis and treatment decisions.[22,23] Fractal analysis is a valuable alternative to quantitatively evaluate trabecular changes in alveolar bone defects, including furcation involvement.[12,21]

In the literature, studies show the alveolar bone changes in periodontitis with FD analysis. Aktuna-Belgin et al.[12] demonstrated that the mean FD values of the mandibular first molar in patients with periodontitis were significantly lower than those of periodontally healthy individuals.[12] In a previous study evaluating the furcation region of mandibular molars on periapical radiographs, it was observed that the FD value of the control group was significantly higher than that of the periodontitis group.[21] In another study with digital periapical radiographs, it was stated that FD values of healthy periodontal bone differed significantly from moderate and severe periodontitis. However, there was no statistically significant difference between FD values of periodontally healthy bone and mild periodontitis.[11] Also, Updike et al.[19] reported substantial differences in FD between the healthy controls and moderate periodontitis groups and between control and severe periodontitis groups. At the same time, there was no significant difference in FD between moderate and severe periodontitis groups.[19] A previous study evaluating healthy gingiva and moderate periodontitis with fractal analysis on digital images to determine the initial trabecular bone changes in periodontitis established that the detection of bone changes in the interdental trabecular pattern of early stages of periodontal destruction may be able to make with the fractal analysis.[24] In line with previous results, the present study displayed that FD values of degree I and II furcation involvements in both CBCT and OPG images were significantly lower than those of periodontally healthy molars, even though the difference of FD values between degree I and II FI was not statistically significant. Consequently, fractal analysis can effectively distinguish changes in trabecular bone structures among periodontal health, furcation involvement, and interdental bone defects, as shown in previous studies.

In the present study, the mean age of the control group was significantly lower than the FI group. The prevalence of periodontitis increases from 15-19 years to 50-54 years of age.[25] The significant age difference between the control group and the periodontitis groups with furcation defect can be attributed to the fact that most of the individuals in this study were in the age range where the severity of periodontitis increases with age. However, the significant relationship between fractal dimension and furcation involvement did not change when the impact of age was eliminated. Hereby, fractal dimension measurement on digital OPG and CBCT images has been shown to have diagnostic capacity for detecting furcation defects regardless of age. The present study's comparison of ROC curves indicated no significant difference between CBCT and OPG images in detecting furcation involvements by the fractal analysis method. Although CBCT showed a superior ability to diagnose FI-I than OPG in this study, it can be assumed that performing fractal analysis on OPGs obtained to detect periodontal bone loss can provide accurate detection of FI.

The complex anatomical structure of the furcation region of molars is a limiting factor for fractal dimension measurement. While determining the ROI region, attention was paid to including the same structures, and the ROI area was limited due to the furcation anatomy. Moreover, fractal analysis was performed on each molar's OPG and CBCT images. Another limitation of this study is that the measurement of FD in CBCT imaging was limited to the sagittal sections. Due to the superimposition of the molar roots on the furcation region, fractal analysis could not be performed on cross-sectional CBCT images. Finally, further studies that exclude other factors that may impact bone metabolism and periodontal health, as well as clinical measurements of furcation involvement, are needed to reveal more clearly the relationship between FI and fractal dimension.

The current study emphasizes the crucial importance of early and accurate diagnosis of the presence and extent of FI as a complicating factor. This can significantly influence the decision-making process, treatment outcomes, and the long-term success of periodontal treatment. Furthermore, it underscores the need for a comprehensive evaluation of dental images to better support clinical examinations.

CONCLUSION

As fractal analysis has the potential to determine the presence and the severity of FI in both panoramic and CBCT images, it can serve as a measure for a thorough analysis of cases with FI. Additionally, fractal analysis's quantitative and non-invasive features suggest its use in evaluating FI.

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AUTHORSHIP CONTRIBUTIONS

Design of the work: NT, BA and NK, the acquisition and interpretation of the data: BA and NK, drafting the manuscript: BA, revising critically and final approval of the version: NT, BA, and NK.

DATA AVAILABILITY STATEMENT

The data supporting this study's findings are available from the corresponding author upon reasonable request. The data are not publicly available because of privacy or ethical restrictions.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ETHICS STATEMENT

The present study was approved by the Institutional Ethics Committee (GO 22/899).

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