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ORIGINAL ARTICLE

# Evaluation of the mandibular trabecular bone in patients with bruxism using fractal analysis

Melike Gulec[1] · Melek Tassoker[1] · Sevgi Ozcan[1] · Kaan Orhan[2]

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## Abstract

**Objective** The aims of this study were (1) to investigate the effect of bruxism on the fractal dimension (FD) of the mandibular trabecular bone through digital panoramic radiographs, and (2) to evaluate the effectiveness of fractal analysis as a diagnostic test for bruxism.

**Methods** One hundred and six bruxer and 106 non-bruxer patients were included in the study. Three bilateral regions of interest (ROI) were selected: ROI-1, the mandibular condyle; ROI-2, the mandibular angle; ROI-3, the-area between the apical regions of the mandibular second premolar and the first molar teeth. FD values for the bruxer and non-bruxer groups were compared for each ROI.

**Results** Only the FD measurements for the right mandibular condyle (ROI-1) showed a statistically significant difference ($p = 0.041$) between the bruxer and non-bruxer individuals. FD values measured in the bruxers ($1.40 \pm 0.09$) were lower than in the non-bruxers ($1.42 \pm 0.08$).

**Conclusion** Fractal analysis may be a useful method for discerning trabecular differences in the condylar areas of bruxer individuals. In future studies, the unilateral mastication habits, the characteristics of dental wear, and the occlusal bite forces of individuals should be documented.

**Keywords** Bruxism · Fractal analysis · Mandible · Trabecular bone

## Introduction

A fractal is characterized as a complex set of structures that have the property of looking like itself and that cannot be defined with common geometrical shapes such as squares, circles or triangles [1]. The word fractal is derived from the word "fractus" which means broken in Latin [2]. This concept was first used by the famous mathematician Benoit Mandelbrot in the 1960s and 1970s [2–4]. In the literature, increased complexity in a structure is associated with an increase in its fractal dimension (FD). Structures with a high FD are more complex, while structures with a low FD have a simpler internal order [4–6].

Fractal analysis is a method that has become increasingly popular in recent years due to features such as being easily accessible, being unaffected by variables such as projection geometry and radiodensity, and being able to provide objective data about trabecular internal structures [7, 8]. In dentistry, fractal analysis studies have been conducted in various areas, such as the determination of early periodontal changes in the alveolar bone [9], diagnosis of osteoporosis-related pathologies [10], evaluation of bone tissue adjacent to an implant site [11], analysis of patients with temporomandibular joint (TMJ) dysfunction [12], and the relationship between the severity of disease and changes in the trabecular bone structure [12, 13].

Bruxism is defined as the clenching and/or grinding action performed by the teeth without a functional purpose such as chewing or crushing [14]. In its etiology, morphological, psychological, and parafunctional factors are generally found to be accountable. There is no universally accepted method for the diagnosis of bruxism due to its subjective nature [15]. Bruxism can occur in sleep (nocturnal bruxism) or while awake (diurnal bruxism). While

✉ Kaan Orhan
call53@yahoo.com

[1] Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Necmettin Erbakan University, Konya, Turkey

[2] Department of Dentomaxillofacial Radiology, Faculty of Dentistry, Ankara University, Besevler, 06560 Ankara, Turkey

sleep bruxism does not show gender-related differences, awake bruxism is more common in women [16]. Bruxism can result in tooth wear and fractures, loss of periodontal support and mobility, pain in the masticatory system and orofacial structures, and TMJ dysfunction [17]. Bruxism is reported to be associated with diseases of the TMJ [18]. In the literature, it has been reported that parafunctional habits cause mechanical stress on the condyle and that mechanical stress is able to initiate condylar resorption or to accelerate progressive resorption [19]. The purpose of this study was to evaluate the efficacy of fractal analysis as a diagnostic test for bruxism and to investigate the effects of bruxism on the FD of the mandibular trabecular bone by using digital panoramic radiographs (DPR). There is no study in the literature that evaluates this relationship.

## Materials and methods

### Patient selection

In this study, individuals who applied to the Necmettin Erbakan University Faculty of Dentistry, Oral and Maxillofacial Radiology clinic for routine examination and who volunteered to participate in the study were included. The study was carried out in accordance with the principles defined in the Declaration of Helsinki and included all the necessary arrangements and revisions. The conformity of the research with ethical principles was evaluated and approved by the Scientific Researches Evaluation Committee of the Faculty of Dentistry of Necmettin Erbakan University (Decision No: 2017/12). Individuals included in the study were informed in detail about the study before the examination, and an Informed Consent Form was signed by all individuals willing to participate.

Inclusion criteria for individuals were that they were systemically healthy (an absence of diseases, especially those affecting bone metabolism such as Paget's disease, hyperparathyroidism, hypoparathyroidism, osteomalacia, renal osteodystrophy, osteogenesis imperfecta), were aged between 21 and 40 years, and had angle class 1 occlusion.

Exclusion criteria for individuals were having any tooth missing in the upper or lower jaw (except for third molar teeth), pathology in the maxillofacial region, neurological and psychiatric diseases, alcohol and drug addiction, a history of concluded or continuing orthodontic treatment, prosthetic restoration in any tooth, and premature contact by any type of restoration during occlusion.

Both the clinical symptoms and the anamnesis results were evaluated by the same observer (MG) for the diagnosis of bruxism.

### Clinical examination

Tooth wear was evaluated without differentiation between functional and non-functional tubercles. In the early stages, tooth wear is seen as glossy surfaces on the incisal surfaces of the anterior teeth and on the occlusal surfaces of the posterior teeth.

The following anamnesis findings were taken into consideration: the individual reports that he or she clenches or grinds during the day or night, tooth grinding noise reported by a partner during sleep, and reports of tension, pain, and fatigue in the masticatory muscles (temporal and/or masseter) after awakening or during the daytime.

In this study, the clinical existence of tooth wear with the presence of at least one of the anamnesis findings was evaluated as bruxism positive [20–24].

The bruxer group consisted of 106 individuals who met the conditions already stated, while 106 individuals with no diagnostic criteria for bruxism were identified as the non-bruxer group. The bruxer and non-bruxer groups were matched by age and gender. In the power analysis performed to evaluate the adequacy of the sample, the power of the study with a confidence level of 95% was found to be 80%. This ratio shows that the sample size, determined as 212 individuals, is sufficient to evaluate the usability of fractal analysis as a diagnostic test for bruxism.

### Radiographic examination

All panoramic radiographs in the study were obtained by using a digital panoramic X-ray device of 2D Veraviewpocs (J MORITA MFG corp., Kyoto, Japan) with parameters of 70 kVp, 5 mA and 15 s exposure time. Radiographs with no diagnostic capability due to imprecise patient positioning or exposure errors were not included in the study. The teeth with caries and/or restorations were determined on the panoramic and bitewing radiographs of the individuals and they were recorded on the right or left sides.

### Display features

A Windows XPTM Professional operating system with a 2.66 GHz Intel Xeon processor, a 3.25 Gb RAM, and a 27-inch flat-panel color display (Dell U2711HTM) with a resolution of 2.560 × 1.600 pixels was used to examine the radiographs.

### Image processing (fractal analysis)

Panoramic radiographs of individuals included in the study were recorded in high-resolution TIF (tagged image file) format. For standardization of the radiographs, the dimensions of all the images were set to 2836 × 1500 pixels by Adobe Photoshop CS5 (Adobe Systems Inc., San Jose, CA, USA). Java-based 64-bit software called ImageJ v1.52 for Windows, which is a version of the National Institutes of Health (NIH) Image software was used for the fractal analysis. The program was downloaded from the internet at https://imagej.nih.gov/ij/download.html.

### Region of interest (ROI) selection

Six bilateral ROIs were identified on the panoramic radiographs for fractal analysis:

1. 50 × 50 pixels in the condylar region,
2. 100 × 100 pixels in the mandibular angle,
3. 100 × 100 pixels in the region between the apical of the mandibular second premolar and the first molar teeth (excluding the periodontium of the teeth and the cortical boundaries of the mandibular canal) (Fig. 1).

Fractal analysis was performed according to the method described by White and Rudolph [6] (Fig. 2). In this method:

First, the copied ROI was blurred using the "Gaussian Blur" filter (sigma, 35 pixels). With this step, the bright areas formed due to changes in soft tissue and bone thickness were blurred (Fig. 2a).

The blurred rendered images were then removed from the original image (Fig. 2b) and 128 Gy values were added for each pixel (Fig. 2c). Areas of different brightness in the images with a mean value of 128 Gy value help distinguish bone marrow from the trabecular structure.

After that, by using the "Make Binary" option, the image was converted to a two-color format that was black and white. Thus, the boundaries of the bone marrow and trabecular structure were made distinguishable (Fig. 2d).

Next, the "Erode" step was applied to reduce the noise on the image (Fig. 2e).

Then, with the "Dilate" option, the existing fields were expanded and made more pronounced (Fig. 2f).

In the "Invert" step, the white areas on the image were modified to black and the black areas to white, revealing the boundaries of the trabecular bone (Fig. 2g).

Finally, using the "Skeletonize" option, the image with the trabecular structure was converted into the skeletal structure format and made ready for fractal analysis (Fig. 2h).

For calculation of the fractal size, the image was divided into squares with dimensions of 2, 3, 4, 6, 8, 12, 16, 32, and 64 pixels using the option "Fractal Box Counter" under the "Analyze" button. The squares containing the trabecula and the total number of frames in the image were calculated for the different sizes of the pixel. These values were plotted on the logarithmic scale, and the slope of the line that best fitted the points in the graph gave the FD.

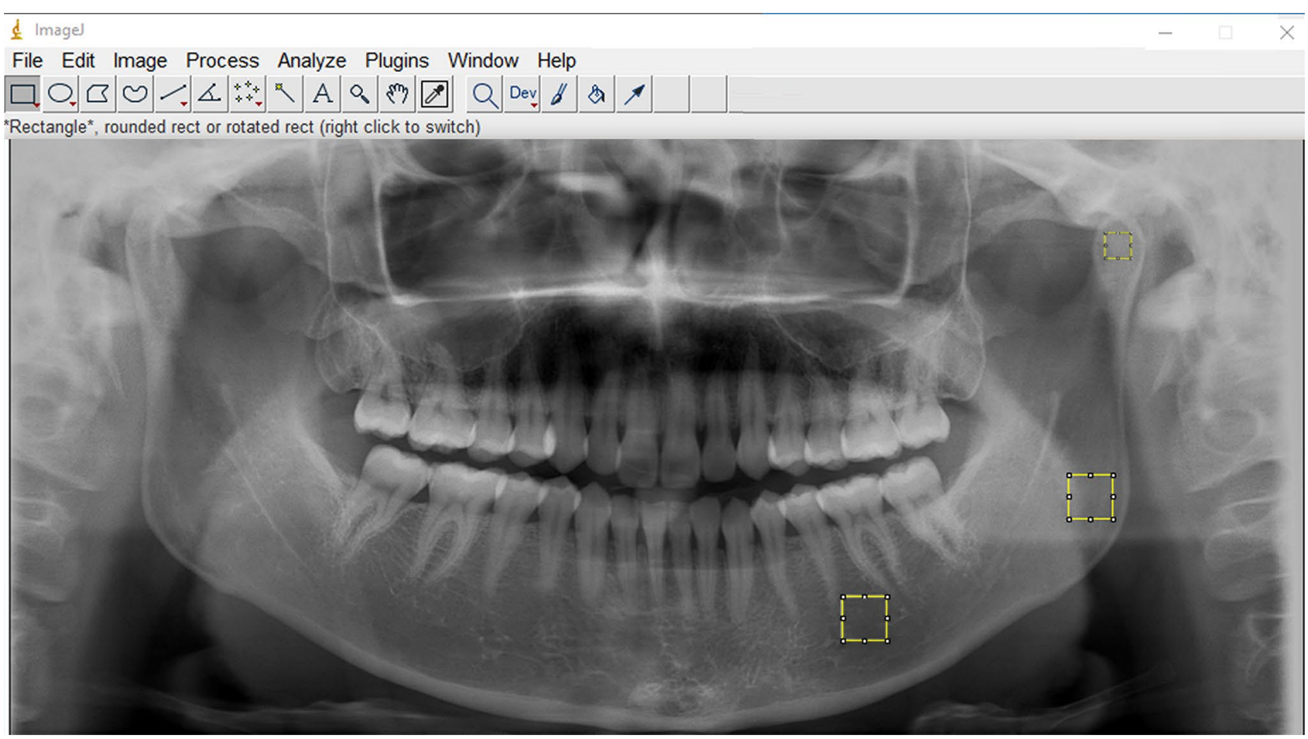


**Fig. 1** Selection of the specified ROIs (region of interest) on the program

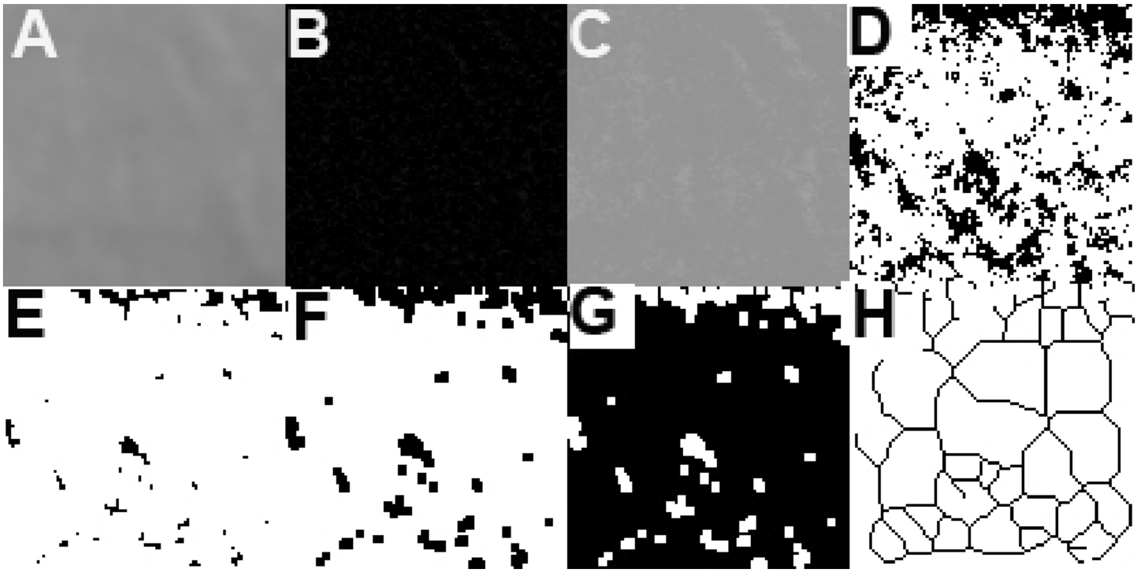


**Fig. 2** **a** Blurring; **b** removal of the blurred image from the original image; **c** addition of 128 Gy values; **d** conversion of image to black and white; **e** noise reduction with Erode; **f** expansion with Dilate; **g** inversion of the colors; **h** conversion to skeletal format

## Statistical analysis

The FD measurements of the ROIs indicated for each radiograph were done twice by two observers after an interval of 14 days. The observers were blind to the first measurements when doing the second measurements. Cronbach's alpha analysis was used to evaluate the inter-observer and intra-observer correlation. Data were evaluated with the SPSS 21.0 (SPSS, Chicago, IL, USA) program. Descriptive statistics were calculated for all parameters in the study. Categorical data are presented with frequency and a percentage ratio, and numerical data are presented with tables using mean ± SD. The conformity of the continuous numerical variables to a normal distribution was analyzed by the Kolmogorov–Smirnov test. It was observed that the distribution of the variables did not generally conform to a normal distribution, and so non-parametric tests were applied. The Wilcoxon signed sequence test, the Kruskal–Wallis test, the Mann–Whitney *U* test, and Spearman correlation analysis were used to compare the measurements. ROC analysis was applied to evaluate FD as a diagnostic test. The type-I error value was taken as 5% in all analyses and $p < 0.05$ was accepted as statistically significant.

## Results

The current study was conducted on 106 (53 bruxers, 53 non-bruxers) male and 106 female (53 bruxers, 53 non-bruxers) individuals. The mean age of all individuals was 27 ± 5.7 years (for women 27 ± 5.9, for men 27 ± 5.5). The distribution of all individuals according to gender, age groups, and mean ages are shown in Table 1.

In the present study, FD analysis was performed in 1272 (212 × 6) ROIs, determined from the panoramic radiographs of 212 individuals. Fractal analysis of the ROIs was conducted on 50 patients and was repeated twice by two observers with 2 weeks between each analysis. Since no statistically significant difference could be detected between intra-observer and inter-observer repeated measurements,

**Table 1** The number of people by age groups

| Age group | Female | | Male | | Total | Female | Male | Total |
|---|---|---|---|---|---|---|---|---|
| | B | NB | B | NB | | Mean age ± SD | Mean age ± SD | Mean age ± SD |
| 21–25 | 22 | 22 | 30 | 30 | 104 | 22 ± 1.0 | 23 ± 1.6 | 22 ± 1.4 |
| 26–30 | 19 | 19 | 7 | 7 | 52 | 27 ± 1.3 | 28 ± 0.9 | 28 ± 1.3 |
| 31–35 | 6 | 6 | 12 | 12 | 36 | 34 ± 1.1 | 32 ± 1.5 | 33 ± 1.6 |
| 36–40 | 6 | 6 | 4 | 4 | 20 | 39 ± 0.9 | 39 ± 0.9 | 39 ± 0.9 |
| Total | 53 | 53 | 53 | 53 | 212 | 27 ± 5.8 | 27 ± 5.5 | 27 ± 5.6 |

*B* bruxer, *NB* non-bruxer, *SD* standard deviation the measurements of the first observer were used for the data analysis. The mean FD values measured for the 212 individuals are shown in Table 2. Looking at the mean FD values of all individuals: FD values calculated from the gonial regions had the highest average, and FD values calculated from the dentate regions had the lowest average. The FD values for the condylar, gonial and dentate regions selected from the same side of the jaw were significantly different from each other ($p < 0.05$), and no correlation was found between them (Spearman Rho, $r < 0.2$, $p > 0.05$). FD measurements made from condylar, gonial and dentate regions on the right and left sides were not found to have a statistically significant difference ($p > 0.05$).

When the relationship between gender and FD was investigated, it was found that there was a statistically significant difference between the FD values in the right gonial ($p = 0.000$), left condyle ($p = 0.017$) and left gonial ($p = 0.000$) regions (Table 2). In these regions, the FD values of women were lower than those of men.

When the FD values of 212 individuals were evaluated for the relationship between age and FD, a statistically significant difference was found only in the left gonial area ($p = 0.012$). FD values for the 21–25 years age group had the highest average (FD = 1.47), and the lowest average was in the 26–30 and 36–40 years age groups (FD = 1.44) (Table 3). Correlation analysis between age and FD measurements in all subjects showed only a weak negative correlation in the right condyle region (Spearman Rho, $r = -0.16$, $p = 0.020$), but no significant correlation with age was found in the other regions.

According to the Mann–Whitney $U$ test, performed to investigate the variability of FD values according to bruxism, only the right condyle FD measurements showed a statistically significant difference ($p = 0.041$). The FD values measured from the bruxer individuals were lower in this region (Table 4). The FD values of the right condyle, which were found to be statistically significant, were used as a diagnostic method for bruxism, but the ROC analysis tests showed that the area under the curve (AUC) was not significant [AUC = 0.419 ± 0.077 (95% CI AUC = 0.342–0.496)]. Chi-square test was used to evaluate the difference between the right and left sides to relate to the presence of caries and/or restoration, as a result it was found that there was a statistically significant difference between the right and left sides ($p = 0.000$) (Table 5).

## Discussion

There has been no consensus on the diagnosis of bruxism due to its controversial, non-specific, and subjective character. Therefore, there is a need to utilize quantitative data in the diagnosis of bruxism. The aim of this study was to use the fractal analysis method to evaluate whether bruxism causes changes in the structure of the mandibular trabecular bone. In addition to the calculation of the FD values of bruxer and non-bruxer individuals, the differences in FD according to age and gender were also calculated.

In the literature, intraoral radiographs have been used to measure FD values because they are reported to have higher resolution than panoramic radiographs and are indicated to give more precise and accurate results. Panoramic radiographs have also been used because they are sufficient to show the trabecular pattern. Individuals who applied for routine examinations and had panoramic radiographs were included in the present study. Panoramic radiographs were preferred because of the ROI preferences (gonial, condylar, and dentate regions). Although Chen et al. [25] report that during digitization, inhomogeneity in the screening process has a limited effect on the outcomes, the digital system is able to prevent the loss of data that results from the digitization of conventional radiographs. In the current study, to prevent the effects of digitization and the bath stages on

**Table 2** The mean FD values of all individuals by gender

| ROI | Total<br>Mean FD ± SD | Male<br>Mean FD ± SD | Female<br>Mean FD ± SD | Mann–Whitney *U*<br>*p* |
|---|---|---|---|---|
| Right condyle | 1.41 ± 0.08 | 1.40 ± 0.09 | 1.42 ± 0.07 | 0.252 |
| Right gonial | 1.45 ± 0.06 | 1.47 ± 0.05 | 1.44 ± 0.07 | 0.000* |
| Right dentate | 1.38 ± 0.05 | 1.38 ± 0.05 | 1.38 ± 0.05 | 0.996 |
| Left condyle | 1.40 ± 0.09 | 1.41 ± 0.09 | 1.38 ± 0.08 | 0.017** |
| Left gonial | 1.46 ± 0.06 | 1.48 ± 0.04 | 1.44 ± 0.07 | 0.000* |
| Left dentate | 1.37 ± 0.06 | 1.38 ± 0.05 | 1.37 ± 0.07 | 0.858 |
| Mean condyle | 1.40 ± 0.07 | 1.40 ± 0.08 | 1.40 ± 0.06 | 0.384 |
| Mean gonial | 1.45 ± 0.06 | 1.47 ± 0.04 | 1.44 ± 0.06 | 0.000* |
| Mean dentate | 1.38 ± 0.05 | 1.38 ± 0.04 | 1.38 ± 0.05 | 0.779 |

*ROI* region of interest, *SD* standard deviation, *FD* fractal dimension, *p* degree of significance

*Significance on $p < 0.001$ scale, **significance on $p < 0.05$ scale

**Table 3** FD and *p* values according to age groups of all individuals (mean FD of male and female)

| ROI | 21–25 Age Mean FD ± SD | 26–30 Age Mean FD ± SD | 31–35 Age Mean FD ± SD | 36–40 Age Mean FD ± SD | Kruskal–Wallis *p* |
|---|---|---|---|---|---|
| Right condyle | 1.42 ± 0.08 | 1.41 ± 0.09 | 1.40 ± 0.09 | 1.39 ± 0.08 | 0.336 |
| Male | 1.41 ± 0.09 | 1.37 ± 0.11 | 1.39 ± 0.09 | 1.40 ± 0.09 | |
| Female | 1.43 ± 0.06 | 1.42 ± 0.07 | 1.40 ± 0.10 | 1.38 ± 0.08 | |
| Right gonial | 1.46 ± 0.06 | 1.44 ± 0.06 | 1.45 ± 0.08 | 1.44 ± 0.07 | 0.184 |
| Male | 1.47 ± 0.05 | 1.46 ± 0.06 | 1.47 ± 0.05 | 1.45 ± 0.08 | |
| Female | 1.45 ± 0.06 | 1.44 ± 0.06 | 1.40 ± 0.11 | 1.43 ± 0.07 | |
| Right dentate | 1.38 ± 0.05 | 1.38 ± 0.06 | 1.38 ± 0.06 | 1.38 ± 0.04 | 0.514 |
| Male | 1.37 ± 0.05 | 1.38 ± 0.06 | 1.39 ± 0.07 | 1.40 ± 0.04 | |
| Female | 1.38 ± 0.04 | 1.38 ± 0.07 | 1.37 ± 0.06 | 1.37 ± 0.04 | |
| Left condyle | 1.41 ± 0.08 | 1.38 ± 0.09 | 1.41 ± 0.09 | 1.37 ± 0.08 | 0.063 |
| Male | 1.42 ± 0.08 | 1.35 ± 0.11 | 1.41 ± 0.09 | 1.40 ± 0.08 | |
| Female | 1.39 ± 0.08 | 1.39 ± 0.09 | 1.40 ± 0.10 | 1.36 ± 0.07 | |
| Left gonial | 1.47 ± 0.06 | 1.44 ± 0.07 | 1.46 ± 0.05 | 1.44 ± 0.07 | 0.012* |
| Male | 1.48 ± 0.04 | 1.47 ± 0.05 | 1.47 ± 0.04 | 1.46 ± 0.06 | |
| Female | 1.45 ± 0.08 | 1.42 ± 0.07 | 1.44 ± 0.07 | 1.42 ± 0.07 | |
| Left dentate | 1.37 ± 0.06 | 1.38 ± 0.06 | 1.37 ± 0.06 | 1.39 ± 0.06 | 0.791 |
| Male | 1.38 ± 0.06 | 1.38 ± 0.04 | 1.38 ± 0.05 | 1.38 ± 0.04 | |
| Female | 1.37 ± 0.06 | 1.38 ± 0.07 | 1.37 ± 0.08 | 1.39 ± 0.08 | |

*ROI* region of interest, *FD* fractal dimension, *SD* standard deviation, *M* male, *F* female, *p* degree of significance

*Significance on $p < 0.05$ scale

**Table 4** Statistical analysis of FD measurements according to bruxism

| ROI | Total B Mean FD ± SD | Total NB Mean FD ± SD | Mann–Whitney *U* *p* | B-M Mean FD | B-F Mean FD | Mann–Whitney *U* *p* | NB-M Mean FD | NB-F Mean FD | Mann–Whitney *U* *p* |
|---|---|---|---|---|---|---|---|---|---|
| Right condyle | 1.40 ± 0.09 | 1.42 ± 0.08 | 0.041* | 1.38 ± 0.09 | 1.41 ± 0.08 | 0.063 | 1.42 ± 0.09 | 1.42 ± 0.07 | 0.776 |
| Right gonial | 1.46 ± 0.06 | 1.45 ± 0.07 | 0.598 | 1.47 ± 0.06 | 1.44 ± 0.07 | 0.001* | 1.47 ± 0.05 | 1.44 ± 0.07 | 0.024* |
| Right dentate | 1.38 ± 0.05 | 1.38 ± 0.06 | 0.956 | 1.38 ± 0.05 | 1.38 ± 0.05 | 0.612 | 1.38 ± 0.06 | 1.38 ± 0.06 | 0.658 |
| Left condyle | 1.39 ± 0.09 | 1.41 ± 0.08 | 0.163 | 1.39 ± 0.09 | 1.38 ± 0.09 | 0.477 | 1.42 ± 0.08 | 1.39 ± 0.08 | 0.009* |
| Left gonial | 1.45 ± 0.07 | 1.46 ± 0.06 | 0.542 | 1.48 ± 0.05 | 1.42 ± 0.08 | 0.000** | 1.47 ± 0.04 | 1.45 ± 0.07 | 0.262 |
| Left dentate | 1.37 ± 0.06 | 1.38 ± 0.07 | 0.537 | 1.38 ± 0.04 | 1.37 ± 0.06 | 0.478 | 1.37 ± 0.06 | 1.38 ± 0.07 | 0.374 |
| Mean condyle | 1.39 ± 0.07 | 1.41 ± 0.07 | 0.022* | 1.39 ± 0.07 | 1.40 ± 0.07 | 0.635 | 1.42 ± 0.08 | 1.41 ± 0.06 | 0.079 |
| Mean gonial | 1.45 ± 0.06 | 1.46 ± 0.05 | 0.712 | 1.48 ± 0.04 | 1.43 ± 0.06 | 0.000** | 1.47 ± 0.04 | 1.44 ± 0.06 | 0.037* |
| Mean dentate | 1.38 ± 0.04 | 1.38 ± 0.05 | 0.884 | 1.38 ± 0.04 | 1.37 ± 0.04 | 0.374 | 1.37 ± 0.05 | 1.38 ± 0.06 | 0.667 |

*B* bruxer, *NB* non-bruxer, *ROI* region of interest, *FD* fractal dimension, *SD* standard deviation, *M* male, *F* female, *p* degree of significance

*Significant on $p < 0.05$ scale, **significance on $p < 0.001$ scale

**Table 5** The distribution of the individuals with decayed or restored teeth relative to the right and left sides

| | Presence | Absent | Total |
|---|---|---|---|
| Right Side | 127 | 85 | 212 |
| Left Side | 143 | 69 | 212 |

FD, direct DPRs were obtained according to the 70 kVp and 5 mA exposure parameters.

In contrast to studies that show that fractal analysis is not affected by a projection degree of up to 20° or by radiation dose [26], Jolley et al. [27] report that FD may be affected by minimal changes in projection geometry and radiation dose in periapical radiographs. Ruttimann et al. [28], in their periapical radiographs obtained from three different projection angles (− 5°, 0°, + 5°), performed partial decalcification of their cadaver mandible with the help of acid in an in vitro study in which they evaluated changes in the alveolar bone through fractal analysis. After that, they calculated the FD of the decalcified mandible segments. As a result, they determined that while fractal analysis was affected by anatomical location, it was not affected by projection. Shrout et al. [29], in a study in which they investigated the effects of image variables on FD, digitized the periapical radiographs of six cadaveric mandibulae at three different exposure levels and at two different projection angles to form rectangular ROIs in the mandibular molar region, and from this, they performed fractal analysis. They found that the FDs calculated from the ROIs determined from the radiographs taken at different angles did not show a statistically significant difference, and they stated that the fractal analysis was not affected by minimal changes in radiation dose, by ROI parameters, or by X-ray angle (4°–6°). The same researchers, in a study on the effect of the size and shape of the ROI on FD, digitized bitewing radiographs taken at the clinic during routine examination and determined three different sizes of ROI in the mandibular premolar and molar region. As a result, they found that the FD of the smallest ROI, without any dental tissue, was significantly different from the FD of the other two ROIs consisting of dental structures, and they emphasized that dental structures should not be included in the ROI boundaries in studies aimed at examining trabecular bone structure [30]. FD analysis has been shown to have the ability to distinguish between cortical and trabecular bone [31]. Trabecular bone has a higher metabolic activity than cortical bone and, because of this, it is more decisive in the evaluation of changes in bone structure [27]. In this study, the fractal analysis was performed on square ROIs in the condyle regions with dimensions of 50 × 50 pixels, excluding cortical boundaries, in the gonial regions with dimensions of 100 × 100 pixels, excluding cortical boundaries, and in the interdental regions with dimensions of 100 × 100 pixels, excluding periodontium boundaries. In their study, Shrout et al. [32], digitized the vertical bitewing radiographs taken from 45 patients and determined four different ROIs from each patient's maxillary and mandibular premolar and molar regions. As a result, they reported that morphological operation values (e.g., erode, dilate, skeletonize) were affected by ROI location and size rather than by gray level values. In this study, where segmentation was applied to represent the trabecular bone with the help of the ImageJ program on panoramic radiographs, care was taken that there was no tissue except trabecular bone within the boundaries of the ROI.

In the present study, no significant difference was found between ROIs selected from the same region on the right and left sides of individuals, but the FD values of the different ROIs on the same side were found to be significantly different from each other. When the FD values of all individuals were examined, it was observed that FD values calculated from the gonial regions were the highest, and FD values calculated from the dentate regions were the lowest. Lower FD values have been associated with less trabecular complexity and less trabeculation. In the literature, an increase in FD is associated with an increase in the complexity of the structure. Structures with higher FD levels are more complex, and structures with lower FD have a simpler internal order [4–6]. On the basis of this information, it can be said that among the regions studied in this study, trabecular complexity in the gonial region is greater than in the other areas. Sener and Baksı [33] performed fractal analysis in three different ROIs from the mandibular corpus, the angulus, and interdental regions to evaluate the trabecular structure in osteoporotic patients receiving bisphosphonate treatment. Their results showed that FD values were lower in the dentate region in both the bruxer and non-bruxer groups, which is in accord with the results of the present study. Yasar and Akgunlu [34], in a study in which they investigated differences in the trabecular structure of dentate and edentulous regions, associated the lower FD values in the toothed regions with the fact that these regions have a more organized trabecular structure, designed to resist occlusal forces. Although there are different methods for calculating FD in fractal analysis, in the current study the authors used the method most commonly described in the literature, which is the box-counting method [12]. In another study [35], the FD values calculated from the dentate region were higher than those in the edentulous region. The possible reason for the difference between these results and those of this study may be the use of different methods for measuring FD (based on volume calculation) during the fractal analysis procedures.

In studies examining the effect of gender on FD, it is generally found that FD values are lower for women than for men. Kayipmaz et al. [36] conducted a study in which they performed fractal analysis in ROI's with dimensions of 64 × 32 pixels in the condyle region of a total of 70 participants, composed of 35 healthy individuals and 35 patients with TMJ arthritis. From the images obtained using cone-beam computed tomography, they evaluated changes in the trabecular structure of the condyle region of the patients. They concluded that women had smaller FD values than men. They based this investigation on other studies in the literature suggesting that gender is influential on the trabecular structure and on FD [37]. Arsan et al. [12] in a study using fractal analysis with panoramic radiographs, investigated the trabecular structure of mandibular condyle and concluded that the average FD value for men was 2.54 and for women 2.49. The present study confirmed that FD values for women are lower than those of men. The higher FD values in men are associated with more complex trabecular structures and higher trabeculation, whereas the trabecular structure is more porous in women and had fewer trabeculae [38]. There are also studies in the literature that indicate that there is no relationship between gender and FD [9, 39, 40]. In a study of 56 men and 52 women investigating the effect of chronic periodontitis on FD, no correlation was found between gender and FD [9]. In another study, composed of 28 women and 23 men, where the fractal analysis was used to investigate the changes that chronic renal failure caused in the trabecular structure of the mandible, no relationship was found between gender, age, and FD [39]. The current research was with a sample of 212 people, which included equal numbers of men and women. In studies that indicate that there is no correlation between gender and FD, it may be that the sample size is small [9], and inequalities in the distribution of females and males may be affecting the results.

Because trabecular bone has a more dynamic structure, it has been reported that age-related changes affect trabecular bone more than cortical bone [41]. Since the authors were investigating the effect of bruxism on the jawbones in this study, the age range of the sample was kept narrow (21–40 years) to minimize the effect of age-related changes on FD values. The correlation analysis between age and FD measurements showed only a weak negative correlation in the right condyle region (Spearman Rho, $r = -0.16$, $p = 0.020$) and no significant correlation was observed in the other regions. It can be assumed that correlation values would become more significant in a sample where the age range was larger. Ruttimann et al. [28], in the in vivo part of their study in which they made a random selection of six premenopausal women and six postmenopausal women and then made FD measurements from their periapical radiographs, found that, in contrast to results of this study, the group with the higher average age had higher FD values. Unlike the authors of the current study, who used DPR, they used digitized periapical radiographs. It can be assumed that differences in the results are caused by the differences in the methods used. In a study in which Yasar [42] investigated osteoporotic individuals' trabeculation differences, as evidenced in their mandibular bones, a positive correlation was found between age and osteoporosis and FD. While there was a decrease in the amount of bone with age and osteoporosis, in contrast to the increase in FD values, it was suggested that the FD values were related to the number of segmentations after bone resorption rather than to bone density.

A generally accepted method for the diagnosis of bruxism has not been found due to its subjective character. While some researchers diagnose bruxism on the basis of patients' reports (self-reported) [43, 44], others have used more objective methods, such as polysomnography, for its diagnosis [45]. An international consensus was reached regarding the identification and evaluation of bruxism in 2013, and it was stated that this classification could be used in clinical studies. It was emphasized that, although there are many methods for the diagnosis of bruxism (questionnaire method, clinical examination, electromyography, polysomnography), each of these has its own disadvantages, and there is a need to take into consideration the fact that a generally accepted method does not exist. According to this definition, possible bruxism is based on the patient's report, and diagnosis is based on a history of clinical examination. When bruxism is identified by the patient's report and by clinical examination based on inspection, it is defined as probable bruxism. Bruxism that is confirmed by polysomnographic or electromyographic records, in addition to the patient report and the clinical examination, is called definitive bruxism [24]. Since this definition is one of the most recent definitions in the literature, for this study, if at least one of the findings based on the anamnesis obtained from the patient was positive and there was a presence of tooth wear, the individual was determined as bruxism-positive [20–24].

According to the results of this study, only the FD values of the right condyle region showed a statistically significant difference ($p = 0.041$) between the FD values of the bruxer and non-bruxer individuals. The FD values of the bruxer individuals were found to be lower than those of the non-bruxer group (mean FD = 1.40 in the bruxer group and 1.42 in the non-bruxer group). Lower FD values have been associated with resorptive changes [12]. Although the difference observed between the two groups in the present study was significant, the value of $p = 0.041$ did not express a strong significant difference. In the ROC analysis evaluating the relevance of FD analysis as a diagnostic test for bruxism, AUC did not show statistical significance. In the current study, only patient reports and clinically visible tooth wear were taken into consideration when determining bruxer patients. It is one of the limitations of the current study that the authors were unable to rule out individuals with TMJ being diagnosed with bruxism from the current diagnostic criteria. In the present study, it should also be noted that individuals who are unaware of the presence of bruxism could possibly be included in the non-bruxer group (patient report = negative). When the diagnosis of bruxism is made with more definitive methods, it is possible that the statistical significance value will change. Arsan et al. [12], in a study in which they performed fractal analysis on panoramic radiographs of the condylar regions of 100 patients diagnosed with TMJ dysfunction during clinical examination and anamnesis, reported that the FD values of patients were lower than the FD values of 100 individuals in a non-bruxer group. These results were connected to the degenerative changes seen in patients. Compared to the non-bruxer group, the bruxer group had low FD values in the condyle region, which may support resorptive activity in this region.

In the clinical examination, the excessive occlusal force on teeth can possibly result in dental wear, increased mobility, and percussion sensitivity with an increase in the periodontal ligament space, a thickening of the lamina dura, a loss of alveolar bone, and an increase in trabecular number and size under radiographic examination. In addition, hypercementosis and root fractures may be observed [46]. In the present study, lower FD values of the right condyle in bruxer individuals were related to bruxism-associated non-functional occlusal forces causing resorptive changes in the condylar region. Statistically significant differences were found only on the right side, which may be a result of the unilateral mastication habits due to the presence of more caries and/or restorations on the left side of individuals, while the possibility of TMJ dysfunction in the right condyle could not be eliminated. Additionally, this difference could be attributed to the variability in the occlusal bite forces among individuals. Failure to determine the type, size, and severity of dental wear was another limitation of the current study. In future studies, the unilateral mastication habits, the characteristics of dental wear, and the occlusal bite forces of individuals should be documented. Moreover, it is recommended that the lower FD values in bruxer individuals be confirmed through using a study group in which TMJ diseases have been excluded.

## Conclusion

The fractal analysis may be a useful method for identifying trabecular differences in the condylar areas of bruxer individuals. Bruxers had lower FD values in the right condylar region.

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