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Investigation of mandibular fractal dimension on digital panoramic radiographs in bruxist individuals

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Objective. This study aimed to evaluate changes in mandibular trabecular bone structure in bruxism using fractal analysis on digital panoramic radiographs obtained with automatic dosing.

Study Design. In this prospective study, fractal analysis was performed on radiographs of 126 bruxists and 126 non-bruxists. Eight paired mandibular regions of interest were selected: the bilateral condylar and gonial regions, and the bilateral dentate regions between the apical areas of the first molar and second premolar and between the first premolar and canine. Fractal dimensions (FDs) were calculated at each site.

Results. Mean FD values in the bilateral gonial regions of the bruxists were significantly lower than those of controls ($P \leq .049$). In both groups, FD values of the right dentate region anterior to the mental foramen were significantly lower than those on the left side ($P \leq .042$). Females exhibited significantly lower FD values in both condylar regions in both groups ($P \leq .039$) and in the right dentate regions in the controls ($P \leq .022$). Correlations between age and FD in all regions were positive but nonsignificant in both groups ($P > .05$).

Conclusions. FD values of mandibular trabecular bone are affected by bruxism in the gonial region and by laterality and sex differences in the condylar and dentate regions. (Oral Surg Oral Med Oral Pathol Oral Radiol 2021;131:600−609)

Bruxism is defined as nonfunctional grinding or clenching of teeth in other than chewing and swallowing movements.[1] Three different definitions of bruxism are clinically based on a diagnostic grading system: possible, probable, and definite bruxism.[2] According to this system, "possible" bruxism is based on self-reporting through questionnaires and/or the anamnestic part of the clinical examination. "Probable" bruxism is based on self-reporting plus a clinical examination. Patients with sleep bruxism may not be aware that they are grinding or clenching their teeth. Therefore, "definite" bruxism is diagnosed on the basis of self-reporting, a clinical examination, and polysomnographic or electromyographic records of the patients.

Failure to control the forces generated by bruxism induces osteoclastic activity in the bone, which can result in dilation of the periodontal ligament. In addition, a decrease in the vertical bone height observed in the interdental septa can result in dental mobility.[3]

The term "fractal" was first introduced by Mandelbrot in 1975[4] to describe objects of complex geometry consisting of curves, independent points, surfaces, and unique shapes.[4-6] The fractal dimension (FD) of trabecular bone structure has been shown to have a significant correlation with the physical properties of the bone. As the complexity of the examined structure increases, the FD increases. A greater FD value indicates that the bone structure is more dense and the cavities in the bone are smaller, and a lower FD value indicates that the bone is more porous and has a large number of gaps.[7,8] It has been shown that 2D images provide information about the 3D structure of the bone, and with advances in digital image processing techniques such as fractal analysis (FA), details that can be missed on radiographs can be identified.[9] Changes in the trabecular internal structure of the alveolar bone have been detected in studies using FA.[10] This type of analysis is often chosen to evaluate trabecular internal structure of the mandible because of its accessibility and convenience, noninvasive nature, insensitivity to variables such as projection geometry and radiation dose, and ability to provide objective data. Moreover, FA can be used for follow-up of bone density changes after treatment of these patients.

Few studies have investigated changes in trabecular bone structure in bruxism, and only 1 study reported on condylar, gonial, and dentate mandibular regions. However, it is doubtful that a reliable study group was created because bruxist patients were selected only by looking at tooth wear in that study.[11] In addition, there are no other published papers involving FA on digital radiographs obtained with automatic dosing. Optimal panoramic images can be obtained with the lowest possible dose by

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Statement of Clinical Relevance

Radiographic changes in trabecular structure can be evaluated with fractal analysis. The fractal dimension of mandibular trabecular bone is affected by bruxism in the gonial region and by sex differences in the condyle and dentate regions.

using the automatic dose control feature that is available in some x-ray units.

The objective of the study was to compare the trabecular internal structure of different sites in the mandible in a selected study group classified as probable bruxists (based on questionnaire findings and confirmed clinical inclusion criteria for bruxism) and a control population by measuring FD on panoramic radiographs acquired with automatic dosing of exposures. Comparisons were also made between the right and left sides of both populations and between females and males. In addition, changes in the trabecular structure as a result of osteoporosis that occurs with advancing age may affect FD values. Therefore, the correlation between FD and age was examined in both populations. The null hypotheses stated that there would be no statistically significant differences in FD between the bruxist and control patients at the same sites in the mandible, between the right and left sides for each site in both populations, between females and males at each site in both populations, and between patients of different ages in both populations.

MATERIALS AND METHODS

Patient selection

The study protocol complied with the principles of the Declaration of Helsinki. Approval for the conduct of the study was obtained from the Ethics Committee for Non-Interventional Clinical Research of Sivas Cumhuriyet University (decision no. 2019-03/25). The study was carried out on patients who presented to the Oral, Dental, and Maxillofacial Radiology clinic at the Sivas Cumhuriyet University Faculty of Dentistry for routine clinical examination and volunteered to participate in the research. A written consent form was signed by all individuals.

The inclusion criteria for participants in the project were age between 18 and 45 years, absence of systemic diseases (especially those affecting bone metabolism such as Paget's disease of bone, hyperparathyroidism, hypoparathyroidism, osteomalacia, renal osteodystrophy, diabetes mellitus, rheumatoid arthritis, ankylosing spondylitis, osteogenesis imperfecta, and osteodystrophic diseases such as osteoporosis), missing no more than 1 tooth in the maxillary or mandibular arch (except for third molars), Angle's class 1 occlusion, and for those with bruxism a history of jaw clenching/teeth grinding for at least 6 months.

The exclusion criteria were current or past use of bisphosphonates, presence of diseases including cysts or tumors in the maxillofacial region, previous or current orthodontic treatment, early menopausal status, neurologic and psychiatric diseases, alcoholism, and drug addiction. Also excluded were individuals with prosthetic restorations in any tooth, dental restorations with premature contacts in occlusion, and severe malocclusion (defined as overjet and overbite more than 6 mm, unilateral and anterior cross-bite, and position difference between centric relation and maximum intercuspation of greater than 5 mm).

Clinical examination

In this study, the questionnaire proposed by Pintado et al.[12] and the clinical selection criteria described by Rompré et al.[13] were used for the diagnosis of probable bruxism. Responses to the questionnaire, clinical findings, and the diagnosis of bruxism were evaluated by a single dentomaxillofacial radiologist with a total of 9 years of clinical experience including 3 years of experience in maxillofacial radiology.

When identifying bruxist individuals according to Pintado et al.'s criteria, participants had to answer positively to at least 2 of the following questions[12]:

1. Has anyone told you before that you grind your teeth at night?
2. Is your jaw ever fatigued when you wake up in the morning?
3. Are your teeth and gums ever sore on awakening in the morning?
4. Do you ever have a headache on awakening in the morning?
5. Have you ever noticed that you grind your teeth during the day?
6. Have you ever noticed that you have clenched your teeth during the day?

Additionally, bruxists were identified based on the presence of all clinical diagnostic criteria for bruxism proposed by Rompre et al.[13]:

1. Clenching and grinding sounds for at least 6 months and more than 3 nights per week.
2. Tooth wear consistent with the movements of the jaw in normal or eccentric position.
3. Hypertrophy of the masseter muscle during voluntary contraction.
4. Feelings of discomfort, tiredness, or stiffness in the chewing muscles on awakening in the morning.

Radiographic examination

This study was conducted by examining the panoramic radiographs acquired for clinical examination of patients. All panoramic radiographs to be used for FA were obtained by the same technician using a digital panoramic x-ray device (Instrumentarium OP200 D, Instrumentarium Dental, Tuusula, Finland) in the P1 mode with which standard panoramic images are acquired. Automatic dose control was used instead of fixed dose application in the study group. In automatic dosing, the x-ray dose is adjusted according to the transmittance of the irradiated region. The device adjusts the dose to be administered to the patient 0.1 s before the exposure depending on the bone density of each patient. As the photons pass through a region of greater density and radiopacity such as the cervical vertebrae, the tube current is maintained at the highest level. If the x-rays pass through a less dense region, the current is reduced and the optimum dose is delivered. In this way, optimum image quality is obtained with the minimum required dose.[14] For standardization purposes, all panoramic radiographs had a width and height of 2976 × 1536 pixels.

Radiographs were not included in the study if there were artifacts or positioning errors in the panoramic images, the image quality did not allow adequate examination, or the fractal values could not be calculated because the location of the mandibular canal was very close to the apices of the teeth. Therefore, 13 radiographs from the bruxist group and 9 radiographs from the control group were excluded. As a result, the study was conducted on 126 patients who met the inclusion and exclusion criteria as probable bruxists and 126 control patients without evidence of bruxism. With significance criteria established at $\alpha = .05$, $\beta = 0.10$, and $1 - \beta = 0.90$, the power of the test was estimated at $P = .91$.

Display features

For the analysis of FD values, all digital radiographs were examined by the dentomaxillofacial radiologist mentioned above. The radiographs were examined in a semi-dark room using a Lenovo IdeaPad Z500 Intel Core i5 monitor with a 64-bit LCD (liquid crystal display) screen, 15.6-in LED (light emitting diode) illumination, and resolution of 1366 × 768 pixels (Lenovo, Beijing, China).

Image processing (fractal analysis)

The ImageJ v1.52 software (with 64-bit Java) for Windows, a version of the National Institutes of Health Image software, was used in FA. The software was downloaded from https://imagej.nih.gov.

After downloading the software, regions of interest (ROIs) were selected and the images were recorded in high-resolution TIF (Tagged Image File) format.

Region of interest selection

Four bilateral ROIs, each consisting of 45 × 45 pixels, were selected for FA on each panoramic radiograph at the following locations in the mandible:

FD1: Right condylar region

FD2: Right gonial region

FD3: Region between the apical areas of the right first molar and second premolar

FD4: Region between the apical areas of the right first premolar and canine

FD5: Region between the apical areas of the left canine and first premolar

FD6: Region between the apical areas of the left second premolar and first molar

FD7: Left gonial region

FD8: Left condylar region.

All ROIs excluded the periodontium of the teeth and the cortical boundaries of the mandibular canal, condyle, and gonial region (Figure 1).

For FA, the box counting method described by White and Rudolph was applied to the ROIs.[15] This method was used because it is currently the most widely employed method for calculating FD values.[16-19] The selected ROIs from the original radiographs were cropped and duplicated. Next, the Gaussian blur filter (σ = 35 pixels) was applied on the duplicated image to remove brightness variations due to overlying soft tissues and varying bone thickness. Thus, details were obscured to visualize only the areas with significant density variations (Figure 2A). The resulting image was then subtracted from the original image (Figure 2B). Bone marrow spaces and trabeculae were discriminated from each other with the addition of a grayscale value of 128 to each pixel location (Figure 2C). Using the “Make Threshold” option, the image was converted to a 2-color format that was black and white (Figure 2D). Thus, the boundaries of the bone marrow and trabecular structure were made discernable. The “Erode” option was applied to reduce the noise in the image (Figure 2E). Then, using the “Dilate” option, the existing areas were expanded and made more visible (Figure 2F). At the “Invert” step, the white areas on the image were turned black and the black areas were turned white to reveal the outlines of the trabecular bone (Figure 2G). With the “Skeletonize” option, the outlines of the trabecular structure were determined skeletally with lines, making it ready for fractal analysis (Figure 2H).

The fractal dimension was calculated for the outlines of the trabeculae by selecting the “Fractal box counter” option from the “Analyze” tab. The image was divided into squares with dimensions of 2, 3, 4, 6, 8, 12, 16, 32, and 64 pixels. For each pixel, the squares with trabeculae and the total number of frames in the image were calculated. These values were plotted on a logarithmic scale. The slope of the line that best fitted the points on the graph gave the FD value, indicating the complexity of the structure. FD measurement was performed for each of the 8 ROIs listed above on each radiograph. The means

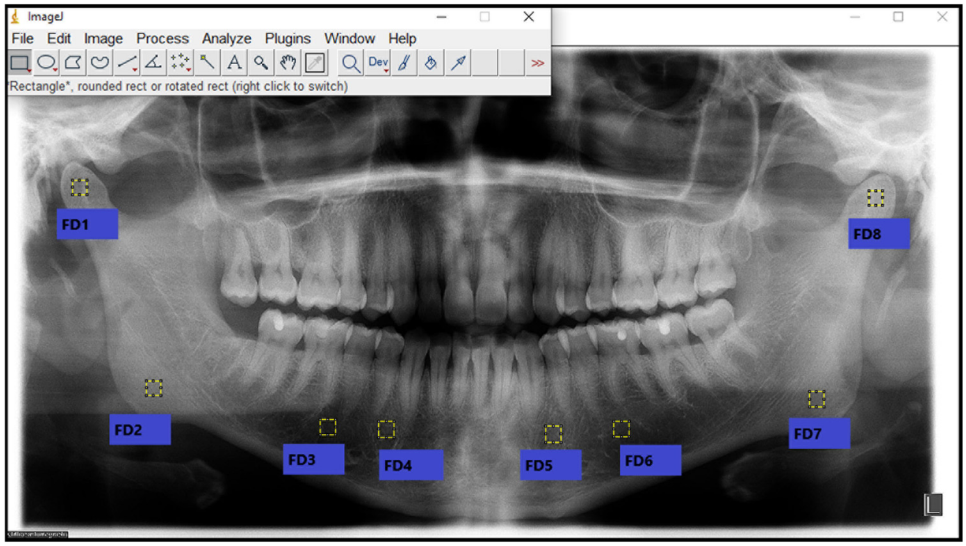

Fig. 1. Selection of the specified regions of interest in the mandible on the panoramic image.

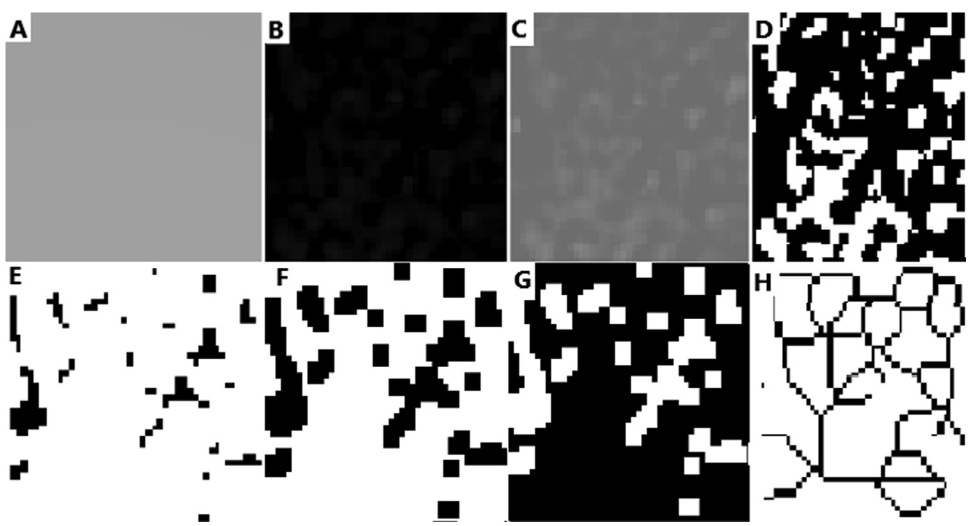

Fig. 2. [1]**(A)** Blurred image of the cropped and duplicated region of interest. **(B)** Blurred image subtracted from the original image. **(C)** Addition of 128 grayscale value to each pixel location. **(D)** Conversion of image to black and white. **(E)** Erosion, **(F)** Dilation, **(G)** Inversion, and **(H)** Skeletonization.

and standard deviations of all values at each site were used for statistical evaluation.

Statistical analysis

The data obtained from this study were uploaded to the SPSS, Sivas Cumhuriyet University. (22.0) software. All FD measurements were performed by the same dentomaxillofacial radiologist.

Conformity of the continuous numerical variables to a normal distribution was analyzed using the Kolmogorov-Smirnov test. Data used in comparing the means of FD between the bruxist and control groups were not normally distributed, so the Mann-Whitney *U* test was employed to analyze the significance of differences. Results were tabulated as mean, standard deviation, median, minimum, and maximum. Data used in comparing the FD means on the right vs left ROIs and in comparing the data of females vs males were normally distributed; therefore, independent *t*-tests were employed for analysis with results listed as mean and standard deviation. Age was treated as continuous quantitative values and the Pearson correlation test was used to analyze significant differences in FD by age. The error level was set at .05. A *P* value <.05 was considered statistically significant.

[1]This study has been produced from a thesis.

Table I. Comparison of FD values of bruxists vs control patients by ROI

ROI		*N*	*FD Mean ± SD*	*Median*	*Minimum*	*Maximum*	*P value*
FD1	Bruxists	126	1.40 ± 0.1	1.41	1.09	1.56	.152
	Controls	126	1.41 ± 0.08	1.43	1.16	1.55	
FD2	Bruxists	126	1.36 ± 0.13	1.35	1.05	1.58	.049*
	Controls	126	1.40 ± 0.1	1.42	1.12	1.55	
FD3	Bruxists	126	1.43 ± 0.07	1.43	1.19	1.55	.319
	Controls	126	1.42 ± 0.06	1.43	1.17	1.55	
FD4	Bruxists	126	1.40 ± 0.07	1.41	1.21	1.53	.889
	Controls	126	1.40 ± 0.07	1.41	1.22	1.53	
FD5	Bruxists	126	1.42 ± 0.07	1.42	1.20	1.55	.976
	Controls	126	1.41 ± 0.07	1.41	1.20	1.56	
FD6	Bruxists	126	1.44 ± 0.06	1.44	1.23	1.54	.077
	Controls	126	1.42 ± 0.06	1.42	1.22	1.54	
FD7	Bruxists	126	1.37 ± 0.12	1.38	0.92	1.58	.004*
	Controls	126	1.41 ± 0.08	1.42	1.15	1.57	
FD8	Bruxists	126	1.41 ± 0.09	1.41	1.13	1.56	.620
	Controls	126	1.41 ± 0.09	1.42	1.10	1.53	

FD, fractal dimension; *ROI*, region of interest; *FD1-8*, condylar region; *FD2-7*, gonial region; *FD3-6*, region between second premolar and first molar; *FD4-5*, region between first premolar and canine.
*Significant at $P < .05$ (Mann-Whitney *U* test).

Measurements were reevaluated on 63 randomly selected radiographs (25%) 2 weeks later by the same observer. Intraclass correlation coefficients were used to assess intraobserver agreement.

RESULTS

The mean age of the study population (126 bruxists and 126 controls) was 26.34 ± 6.92 years (range, 18-45). The mean age of bruxists was 26.89 ± 7.28 years and the mean age of control patients was 25.80 ± 6.52 years. There was no significant age difference between the groups ($P > .05$).

The FD values at the 8 ROIs of the 252 individuals are shown in Table I. When the groups were compared, bruxists were found to have significantly lower mean FD values measured from the gonial regions (FD2 and FD7) than control patients (FD2: $P = .049$; FD7: $P = .004$). The differences in FD values between groups were not significant in the condylar and dentate regions ($P \geq .077$).

Symmetric regions in the right and left sides of the mandible were compared in bruxist and control groups. In both groups, the FD values of the dentate region anterior to the right mental foramen (FD4) were significantly lower than the FD values of the dentate region anterior to the left mental foramen (FD5; bruxists: $P = .037$; controls: $P = .042$). The differences between other symmetric regions were not significant ($P \geq .088$; Table II).

Considering the relationship between sex and FD, significantly lower FD values were observed in females compared to males in the right (FD1) and left (FD8) condylar regions in both groups ($P \leq .039$ for bruxists, $P \leq .004$ for controls). In addition, FD values were significantly smaller for females than for males in the 2 dentate ROIs on the right side in the control group ($P = .022$ in FD3, $P = .007$ in FD4). There were no significant differences between females and males in any other regions in either group ($P \geq .130$; Table III).

Table II. Comparison of FD values of symmetric right vs left mandibular regions for bruxist and control groups

		FD Mean ± SD	*Results*
Bruxists	FD1	1.40 ± 0.1	t = 0.53
	FD8	1.41 ± 0.09	P = .594
	FD2	1.36 ± 0.13	t = 0.60
	FD7	1.37 ± 0.12	P = .546
	FD3	1.43 ± 0.07	t = 1.59
	FD6	1.44 ± 0.06	P = .114
	FD4	1.40 ± 0.07	t = 2.10
	FD5	1.42 ± 0.07	P = .037*
Controls	FD1	1.42 ± 0.08	t = 1.27
	FD8	1.41 ± 0.09	P = .203
	FD2	1.40 ± 0.1	t = 1.71
	FD7	1.41 ± 0.08	P = .088
	FD3	1.42 ± 0.06	t = 0.47
	FD6	1.42 ± 0.06	P = .635
	FD4	1.40 ± 0.07	t = 2.05
	FD5	1.41 ± 0.07	P = .042*

FD, fractal dimension; *FD1-8*, condylar region; *FD2-7*, gonial region; *FD3-6*, region between second premolar and first molar; *FD4-5*, region between first premolar and canine.
*Significant at $P < .05$ (independent *t*-test).

Table III. Comparison of FD values of females vs males for bruxist and control groups

	Sex	*N*	*Bruxists FD Mean ± SD*	*Bruxist Results*	*Controls FD Mean ± SD*	*Controls Results*
FD1	Female	66	1.38 ± 0.1	t = 2.53	1.39 ± 0.09	t = 4.05
	Male	60	1.42 ± 0.08	P = .013*	1.45 ± 0.05	P = .001*
FD2	Female	66	1.35 ± 0.13	t = 1.05	1.39 ± 0.1	t = 0.57
	Male	60	1.37 ± 0.13	P = .292	1.40 ± 0.11	P = .568
FD3	Female	66	1.43 ± 0.06	t = 0.10	1.41 ± 0.06	t = 2.32
	Male	60	1.43 ± 0.07	P = .914	1.43 ± 0.07	P = .022*
FD4	Female	66	1.39 ± 0.08	t = 1.52	1.39 ± 0.06	t = 2.74
	Male	60	1.41 ± 0.07	P = .130	1.42 ± 0.06	P = .007*
FD5	Female	66	1.41 ± 0.06	t = 0.61	1.41 ± 0.07	t = 1.40
	Male	60	1.42 ± 0.07	P = .540	1.42 ± 0.07	P = .165
FD6	Female	66	1.44 ± 0.06	t = 0.38	1.42 ± 0.06	t = 0.53
	Male	60	1.44 ± 0.07	P = .700	1.43 ± 0.06	P = .596
FD7	Female	66	1.36 ± 0.12	t = 0.89	1.41 ± 0.09	t = 1.14
	Male	60	1.38 ± 0.12	P = .375	1.42 ± 0.07	P = .254
FD8	Female	66	1.39 ± 0.09	t = 2.13	1.39 ± 0.09	t = 2.93
	Male	60	1.42 ± 0.08	P = .039*	1.43 ± 0.08	P = .004*

FD, fractal dimension; *FD1-8*, condylar region; *FD2-7*, gonial region; *FD3-6*, region between second premolar and first molar; *FD4-5*, region between first premolar and canine.
*Significant at $P < .05$ (independent *t*-test).

Table IV. Correlation of FD values with age

		r	*P value*
FD1	Bruxists	0.046	.611
	Controls	0.009	.918
FD2	Bruxists	0.166	.063
	Controls	0.193	.054
FD3	Bruxists	0.016	.859
	Controls	0.139	.121
FD4	Bruxists	0.093	.300
	Controls	0.071	.431
FD5	Bruxists	0.027	.765
	Controls	0.077	.392
FD6	Bruxists	0.056	.535
	Controls	0.018	.843
FD7	Bruxists	0.146	.103
	Controls	0.049	.584
FD8	Bruxists	0.106	.240
	Controls	0.066	.460

FD, fractal dimension; *FD1-8*, condylar region; *FD2-7*, gonial region; *FD3-6*, region between second premolar and first molar; *FD4-5*, region between first premolar and canine.

Table V. Results of statistical analysis of intraobserver agreement by ROI

	Intraclass correlation coefficient	*P value*
FD1	0.933	.001*
FD2	0.983	.001*
FD3	0.942	.001*
FD4	0.810	.001*
FD5	0.968	.001*
FD6	0.963	.001*
FD7	0.947	.001*
FD8	0.979	.001*

ROI, region of interest; *FD1-8*, condylar region; *FD2-7*, gonial region; *FD3-6*, region between second premolar and first molar; *FD4-5*, region between first premolar and canine.
*Significant at $P < .05$.

When the correlation between age and FD values was examined in both groups, the correlations among all regions (FD1 through FD8) were positive but statistically nonsignificant ($P > .05$; Table IV).

Intraobserver agreement ranged from .810 in FD4 to .983 in FD2 (Table V). The level of agreement varied between high and excellent.[20]

DISCUSSION

There is no consensus on the diagnosis of bruxism because it is subjective, controversial, and nonspecific.[16,17] The factors involved in the etiology and prevalence of this parafunction are still unclear, making the diagnosis of the condition difficult.[18] A generally accepted method for the diagnosis of bruxism is not available because although several methods are used, including the questionnaire method, clinical examination, polysomnography, and electromyography, each of them has its own advantages and shortcomings.[19]

A 1996 study by Lavigne et al. involved 18 bruxists and 18 healthy patients.[21] The bruxists each had a history of grinding sounds and jaw clenching during sleep at least 5 nights per week for 6 months, tooth wear, fatigued and sore chewing muscles in the morning, and masseter muscle hypertrophy. By using polysomnography, the clinical diagnosis was correctly predicted in 83.3% of the bruxists and 81.3% of the controls.[21] In another study conducted by the same authors with a larger sample of 143 patients, the criterion for grinding sounds during sleep was changed from 5 nights to 3 nights per week and it was confirmed that clinical diagnostic criteria allowed a high level of discrimination between bruxists and control patients.[13] In light of these studies and due to the high cost and relative difficulty of access to polysomnographic and electromyographic recording used for the diagnosis of definite bruxism,[2] the questionnaire and clinical examination criteria that are most practical in the clinical setting were employed in the present investigation. In addition to the easy-to-use questionnaire method described by Pintado et al.,[12] the sleep bruxism research diagnostic criteria proposed by Rompre et al.[13] were employed, considering that a significant impact of bruxism takes place over a period of at least 6 months and that bruxism diagnosis was confirmed polysomnographically. The individuals in the present study were required to give a positive response to at least 2 of the 6 items introduced by Pintado et al. for the diagnosis of bruxism[12] and meet all criteria proposed by Rompre et al.[13] A group of probable bruxists and a non-bruxist group were formed using the subjective data from the responses to the questionnaire and objective data from clinical examination. Though there are no patient selection criteria to make a clear and unambiguous diagnosis of probable bruxism, selection criteria confirmed by polysomnographic readings were used for the present study, providing a more reliable selection of patients than that achieved by the diagnostic criteria of possible bruxism.

For the diagnosis of bruxism, tooth wear and masseter muscle hypertrophy have been assessed during clinical examination. One study found that 40% of tooth wear in the participants was caused by factors other than bruxism and underscored that tooth wear observed in bruxism should be distinguished from changes associated with oral habits such as acidic diet, pencil biting, pipe smoking, and age-related dental attrition.[22] Because the etiology of existing dental hard tissue damage was not investigated in the present study, parafunctional tooth wear was taken into consideration. The diagnosis of bruxism was made when all clinical diagnostic criteria described by Rompre et al.[13] were met.

Intraoral radiographs have been used for calculation of FD because of their higher resolution compared to panoramic radiographs.[23-25] When FD values were compared between periapical and panoramic radiographs of the same patient, FDs measured on panoramic radiographs were lower than FDs from periapical radiographs.[26] The lower spatial resolution of panoramic radiographs in comparison to periapical radiographs eliminates details and only thick trabecular structures can be visualized. Although panoramic radiographs produce lower FD values than periapical radiographs, it was reported that they adequately identified osteoporotic changes in trabecular bone.[10,26] Because condylar and gonial regions were included in the present study, panoramic radiographs were preferred.

Different formats are used for storage and transfer of radiographic images in digital systems, and these formats may cause loss of information while compressing the images.[27] A digital image stored in TIF format (TIFF) is a high-quality image that requires a large quantity of memory.[28,29] In a study by Yaşar et al.,[27] FD values measured from TIFF images were greater than those of JPEG compressed images, which is consistent with more loss of details in JPEG images. In addition, Gürdal et al.[30] evaluated the ability of TIF and JPEG formats to restore grayscale values of images using 3 different software programs and concluded that the TIF image format was more effective for grayscale images than the JPEG format, which was why FD measurements in the present research were performed on TIFF images.

Although there are studies suggesting that fractal analysis is not affected by projection angles of up to 20° or radiation dose,[31] Jolley et al.[32] reported that minimal changes in these parameters may have an impact on fractal dimension on periapical radiographs. Ruttimann et al.[25] investigated changes in alveolar bone on periapical radiographs obtained at 3 projection angles (−5°, 0°, +5°) using FA. In their in vitro study, they found that FA was not affected by radiographic projection angle but varied among anatomic locations. Shrout et al.[33] investigated the FD of trabecular bone and suggested that dental structures should not be included in the ROI that is used for FD calculations. In a separate study, the same authors[34] reported that morphologic operation values (e.g., erosion, dilation, skeletonization) varied in relation to ROI location more than did gray-level values and were not affected by minimal changes (4°-6°) in x-ray beam angulation. The ROIs did not include any tissue other than trabecular bone in the present study. For standardization purposes, all images were obtained by the same technician and changes in the projection angle were kept to a minimum.

In previous research, fixed dose application was preferred for the exposure technique in order to achieve standardization when comparing patient and control groups.[11,35,36] However, bone density varies between individuals. In order to visualize trabecular bone structure clearly, it is necessary to use a higher dose in individuals with denser bone tissue to achieve optimum image quality, whereas a lower radiation dose is sufficient for those with lower bone density. In automatic dose control, a test exposure is first performed with a very short exposure time (e.g., 0.1 s). This test exposure is then analyzed by the device and the optimal radiation dose for the patient is calculated based on bone density. In the present investigation, the automatic dose feature was used to obtain optimal image quality with the best possible individualized dose to protect the patients from exposure to unnecessary radiation. To the best of the authors' knowledge, this is the first study to use the automatic dose control feature for FD calculations.

Previous studies have reported that parafunctional habits cause mechanical stress on the mandibular condyle and can initiate condylar resorption or accelerate existing resorption.[37] There are only a few studies of FD assessment on the condylar region of bruxists.[11] Arsan et al.[38] conducted FA on panoramic radiographs of mandibular condyles in 100 patients with temporomandibular joint (TMJ) dysfunction that was diagnosed by clinical examination and anamnestic findings. They reported lower FD values in the patient group compared to the control group and attributed this finding to degenerative changes in the TMJ. Güleç et al.[11] evaluated FD values of ROIs placed in bilateral condylar, gonial, and dentate regions of the mandible in bruxists, diagnosed by self-report and tooth wear, vs non-bruxists. They found that only the FD values for the right condyle were significantly lower in bruxists than in non-bruxists. The authors suggested that this difference in the right condyle could be associated with resorptive changes as a result of nonfunctional forces caused by bruxism. They hypothesized that the low FD values observed in bruxists may be related to TMJ dysfunction and the difference in FD measurements for the right condyle could result from unilateral mastication habits. No significant difference was found in FD values in mandibular condyles between bruxists and non-bruxists in the present study ($P \geq .152$). Most bruxists also have TMJ problems,[19] but individuals with TMJ disorders could not be excluded from the study, which represents a limitation.

Studies have reported that bruxism also causes changes in the mandibular gonial region. Because the masseter and medial pterygoid muscles attach to the mandible at the gonial area, this site is most commonly affected by masseter muscle hypertrophy in parafunctional conditions.[39,40] In their FA study, Güleç et al.[11] did not find a difference between bruxists and controls in FD values measured from the gonial region. In the present study, the gonial region was affected by bruxism, resulting in significantly lower FDs than in the control patients ($P \leq .049$), due to the use of more selective and stricter criteria for identification of bruxists. This finding was attributed to degenerative effects of constant repetitive contraction forces exerted upon the gonial region. Thus, it can be considered that bruxist individuals have less trabecular complexity and trabeculation in the gonial region compared to control patients.

Individuals with strong maximum chewing force have been reported to have a smaller gonial angle.[40] Karakıs and Dogan[41] observed a lower gonial angle in bruxist women than in non-bruxist women. Ohm and Silness[42] found a poor correlation between age and size of the gonial angle. In their research involving 1000 patients, Ghosh et al.[43] reported that gonial angle values increased with age. In our study of a younger population (18-45 years of age), FD of the gonial region showed no significant correlation with age.

When comparing symmetric ROIs on the right vs left side in both bruxist and control groups, FD values of the dentate region anterior to the right mental foramen (FD4) were significantly lower than the corresponding values anterior to the left mental foramen (FD5; $P \leq .042$) but the differences between other regions were nonsignificant. It is suggested that this difference may have resulted from unilateral mastication habits.

Although some studies advocated that sex has an impact on trabecular structure and FD,[11,44] others reported no association between sex and FD.[23,45,46] In an investigation involving 106 bruxists and 106 non-bruxists, Güleç et al.[11] found significantly lower gonial and condylar FD values in females than in males in both groups. Sex was not correlated with FD in a study that examined the effect of chronic periodontitis on FD in 56 males and 52 females.[23] In the present study with a total sample of 252 individuals, FD values showed variations in relation to sex. Females exhibited significantly lower FD values measured from right and left condylar regions (FD1 and FD8) in both groups ($P \leq .039$) and significantly lower FD values in FD3 and FD4 regions in control patients ($P \leq .022$) in comparison to males, with no significant difference in other regions ($P \geq .130$). As a result, males were found to have numerically greater and more complex trabeculation in certain regions with higher FD values compared to females in the present study. This finding might be due to sex-related differences in muscle forces and hormonal and metabolic variations.

As trabecular bone has a more dynamic structure than cortical bone, it exhibits age-related changes to a greater extent.[47] Published studies have focused on the association between aging and FD.[11,25] Güleç et al.[11] investigated variations in FD in different age groups. The authors reported that the age group 21 to 25 years had the highest average FD values and age groups 26 to 30 and 36 to 40 years had the lowest average FD values. They suggested that aging is associated with diminished trabecular complexity. The correlation analysis between age and FD measurements showed a weak negative correlation in the right condyle region but no strong correlation in other regions in that study. In the current investigation, the age range of the sample was kept as narrow as possible (18-45 years) to minimize age-related changes in FD values and eliminate the risk of osteoporosis in particular. When the correlation between age and FD values was examined in both groups, positive correlations with age were observed but these were statistically nonsignificant ($P > .05$).

CONCLUSION

FA provides quantitative data on changes in the internal structure of trabecular bone. ROIs in the gonial bone region, either right or left, may be preferred when FD values are to be used for the diagnosis or follow-up of treatment of bruxism. FD measurements are affected by right vs left side and by sex in some regions. Further studies should exclude possible unilateral mastication habits and TMJ problems.

PRESENTATION

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