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ORIGINAL RESEARCH ARTICLE

Application of Fractal Analysis in Detecting Trabecular Bone Characteristics Around Mandibular Impacted Third Molars on Dental Panoramic Radiographs

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Abstract

Purpose: Surgical extraction of third molars can be challenging due to several factors, including increased bone density, which causes the bone structures to lose their elastic properties. The purpose of this study is to compare the trabecular structure surrounding the impacted mandibular third molar (M3M) with the normal alveolar trabecular pattern using the fractal analysis method.
Materials and Methods: A total of 47 dental panoramic radiographs (DPRs) of the patients were included in the study. The region of interest (ROI) was defined as the area between the distal root of the second molar and the mesial root of the third molar tooth (ROI1) and between the distal root of the first molar tooth and the mesial root of the second molar tooth (ROI2). Bone tissue was analyzed by FD analysis. Regions other than the area measured with FD were also evaluated using BMFD to assess the bone marrow. Fractal dimension (FD) and bone marrow fractal dimension (BMFD) analyses were performed on the selected ROIs using the ImageJ software.
Results: The mean FD values of 47 patients were found to be 1.135 for ROI1 and 1.105 for ROI2, respectively. The mean BMFD values were found to be 1.591 for ROI1 and 1.587 for ROI2. The results of the FD analysis (p = 0.078) and BMFD analysis (p = 0.731) showed no significant difference between ROI1 and ROI2.
Conclusions: It is crucial to evaluate the trabecular structure prior to surgery of the impacted M3Ms. Bone density surrounding the impacted M3Ms appears to be higher than that of healthy alveolar bone. Furthermore, the fact that males have denser bones than females should be considered in surgical procedures. The FD analysis method may be useful in evaluating the trabecular structure of impacted M3Ms.

Key words: Bone structure; Fractal dimension; Impacted tooth; Panoramic imaging; Third molars

Introduction

Mandibular third molars (M3Ms) are the most frequently impacted teeth in the jaw.[1] Surgical extraction of these teeth is one of the most common outpatient procedures in dentistry. Several complications can occur during the surgical procedures of the impacted M3M teeth. The most common complications are alveolitis, infection, paresthesia, or osteomyelitis.[2] The possible reasons for these complications are difficulty in extraction due to the following factors: angulation of the tooth, available space for extraction, depth of the tooth, relation with mandibular canal, bone density and elasticity around teeth, buccolingual position, tooth morphology, and operator experience.[3]

Dental panoramic radiographs (DPR) have been proposed as the preferred imaging method because this technique provides an overview of the teeth and jaws.[4] The technique is useful for determining the position, eruption path and relationship to the mandibular canal and surrounding bone of the impacted M3Ms. The main advantage of DPR is the low radiation dose and low cost compared to three-dimensional imaging. DPR can not only show changes in the tooth and surrounding structure, but also evaluate changes in the trabecular bone structure.[5] Radiomorphometric indices such as mandibular cortical index, mandibular panoramic index, and mandibular cortical width applied to DPR are useful methods for

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calculating bone density.[6,7] Indices based on linear measurements are unreliable because they are affected by DPR-related magnification, distortion, and patient positioning.[8–10] Fractal dimension (FD) analysis is advantageous over other indices because it is not affected by the technical variables of the DPR or other radiographs and objectively evaluates the internal structure of the bone.[11]

In many studies, FD analysis used two-dimensional radiographs to detect trabecular density, apical healing, periapical bone, and systemic diseases such as osteoporosis.[12–15] FD analysis is a mathematical technique that can help quantify complex structures by characterizing them with a number, including those of trabecular bone.[16,17] In FD analysis, a box-counting algorithm is used to calculate the trabecular bone pattern by counting the interface between the bone marrow and the trabecular bone.[18] A higher box-counting value is associated with a more complex bone structure.[19] Considering all of this information, FD analysis may be a useful method for evaluating trabecular bone density around impacted teeth. To the best of our knowledge, there is no study which has compared bone density around the M3M in the dentoalveolar region with normal bone density in the dentoalveolar region using FD analysis.

The purpose of this study is to compare the trabecular structure of the bone characteristics in the around of the impacted M3M with the bone structure in the healthy dentoalveolar region by using the FD analysis method and to evaluate the density of the bone around the impacted tooth. The secondary objective is to investigate the relationship between the trabecular bone structure around the impacted M3M teeth and gender.

Material and Methods

Study Design and Ethical Considerations

The Declaration of Helsinki was followed for this retrospective study. The Ankara University Clinical Research Ethics Committee approved this study (IRB approval no: 84/2021). Sample calculation was performed using G-power analysis for the study. By using Type 1 error value (α)=0.05, effect size dz=0.5, power=(1-β)=0.90, n=47 was obtained.

Selection and Evaluation of DPR Images

2563 DPR images were evaluated by the DPR unit between 2021 and 2022 in Ankara University Faculty of Dentistry. The DPRs were taken by Planmeca Oy ProMax (Helsinki, Finland) DPR unit. The exposure parameters were 64 kV, 10 mA, and 10 s. According to the inclusion and exclusion criteria (Table 1), 47 images were included in the study. In the study, impacted M3Ms were examined unilaterally in the DPR images. Two oral and maxillofacial radiology research assistants with three years of experience evaluated and analyzed the DPR images. Evaluation and analysis were performed on the same computer and under the same conditions. Intra- and interobserver reliability was assesed by reanalyzing 20% of the images one month later. The correlation coefficient was then calculated. According to the analysis results, there was intra- and interobserver agreement.

Image Processing and FD Analysis

The DPRs of the subjects involved in the study were exported as high-resolution image files called Tag Image File Format (TIFF). The TIFF format is known to be a more successful image format with less loss of detail compared to the JPEG format.[20] The DPRs were exported in TIFF format to avoid data loss. To standardize the radiographs, the dimensions of all images were adjusted to 2836 × 1500 pixels using Adobe Photoshop CS5 (Adobe Systems Inc., San Jose, CA, USA). The Java-based 64-bit image analysis software ImageJ v1.52 (US National Institutes of Health, Bethesda, MD), a version of the National Institutes of Health (NIH) imaging software, was used for FD analysis.

Determining ROIs

The following regions of interest (ROIs) were defined by us for the purpose of comparing the bone structure surrounding the M3M tooth with that of the normal bone structure surrounding the mandibular molars. The ROI selected for analysis was standardized using the MicroDicom DICOM viewer software. In the MicroDicom software, the horizontal and vertical lengths were determined by using the nearest anatomical reference points (tooth and mandibular canal) in relation to the teeth. ROI1: The 25x25 pixel area between the distal root of the mandibular second molar and the mesial root of the M3M. ROI2: The 25x25 pixel area between the distal part of the distal root of the mandibular first molar and the mesial part of the mesial root of the mandibular second molar (Figure 1).

FD Analysis

Selected ROIs were analyzed using the ImageJ program. The ROI size was to 25X25 pixels. Bone fractal dimension (FD) and bone marrow fractal dimension (BMFD) analyses were performed using the box-counting method (Figure 1). The procedures required for FD analysis were performed using the ImageJ v1.52 program, a version of the National Institute of Health Image, and the method developed by White and Rudolph.[21]

The area of interest was cropped and saved in 8-bit format. The 400% up-sampling ratio was applied to the images because it provided the most optimal binarization result found in a previous study.[22] The image was duplicated and was blurred using the Gaussian filter technique (sigma = 35 pixels) to avoid brightness variations depending on the upper soft tissues and the different bone thicknesses in the image. It was then subtracted from the original image using the image calculator. A 128-gray value was then added to each pixel location, regardless of the original brightness of the image. In images with an average 128-gray value, areas of varying brightness help to separate the bone marrow from the trabecular structure. The image with a 128-gray value was converted to a binary format. This revealed the outlines of the bone marrow and trabecular structure. To reduce the noise of the image, erosion, and dilation were applied to the image. The image was then skeletonized. To calculate the fractal size, the image was divided into squares of equal size widths of 2, 3, 4, 6, 8, 12, 16, 32, and 64 pixels by using the Fractal Box Counter function. The number of frames containing trabeculae and the total number of frames in the image were calculated for different pixel sizes. These values were plotted on a logarithmic scale, and the slope of the line that best fit the points on the graph gave the FD (Figure 2).

BMFD Analysis

The same steps, including the erosion and dilation processes described above, were then applied in the same manner to the images destined for BMFD analysis. The image was then duplicated. FD analysis was performed on the first image. The duplicated image was inverted and skeletonized to preserve only the central portions of the trabeculae were preserved. BMFD analysis was performed on the skeletonized image using the box-counting methods in the ImageJ program. All the above procedures were performed on ROI1 and ROI2 defined on OPG images of 47 selected patients. The results were saved in an Excel file with FD, BMFD, and gender information.

Table 1. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Images of patients aged 18-50 years with M3M with complete bone retention and closed apex	Image of patients with the absence of any of the mandibular first, second, or third molars
Images of patients whose mandibular first and second molars present	Images of patients whose M3Ms are not impacted
	Images of patients with distoangular, horizontal, or inversed positioned M3M
	Images of patients with root configuration anomalies in the mandibular first and second molars
	Image of patients with the presence of root canal treatment at one of the mandibular first, second, or third molars
	Images of patients with any pathology (cyst, tumor, periodontal defect, enostosis) in the relevant bone areas
	Images of patients undergoing active orthodontic treatment
	Images of the patients with previous orthodontic treatment
	Images of the patients with systemic disease diagnosis
	Images with artifacts or low resolution that may hinder the examination

Table 2. Distribution of gender and age

		n (%)
Gender	Female	35 (74,5)
	Male	12 (25,5)
Age (24,11±5,66)	18-24	32 (68,1)
	25-46	15 (31,9)

Table 3. Comparison of FD and BMFD measurements of ROIs

	Max-Min (M)	Mean ± hs	p
FD of ROI 1	1,360-0,941 (1,132)	1,135±0,086	**0,078****
FD of ROI 2	1,408-0,912 (1,102)	1,105±0,083	
BMFD of ROI 1	1,690-1,431 (1,594)	1,591±0,056	**0,731***
BMFD of ROI 2	1,670-1,468 (1,586)	1,587±0,046	

**Wilcoxon, * Dependent groups t-tests

Statistical Analysis

Data were analyzed using the SPSS 26.0 program with a 95% confidence level. The mean (Avg), standard deviation (hs), median (M), minimum, and maximum values were statistically recorded for the measurements. The study used dependent groups t (parametric)/Wilcoxon (nonparametric), FD, and independent groups t (parametric)/Mann Whitney (nonparametric) to compare BMFD measurements by gender, Pearson/Spearman correlation test was used for the relationship between FD and BMFD measurements. The significance level was set at 0.05.

One of the procedures for examining the conformity of measurements and continuous variables to the normal distribution is the calculation of skewness and kurtosis values. The kurtosis and skewness values obtained from the measurements between +3 and -3 are considered sufficient for normal distribution.[23] Parametric tests (Pearson) were employed for measurements that met the normal distribution criteria, while nonparametric methods (Spearmen) were utilized for those that did not. In the normality measurements, FD FOV2 was determined as the measurement that did not meet the normal distribution. Other measurements yielded results consistent with a normal distribution.

Results

Descriptive characteristics of the samples are shown in Table 2. The mean FD values of ROI1 and ROI2 were 1.135 and 1.591, respectively. In addition, the mean values of BMFD in ROI1 and ROI2 were 1.105 and 1.587, respectively (Table 3). Although there is no statistically significant difference between the impacted region and the normal dentoalveolar region, the measurement of the FD of the bone is higher in ROI1 (p=0.078 > 0.05).

There was no statistically significant difference in different the ROIs between the genders in FD and BMFD analysis. Bone FD and the BMFD of ROI1 and the BMFD of ROI2 measurements are higher in males, while the bone FD of ROI2 is higher in females (Table 4). Bone FD and the BMFD measurements of ROI1 have a positive and statistically significant correlation. In addition, a significant correlation was found between the bone FD and the BMFD measurements of ROI2 (Table 5).

Discussion

One of the main reasons for the difficulty in extracting impacted M3Ms is the density and elasticity of the bone.[3] As bone density increases, the amount of vascularization of the bone in the region decreases.[24] Therefore, the risk of infection, alveolitis, and osteomyelitis increases. For this reason, it is important to properly assess the bone structure prior to surgery. It has been shown that fractal analysis methods and bone densitometric values are correlated.24,25 For these reasons, it found to be reliable to use fractal analysis, which is not affected by local artifacts, to evaluate bone density.[11,25,26]

Some studies have evaluated bone density around impacted teeth using fractal analysis or other methods.[27–29] Koseoglu Secgin et al.[29] evaluated bone density around impacted maxillary canines using gray values in cone beam computed tomography (CBCT) images. The gray values of the impacted canines were found to be statistically significantly higher than those of nonimpacted teeth (p=0.003). They concluded that the alveolar bone density around the impacted maxillary canine is a potential etiological factor for impaction. In this study, bone density was found to be high in the impacted tooth region, parallel to the study of Koseoglu Secgin et al.[29] However, the result was not significant. Although the use of two distinct imaging techniques and the divergence in methodology may also have contributed to the observed outcome, it was concluded that the primary reason for the non-significant result of this study was the difference in bone density between the mandible and maxilla.[30] In addition, the gray value, which can also be used to assess bone density, is a reliable parameter for computed tomography (CT). It has been reported that large amounts of X-ray scatter and artifacts affect the gray value in CBCT scans, and the gray value does not correlate with Hounsfield Units.[31] Therefore, CBCT is not a reliable parameter for measuring bone density by using gray values.[32] In their study, Gonca et al.[27] examined FD around the impacted M3Ms to evaluate the trabecular structure and compared it with different ROIs, including the gonial, antegonial, sigmoid notch, and ramus regions of the mandible. The objective of their study was to investigate whether the eruption of the M3M was influenced by increasing or decreasing trabecular structure in the ROI. No significant difference was found between the FD values

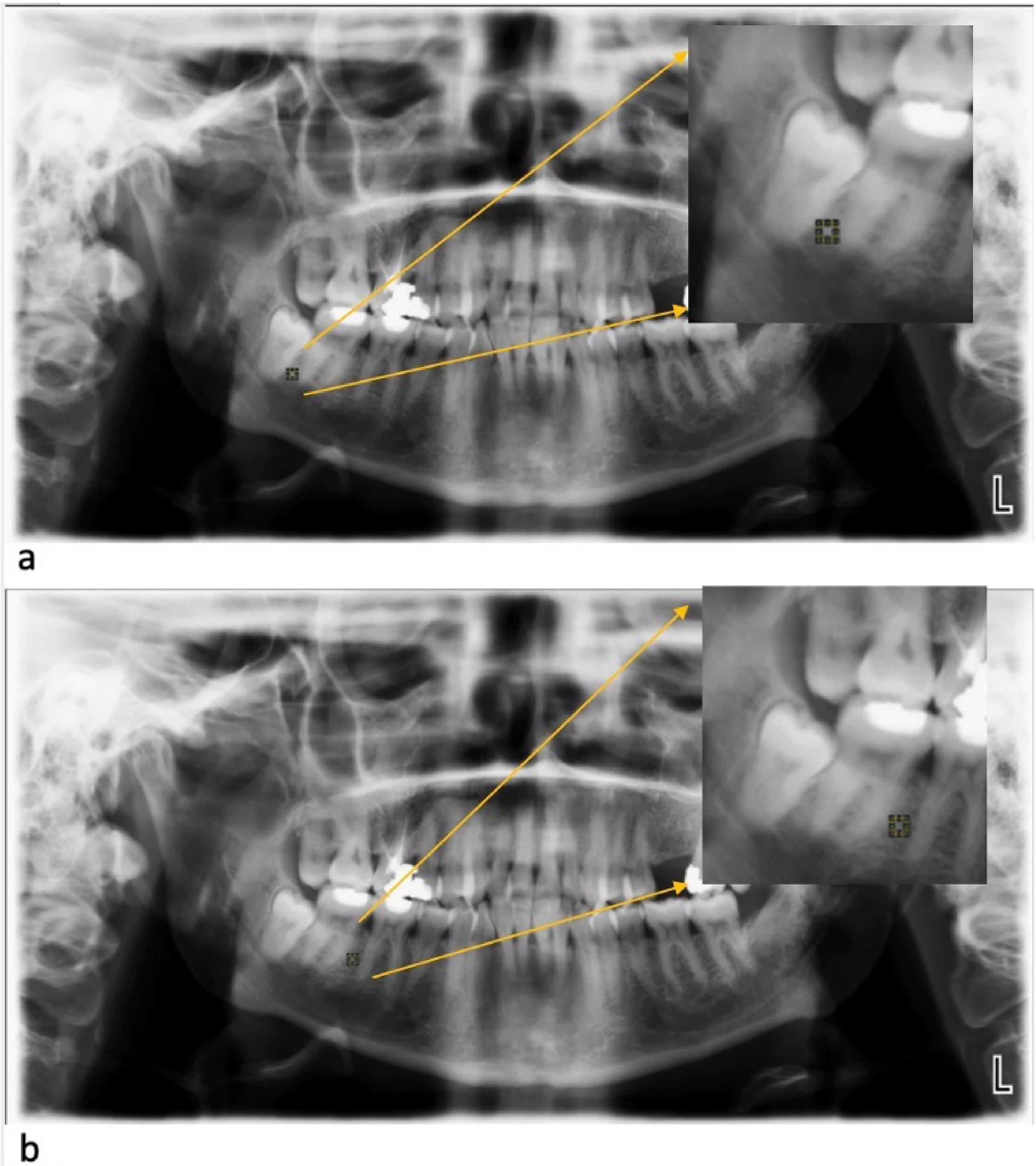

Figure 1. Display of ROI's in DPR (a) ROI1. (b) ROI2.

around the impacted M3Ms and those of the other regions. The researchers proposed that the trabecular structure had no effect on M3M impaction. The selected ROIs in the aforementioned study may not be able to demonstrate the effects of the trabecular bone structure on the impaction. Those ROIs represent the attachment areas of the masticatory muscles. Previous studies have demonstrated that the condylar, ramus, and gonial regions are influenced by the mechanical function of the masseter muscle.[28,33–35] Therefore, it is not appropriate to compare the bone density around the selected regions with that of the impacted M3Ms.

To date, no studies have been conducted to evaluate the difference between bone density around the M3Ms and normal dentoalveolar bone density using fractal size analysis in DPR. Servais et al.[36] evaluated bone density around impacted maxillary canines on CBCT by using fractal analysis. The study included 49 subjects with bilateral and unilateral impacted canines. The bone structure around the impacted canine and in the nonimpacted region was measured by fractal analysis. The study reported that the FD value of the impacted region was 1.248, while that of the non-impacted region was 1.245. They associated the high FD value on the impacted side with the increased bone density in the area. The researchers concluded that the bone density around the impacted teeth may be one of the reasons for developing impaction. In this present study, the mean FD values of the measurements of the impacted region (ROI1) and

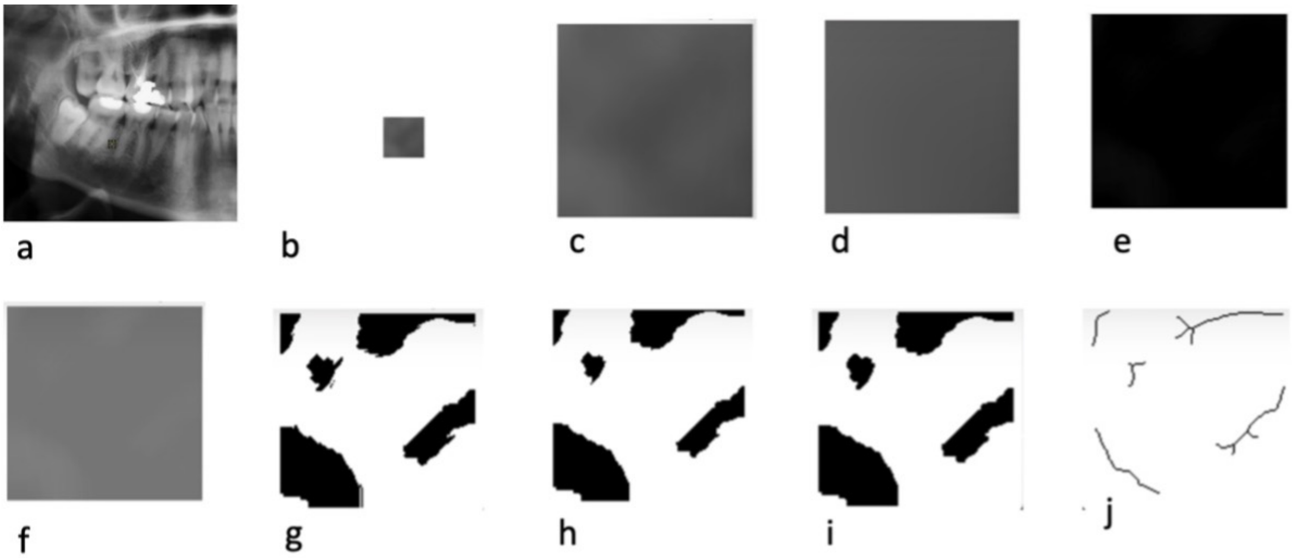

Figure 2. Steps for image processing for bone fractal dimension: (a) original 25 × 25-pixel region of interest. (b) cropped, (c) up-sampling ratio (%400). (d) blurred image. € subtracted image. (f) value-added image (C + 128). (g) binarized image. (h) eroded image. (i) dilated image. (j) skeletonized imag

Table 4. Comparison of FD and BMFD measurements of ROIs by gender.

		Max-Min (M)	Mean ± hs	p
FD of ROI 1 *	Female	1,360-0,996 (1,113)	1,130±0,076	**0,544**
	Male	1,340-0,941 (1,145)	1,148±0,113	
FD of ROI 2**	Female	1,408-0,912 (1,106)	1,111±0,088	**0,457**
	Male	1,203-0,964 (1,082)	1,086±0,066	
BMFD of ROI 1*	Female	1,654-1,431 (1,592)	1,585±0,053	**0,206**
	Male	1,690-1,460 (1,626)	1,609±0,064	
BMFD of ROI 2**	Female	1,670-1,468 (1,579)	1,582±0,050	**0,196**
	Male	1,649-1,548 (1,605)	1,602±0,029	

**Mann-Whitney, * Independent groups t-tests

Table 5. The relationship between the FD and BMFD measurements of ROIs

		BMFD (1)*	BMFD (2)*
FD (1)*	r	,670***	
	p	0,000	
FD (2)**	r		,528***
	p		0,000

**Spearman, * Pearson correlation tests, ***p<0,05

the normal dentoalveolar region (ROI2) were 1.135 ± 0.086 and 1.105 ± 0.083, respectively. The results of this study are consistent with those of Servais et al.[36] However, the present study did not yield statistically significant results, with a p-value of 0.078. A high FD value indicates increased bone density around the impacted M3M. Therefore, the results of the study demonstrate that it can make a clinical difference in the determination of bone density in the region and in surgical operations.

Furthermore, the researchers employed fractal analysis to examine the bone marrow fractal size. The researchers reported BMFD values for impacted regions and nonimpacted regions as 1.284 and 1.305, respectively.[36] In this study, the mean BMFD values for the impacted region (ROI1) and the normal dentoalveolar region (ROI 2) were 1.592 and 1.587, respectively. A positive correlation was identified between the bone FD and the BMFD. In contrast to the findings of Servais et al.[36], a positive correlation was observed between BMFD and FD analysis. It is hypothesized that this discrepancy is due to the fact that Servais et al.[36] conducted their study on the maxilla, which is a more stable bone. In this study, samples were selected from the mandible. It is well established that strong masticatory muscles and occlusal forces play a role in the remodeling of the mandibular bone. In this study, it was hypothesized that the positive correlation observed was due to the more dynamic remodeling of the mandibular bone.

Previous studies have examined bone mineral density in the jaws of males and females using CT by Hounsfield Units values, and dual-energy X-ray absorptiometry (DEXA). These studies have found that male patients have significantly higher bone mineral density than female patients.[37,38] Gaalaas et al.[39] evaluated bilateral molar region and condyle using fractal analysis on CBCT in terms of gender. The study revealed that fractal analysis values in males were higher than in females. While this difference was not statistically significant, the fractal size of bone the around impacted M3M was found to be higher in males (1,148 ± 0,113) than in females (1,130 ± 0,076). This discrepancy could be attributed to the fact that males exert greater masticatory forces than females.[37,38]

This study is subject to a number of limitations. Primarily, the study was conducted using only DPR as an imaging technique and exclusively evaluating the mandibular molar region. DPR was selected as the imaging modality for this study because it is a routine examination technique for M3Ms and the relevant region is less susceptible to superpositions in the DPR images.[40] The rationale behind the exclusion of radiographs of patients over the age of 50 from the study is that diseases affecting bone density, such as osteoporosis, are prevalent in both male and female patients of this age group.[41,42] Furthermore, the study only evaluated vertical impaction according to the classification of Pell and Gregory.[43] It is recommended that other classifications be considered for future studies.

Conclusion

In order to avoid possible complications before the surgery on the M3Ms and to perform the extraction correctly, knowledge of the pattern of the trabecular structures should be obtained. During surgery, it can be considered that bone density is higher in men than in women. The FD analysis method seems to be useful in evaluating the trabecular structure of impacted M3Ms. Further studies are needed to increase the knowledge of the trabecular structure around the different impaction positions.

Author Contributions

Study Idea / Hypothesis: E.P.B., H.A.D., M.H.K., Study Design: E.P.B., H.A.D., M.H.K., Data Collection: E.P.B., H.A.D. Literature Review: E.P.B., H.A.D., M.H.K. Analysis and/or Interpretation of Results: E.P.B., H.A.D., M.H.K. Article Writing: E.P.B., H.A.D., M.H.K., E.S. Critical Review: E.P.B., M.H.K.

Conflict of Interest

The authors have no conflicts of interest related to this work to declare.

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