Evaluation of the Trabecular Structure of Mandibular Condyles in Children Using Fractal Analysis

Muge Bulut*/Muge Tokuc**

Objective: *To evaluate the trabecular internal structure of the mandibular condyle with fractal analysis on panoramic radiography in children.* ***Study Design:*** *159 panoramic radiographs were separated into 8 groups according to age and gender. The radiographs were standardized as 8-bit images. Regions of interest, located on both mandibular condyles, were selected as 64x64 pixel squares. Image J v1.50i software was used to obtain the fractal dimension (FD) values by the box-counting method.* ***Results:*** *The data obtained from the right and left condyles were analyzed in terms of gender and age groups. No statistically significant difference was observed between the genders in respect of the mean FD values for both condyles (p>0.05). Mean, standard deviations and the 95% confidence intervals for the FD values of the left and right condyles were obtained according to age. A statistically significant difference was observed in the mean FD values for both left (p= 0.019) and right (p= 0.000) condyles when all groups were compared and no statistically significant difference was found between all groups except the 6-year-old group for both condyles. In both condyles, the significantly lowest mean FD values were determined in the 6 years age group.* ***Conclusions:*** *The FD values of the mandibular condyle trabecular structure changed with age. It will be possible to evaluate these changes from panoramic radiographs by making calculations using the fractal analysis method.*

Keywords: *Children; fractal analysis; temporomandibular joint; panoramic radiography.*

INTRODUCTION

The temporomandibular joint (TMJ) is a compound joint that makes a hinge and sliding movement between the caput mandible and the mandibular fossa, thereby providing function to the mandible during speech, chewing and swallowing. The coordination between the temporal and the mandibular bone has importance in the maturation of the TMJ [1-3]. The articular surfaces of the condyle and the temporal bone are covered with fibrous connective tissue at birth. Fibrocartilagenous tissue replaces the fibrous tissue with the deepening of the fossa over time and the functional development of the mandibular condyle. Postnatally, remodelling continues in harmony with the developmental process of the condyle and temporal fossa. Mandibular growth occurs in relation to the condylar growth center between 1 and 5 years of age while active mandibular growth associated with muscle function is observed between 10 and 15 years of age [4].

The mechanical properties of the TMJ, such as strength, quality, and resistance, depend on the cortical bone thickness of the mandibular condyle, trabecular bone density and configuration of trabeculae. A change in the structural specifications of the bone such as the porosity, trabecular thickness, inter-trabecular connection and anisotropy provides information about degenerative diseases and fracture risk [5-7]. The trabecular arrangement has a fractal structure character because it resembles itself when viewed at a certain resolution in radiographs [8]. The fractal analysis method has been

From Istanbul Okan University, Faculty of Dentistry, Department of Pediatric Dentistry
*Muge Bulut, DDS, Assistant Professor.
**Muge Tokuc, DDS, Assistant Professor.

Corresponding Author:
Muge Bulut
Istanbul Okan University, Faculty of Dentistry, Department of Pediatric Dentistry
Prof. Dr. Necmettin Erbakan Caddesi, No:2 Aydıntepe -Tuzla/Istanbul, Turkey
Phone: +90 5555644726
E- mail: cimenmg@gmail.com, muge.bulut@okan.edu.tr

 doi 10.17796/1053-4625-45.6.12

found to be suitable for the evaluation of its architecture due to the presence of interconnected trabeculae in the trabecular bone and the complex geometry of these connections [9, 10].

Fractal analysis is a method that shows the complexity of shapes or structures, the value of which is numerically indicated by the fractal dimension (FD) [11, 12]. In medicine, fractal analysis is generally used with imaging techniques, mostly radiographs, to diagnose potential anomalies and the severity of existing disease [13-15]. It has been stated that FD measured on radiographs is associated with changes in bone density and reflects bone mineral loss. It has also been concluded that the anisotropic feature of the trabecular bone and changes in trabecular alignment and trabecular thickness have led to the varying results in studies on fractal dimension [6, 11, 16-20].

In literature, different methods have been proposed to calculate the FD values and the most commonly used is the box-counting dimension. This algorithm includes the evaluation of the trabecular bone and bone marrow interface [21, 22]. Calculations in these areas according to the obtained values give the FD of the structure [23, 24].

The aims of this study were:

1. To determine the FD values for the trabecular structure of the mandibular condyle using the fractal analysis method on panoramic radiographs of children aged 6-13 years and to set a reference for clinicians in cases where the bone structure changes.
2. To evaluate the differences in FD values between age groups and gender.

MATERIALS AND METHOD

The study included the panoramic radiographs of 159 patients (72 girls, 87 boys) aged 6-13 years old (mean ± SD age: 9.65 ± 2.07 years) who presented at our clinic for routine oral and dental examination. The patients were separated into 8 groups according to age and gender. According to the sample size calculation at least 10 patients were needed in each group and had an actual power of 0.9971 with a significance level of .05. Approval for the study was granted by the Clinical Research Ethics Committee of Istanbul Okan University (Decision No: 23).

There was no history of any systemic disease or temporomandibular joint pain in the anamnesis of the patients. While patients with normal dentition for their age were included in the study, patients who had tooth extraction in his/her deciduous or permanent dentition due to tooth decay, trauma or periodontal reasons were excluded.

Panoramic radiographs were taken using a digital panoramic X-ray system Planmeca Promax 2D S2 device (Planmeca Oy, Helsinki, Finland; Kodak 8000, Rochester, NY, USA) at 62- 64 kVp, 5- 6.3 mA, and an exposure time of 13.5- 15.6 seconds according to the age and weight of the children. Panoramic radiographs in which joint surfaces could not be evaluated due to superposition were excluded.

Image J version 1.50i software (National Institutes of Health, USA; https://imagej.nih.gov/ij Java 1.6.0_24 (64 bit)) was used for calculation of the fractal dimension. After saving the digital images in Tagged Image File Format (TIFF) on a personal computer (Intel(R) Core (TM) i7- 6500 CPU) with 1420×810 pixels and 256 gray levels, they were converted to 8-bit images. Two standardized regions of interest (ROI) were selected as 64x64 pixels within the cortical boundaries of bilateral mandibular condyles on each radiograph (Figure 1). The method suggested by White and Rudolph [20] was used to process the ROIs for fractal analysis. According to this, cropped ROIs were duplicated and blurred with a Gaussian filter. The presence of soft tissues and alternating thicknesses of the bone results in high and medium bright areas in the image so this phase is continued with the removal of these bright areas. After subtracting the blurred image from the original image, 128 gray values were added to each pixel. The binary option was used, then the noise was removed by eroding and dilating the binary image. Finally, the image was skeletonized and produced for FD (Figure 2a-2h). The FD values were calculated with the box-counting method in the software from the ''analyze'' menu.

Figure 1: Radiographic image with ROI.

Statistical analysis

Data were analyzed using the Minitab 17.1.0 statistical software. According to the Kolmogorov-Smirnov test, variables were normally distributed. The Paired Samples t-test was used to compare differences between the genders and One-way ANOVA was used to compare the mean FD values of the eight age groups. The level of statistical significance was set as 0.05.

RESULTS

Evaluation was made of a total of 318 measurements (159 areas from both left and right condyles). No statistically significant difference was observed between the genders in respect of the mean FD values for both condyles (p>0.05) (Table 1).

Table 1: The mean and standard deviations of the FD values according to gender.

	N	Mean±SD	SE Mean
Girls Left Condyle	72	1.3454±0.0591	0.0070
Boys Left Condyle	87	1.3341±0.0875	0.0094
			***p* value=** 0.352
Girls Right Condyle	72	1.3216±0.0905	0.011
Boys Right Condyle	87	1.3259±0.0924	0.0099
			***p* value=** 0.771

The mean FD values according to age and 95% confidence intervals of the left condyle are presented in Table 2 and of the right condyle in Table 3.

Table 2: The mean, standard deviations and 95% confidence intervals of FD values for left condyle according to age.

Age	N	*Mean± SD*	95% CI
6(6.0-6.9)	14 (6 girls, 8 boys)	1.2793±0.0548	1.2405- 1.3182
7(7.0-7.9)	21 (10 girls, 11 boys)	1.3554±0.0687	1.3237- 1.3871
8(8.0-8.9)	31 (14 girls, 17 boys)	1.3290±0.0723	1.3028- 1.3551
9(9.0-9.9)	36 (16 girls, 20 boys)	1.3292±0.0864	1.3049- 1,3534
10(10.0-10.9)	12 (5 girls,7 boys)	1.3724±0.0475	1.3304- 1.4144
11(11.0-11.9)	14 (6 girls,8 boys)	1.3476±0.0938	1.3088- 1.3865
12(12.0-12.9)	18 (9 girls, 9 boys)	1.3514±0.0705	1.3171- 1.3857
13(13.0-13.9)	13 (6 girls, 7 boys)	1.3731±0.0594	1.3328- 1.4135
		***p* value**=0.019*	

* Statistically significant in the mean FD values between age groups ($p < 0.05$)

Table 3: The mean, standard deviations and 95% confidence intervals of FD values for right condyle according to age.

Age	N	Mean FD	95% CI
6(6.0-6.9)	14 (6 girls, 8 boys)	1.2145±0.0850	1,1694- 1,2596
7(7.0-7.9)	21 (10 girls, 11 boys)	1.3119±0.1081	1,2750- 1,3487
8(8.0-8.9)	31 (14 girls, 17 boys)	1.3382±0.0679	1,3079- 1,3685
9(9.0-9.9)	36 (16 girls, 20 boys)	1.3378±0.0841	1,3097- 1,3659
10(10.0-10.9)	12 (5 girls,7 boys)	1.3418±0.0747	1,2931- 1,3905
11(11.0-11.9)	14 (6 girls,8 boys)	1.3595±0.0773	1,3144- 1,4046
12(12.0-12.9)	18 (9 girls, 9 boys)	1.3130±0.1138	1,2732- 1,3528
13(13.0-13.9)	13 (6 girls, 7 boys)	1.3494±0.0483	1,3026- 1,3962
		***p* value:** 0.000**	

**Statistically significant in the mean FD values between age groups ($p < 0.05$)

From all the age groups, the mean FD values in both condyles were the lowest in the 6-year old group (Figure 3-4). A statistically significant difference was observed in mean FD values for both left (p= 0.019) and right (p= 0.000) condyles when all the groups were compared (Table 2-3). With the exception of the 6-year old age group, no statistically significant difference was found between all the groups for both left (p=0.622) and right condyles (p=0.329).

Figure 2: Stages of fractal dimension analysis a Gaussian blur b Substraction of the blurred image from the original image c Addition of a gray value of 128 to each pixel location d Binarization e Erosion f Dilatation g Inversion h Skeletonization.

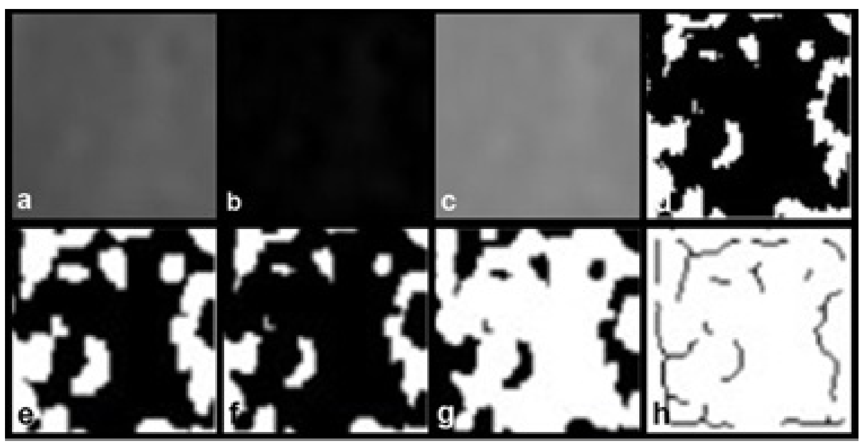


Figure 3: The distribution of the FD values of left condyle according to age

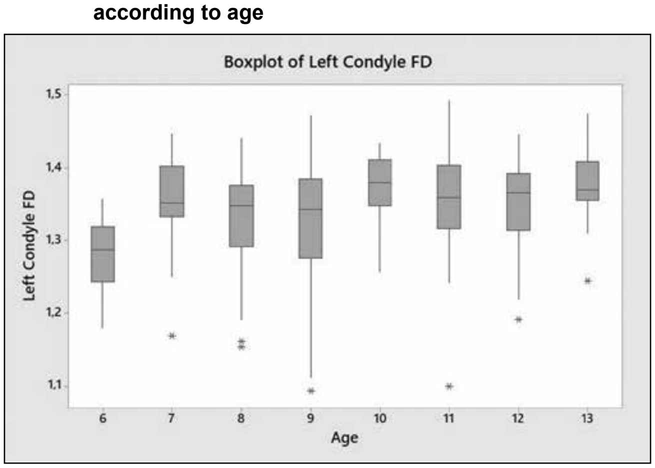
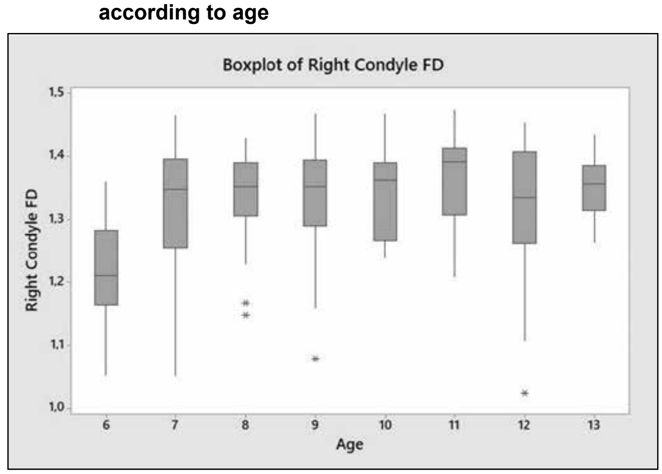


Figure 4: The distribution of the FD values of right condyle according to age



 doi 10.17796/1053-4625-45.6.12

DISCUSSION

The evaluation of changes in bone structure depends on the trabecular bone rather than the cortical bone, since it has a higher metabolic activity [25]. In some studies evaluating the trabecular structure of the bone in dentistry, the quality and healing of the bone has been evaluated with fractal analysis [26]. The use of fractal analysis on radiographs allows both the analysis of the trabecular bone microstructure and measurement of the alveolar bone mineral content [27, 28]. In the current study, the trabecular internal structure of the mandibular condyle was evaluated using the box-counting method, which has been mostly preferred in the literature for the calculation of the fractal dimension [5, 13, 16, 17, 26].

There are many studies in dentistry that have analyzed the trabecular structure of the bone with radiographs and tomographs. Panoramic radiographs were preferred in this study because of the lower dose of radiation compared to tomography [26, 29]. Heo *et al* [30] used fractal analysis on panoramic radiographs to report the changes in the operated region after orthognathic surgery. Demirbaş *et al* [18] evaluated alterations in the mandibular bone tissue of patients with sickle cell anemia (SCA) in panoramic radiograph, and reported that the mean FD values of the SCA patients were significantly lower than those of healthy individuals. In 2017, Arsan *et al* [31] calculated the healthy trabecular structure and degenerative changes of the mandibular condyle on panoramic radiographs using fractal analysis and found that the severity of degenerative changes and FD values were inversely associated. The literature lacks studies on the trabecular structure of mandibular condyles in children. In the current study, the FD values for the trabecular structure of the mandibular condyle of healthy children were determined. The values obtained from this study provide comparative data that can be used as reference in diseases that affect the mandibular condyle.

It can be thought that the FD values in this study may have been affected between children because the panoramic radiographs could not be obtained at fixed exposure parameters since irradiation was performed according to the age and weight of the children. However, considering technical factors, it has been reported that the difference in FD values is insignificant and the fractal analysis method is not affected by the changes in kVp and exposure time [9, 32]. In a study by Lee *et al* [33] the selection of linear ROI was determined to be inadequate to characterize the trabecular structure. Therefore, in the current study, measurements were calculated as 64x64 pixel squares inside the cortical boundaries of both mandibular condyles. These square ROIs within trabecular bone have been commonly used previously [26].

In 2019, Guagnelli *et al.* [34] reported the trabecular bone scores in DXA (bone densitometry images) of lumbar and hand bones in healthy children between 4 and 19 years old (mean age of girls: 10.6 years–boys: 10.9 years) and found that gender showed low association with the trabecular bone score (0.36 for boys and 0.38 for girls) In the current study, no significant difference was found between the trabecular FD values of the right and left condyle of girls and boys in accordance with the literature. Therefore, in all age groups, the mean FD values were calculated for the right and left condyle trabecular structure, regardless of gender.

The results of this study showed that after 6 years of age, the FD values of both condyles increase significantly and after the age of 7 years until 13 years, the difference is insignificant. Both mandibular corpus and mandibular condyle are affected by the mechanical pressure transmitted from dentititon to the mandibular bone and mandibular movements during chewing [35]. Therefore, occlusal forces cause changes in the bone morphology of the condyle [35, 36]. It has been reported that the internal structure of the mandibular condyle is associated with the number of teeth present in the mouth and the existence of the molar teeth in particular is significantly associated with the increase in bone density of the mandibular condyle [37].

Occlusal forces and chewing performance in children are affected by the eruption of the first permanent molars and the loss of deciduous teeth during the mixed dentition phase [38]. Chewing performance increases with the eruption of the first permanent molars after the age of 6 years in children. Conversely, chewing performance may also be decreased during the mixed dentition phase because of the loss of deciduous molars and canines, which results in a decrease in the number of teeth in occlusion and occlusal areas. During permanent dentition, the eruption of permanent teeth re-increases the chewing performance [38, 39]. In the current study, the significant increase in FD values of the mandibular condyles from the age of 6 to 7 can be related to the eruption of the first permanent molars and the increase in posterior contact areas. In addition, the plateau of FD values in the period from 7 to 13 years of age is thought to be an effect of the mixed dentition phase. In previous studies, the trabecular structure has also been shown to be affected by the hormonal changes during puberty and tends to increase with age [34]. Examining groups over the age of 13 years may result in an increase of FD values with the effect of both the permanent dentition phase and the hormonal alterations of puberty and therefore, further studies are needed on this subject.

The limitation of the present study is that the influence of the preferred chewing side on the anatomy and bone composition of the condyles could not be analyzed. It can be recommended to evaluate the FD values in the mandibular condyles by considering the predominant side of chewing with further analysis.

CONCLUSIONS

Fractal analysis from panoramic radiographs provided additonal information about the status of the trabecular structure of the mandibular condyles of children aged 6-13 years. The study results showed that the FD values of the mandibular condyle trabecular structure varies with age. The mandibular condyle FD values obtained from healthy children in this study, together with other imaging techniques, will help to determine the severity of degeneration in the condyle and guide clinicians in the treatment of degenerative TMJ diseases and other systemic diseases that affect the structure of the bone.

Funding:

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of Competing Interest:

The authors deny any conflicts of interest related to this study.

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 doi 10.17796/1053-4625-45.6.12