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Fractal analysis of mandibular condyle trabecular structure in children

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ABSTRACT

Aims: The aim of this study was to investigate the changes in the trabecular structure of the mandibular condyle with age in children using fractal analysis (FA) on dental panoramic radiographs (DPRs) and to evaluate the fractal dimension (FD) differences according to age groups and gender.

Methods: In this retrospective study, 110 pediatric patients with DPR were divided into 2 groups according to age: 6-8 age group (n=55, mean: 6.8±0.704 years), 9-12 age group (n=55, mean: 11.18±1.775 years). FD values obtained from the right and left mandibular condyle were analyzed according to age and gender. For the calculation of FD, a 40x40 pixel square region of interest (ROI) was selected from the geometric center of both mandibular condyles. Image J version 1.52 software was used to obtain FD values by box counting method. Data were analyzed using IBM SPSS Statistics program. T-test was used to compare parametric data and Mann-Whitney U test was used to compare non-parametric data. Statistical significance level was determined as $p<0.05$.

Results: The mean FD of the right condyle was 1.046±0.086 and the mean FD of the left condyle was 1.201±1.205 in the 9-12 age group; the mean FD of the right condyle was 0.909±0.063 and the mean FD of the left condyle was 0.924±0.08 in the 6-8 age group. The mean FD values of both condyles increased with age and this increase was statistically significant ($p<0.001$). There was no significant difference between the mean FD values of the right and left condyles between genders in the same age group ($p>0.05$).

Conclusion: In the present study, FD values were determined for the trabecular structure of the mandibular condyle in healthy children. The results of the study showed that the FD values obtained from both mandibular condyles on DPRs in children increased with age.

Keywords: Fractal analysis, panoramic radiograph, pediatric patients

INTRODUCTION

The temporomandibular joint (TMJ) connects the mandible to the cranium with ligaments and muscles and provides bilateral articulation.[1-3] TMJ performs a crucial role in the facilitation of the jaw's range of motion to enable speaking, chewing, breathing and swallowing.[2] As sucking behavior at the beginning of life gradually transforms into masticatory movement, its evolution continues to adapt to the changing function of TMJ. TMJ's position between the skull base and mandible defines its growth and function.[4] In infants and 2-3 year olds, condyle neck is thick and short, cortical bone is thin, bone marrow is dense and the glenoid fossa is shallow. Similar to the adult anatomy, growth begins at 7-8 years of age.[5,6] The condyle continues to grow with bone apposition without losing its relationship with the glenoid fossa. Mandibular growth occurs from condylar growth center between the ages of 1-5 years, while active mandibular growth occurs between the ages of 10-15 years in relation to muscle function.[7]

At the same time as changes in the condyle, changes in occlusal forces cause microscopic and macroscopic changes in the jaw bones.[8] TMJ's mechanical characteristics such as strength, quality and resistance rely on thickness of the cortical bone of mandibular condyle, the intensity of trabecular bone and the composition of the trabeculae. Trabecular bone architecture has a structure suitable for load-bearing functions. Compared to cortical bone, trabecular bone has a greater metabolic activity, which is more indicative for assessing changes in osseous structure.[9,10]

Fractal analysis (FA) measured on dental panoramic radiographs (DPRs) is a popular method to quantitatively describe the quality of bone tissue, analyzing early changes in alveolar bone and mandibular trabecular architecture.[11,12] In trabecular bone, fractal dimension (FD) results calculated by the box counting method are assumed to be between 1

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and 2. Values closer to 2 represent a highly complex bone microstructure, while values closer to 1 represent simpler bone microstructures that emphasize the porosity of the bone.[13,14]

Despite the fact that DPRs are non-invasive techniques that are frequently utilized and provide early indication during dental diagnosis and treatment, dual-energy X-ray absorptiometry (DXA) is the most widely used densitometric technique for bone mineral density assessment worldwide and is preferred over other techniques due to its speed, sensitivity, safety, low cost and widespread availability. Additionally, DXA is considered the gold standard for the assessment of bone mineral density.[15]

Although DPRs are used routinely in dentistry for diagnosis and treatment, there are limited studies in the literature evaluating FA in pediatric patients using existing DPRs.[3,11,14,16] Understanding age-related changes in bone dynamics can provide significant clinical benefits in monitoring growth and development, planning orthodontic treatments, and early diagnosis of TMJ disorders. Investigating the applicability of FA on DPRs may contribute to the non-invasive assessment of bone structure in pediatric patients.

The aim of this study was to investigate the age-related alterations in the trabecular structure of the mandibular condyle with age in children using FA on DPRs and to assess the FD differences according to age groups and gender.

METHODS

The present retrospective study was executed in the Department of Dentomaxillofacial Radiology, Faculty of Dentistry, Ankara Medipol University, in full compliance with current ethical guidelines, which included the 1964 World Medical Association Declaration of Helsinki and its subsequent revisions. Prior to the study, ethics clearance was received from the Non-interventional Clinical Researches Ethics Board of Ankara Medipol University (Date: 06.06.2023, Decision No: 63). When preparing the dataset, the data was anonymized to prevent information about the patients' identity (except for age and gender) and no additional consent form was obtained from the patients.

This study included DPRs of a total of 220 patients 110 (48 girls, 62 boys) aged 6-8 years and 110 (56 girls, 54 boys) aged 9-12 years) who presented to the Department of Pediatric Dentistry, Faculty of Dentistry for routine oral and dental examinations. The anamnesis of the patients was checked through the patient registration system and patients without any systemic disease affecting the bone, without TMJ pain and craniofacial deformity, without a history of trauma and periodontal disease, and without congenital missing or extracted teeth have been included in that study. We excluded patients with any disease affecting the TMJ. In this regard, patients with inflammatory and infectious diseases such as Juvenile idiopathic arthritis (JIA), rheumatoid arthritis, ankylosing spondylitis, psoriatic arthritis, systemic lupus erythematosus (SLE) and septic arthritis as well as developmental anomalies such as hemifacial microsomia and condylar hypoplasia/hypertrophy were excluded. Additionally, patients with a history of functional disorders such as condylar fracture, TMJ dislocation, osteochondroma and bruxism were also excluded. Individuals with a history of orthodontic treatment and diagnosed malocclusion were also excluded. Subjects who did not have normal dentition for their age and subjects with DPRs of insufficient diagnostic quality were excluded from the study.

All DPRs were acquired with one appliance (Castellini X-Radius Tr10 Plus, Italy) utilizing 60-85 kVp, 4-8mA and 12.3 s exposure time. Each patient's DPRs were taken by the same radiology technologist. During acquisition, it was placed in accordance with the manufacturer's recommendations. Positions were set with Frankfurt horizontal plane parallel to the ground and sagittal plane adjusted in accordance with vertical line reproduced by device.

Fractal Analysis

FD was performed by box counting based on the method described by White and Rudolph.[17] Regions of interests (ROIs) were selected from the condyle region similar to the study of Tokuç et al.[3] in order to examine the change in the effect of growth and development on the condyle with age. For FD analysis, two ROIs of 40×40 pixels were chosen for each patient, the central region of the right (ROI-Rc) and left (ROI-Lc) mandibular condyle (Figure 1). FD was calculated using Image J version 1.52 (National Institutes of Health, Bethesda, MD, USA) software.

Figure 1. Selection of regions of interest in dental panoramic radiography. A: ROI-Rc. B: ROI-Lc
ROI-Rc: Central region of the right, ROI-Lc: Central region of the left

The image was replicated after selecting the ROI (Figure 2a). Gaussian filter was added to the image to create a blurring affect (Figure 2b). The emerging blurred image was subsequently extracted from the initial display (Figure 2c). In order to upgrade specific characteristics with different brightness degrees, like trabeculae and bone marrow, add 128 gray values to each pixel position to acquire a display (Figure 2d). The image was transformed into a binary format by applying a brightness value threshold of 128 (Figure 2e). In order to decrease noise, binary imaging was undergone a process of erosion and dilation (Figure 2f, 2g). The image was subsequently inversed, showing the trabecular areas in as the black and the bone marrow in white (Figure 2h). Eventually, this image was put through a skeletonization process that progressively removes pixels so that only a central line of pixels remains (Figure 2i). The software utilized an algorithm for box counting that split the image into frames of 2, 3, 4, 4, 6, 6, 8, 12, 16, 32, 64 pixels (Figure 2). The count of grids comprising trabeculae and the total number of grids were measured for per pixel size. These values were represented on a graph with a logarithmic scale. In the graph, the slope of the curve of the line connecting the plotted points provided FD value.

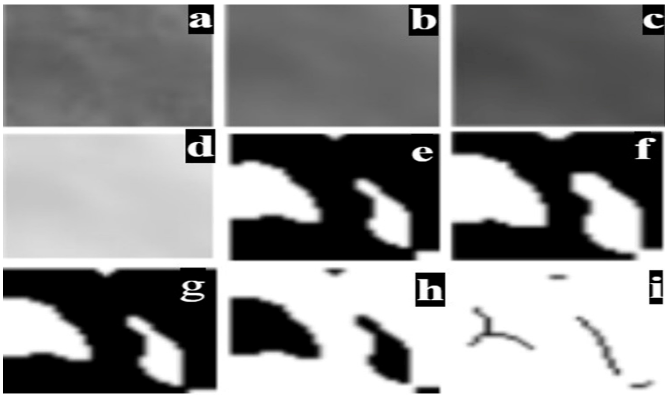

Figure 2. Fractal analysis **a.** Duplicated version of ROI **b.** Gaussian blur **c.** Subtraction **d.** Addition of 128 gray value **e.** Binarization **f.** Erosion **g.** Dilation **h.** inversion **i.** Skeletonization
ROI: Region of interest

FA calculations were conducted by a dentomaxillofacial radiologist with five years of experience (EMAO) who was blinded to participants' medical information. To improve intra-observer calibration and reliability of the assessments, 20% of the images were reviewed by the same observer two weeks after the initial assessment. The average of the results from the initial and subsequent measurements was then used for statistical analysis.

Statistical Analysis

The same observer reviewed 20% of the images two weeks after the initial evaluation to increase the reliability of the assessments and the intra-observer correlation was found to be nearly perfect (κ: 0.92). All data have been analyzed using SPSS 29.0 (IBM Corp., New York) statistical software. The normality of the data was analyzed in accordance with the Kolmogorov-Smirnov test. The t-test was utilized to compare parametric data and the Mann-Whitney U test was utilized to compare nonparametric data. The statistical significant level was determined as $p<0.05$. Prior to commencing the study, G*power version 3.1.9.2 was used to determine the minimum number of patients required ($\alpha=0.05$, $1-\beta=0.95$).

RESULTS

The mean age of the pediatric patients aged 6-12 years (104 girls, 116 boys) participating in this study was 8.9±1.23 years.

The mean FD of the right condyle was 1.046±0.086 and the mean FD of the left condyle was 1.201±1.205 for the 9-12 age group, while the mean FD of the right condyle was 0.909±0.063 and the mean FD of the left condyle was 0.924±0.08 for the 6-8 age group. It was determined that mean FD values increased with age in both condyles, this rise was statistically significant ($p<0.001$) (**Table 1**).

When the mean FD values were analyzed according to gender, it was detected that the mean condyle FD value of boys was higher than that of girls (**Table 2**).

Table 1. Right and left condyle fractal dimension values between age groups

	9-12 age groups	6-8 age groups	p
Right condyle FD	1.046 ±0.086	0.909 ± 0.063	<0.001*
Left condyle FD	1.201±0.986	0.924±0.08	<0.001*

*p<0.05, FD: Fractal dimension

Table 2. Right and left condyle fractal dimension values between age groups in the same gender

		9-12 age groups (n=54)	6-8 age groups (n=62)	p
Boy	Right condyle FD	1.052±0.08	0.896±0.05	<0.001*
	Left condyle FD	1.364±1.71	0.925±0.09	<0.001*
		9-12 age groups (n=56)	6-8 age groups (n=48)	p
Girl	Right condyle FD	1.041±0.09	0.926±0.06	<0.001*
	Left condyle FD	1.045±0.09	0.944±0.09	<0.001*

*p<0.05, FD: Fractal dimension

In the same age group, there was not any significant difference between the mean FD values of the right and left condyles between genders ($p>0.05$). Additionally, though the mean FD of girls was higher than that of boys in the 6-8 age group and the mean FD of boys was higher than that of girls in the 9-12 age group, this difference is not considered to be significant (**Table 3**).

Table 3. Comparison of right and left condyle fractal dimension between genders in the same age group

	6-8 age groups		
	Girl (n=48)	Boy (n=62)	p
Right condyle FD	0.926±0.06	0.896±0.05	0.081
Left condyle FD	0.944±0.09	0.925±0.09	0.472
	9-12 age groups		
	Girl (n=56)	Boy (n=54)	p
Right condyle FD	1.041±0.09	1.052±0.08	0.629
Left condyle FD	1.045±0.09	1.364±1.71	0.724

*p<0.05, FD: Fractal dimension

DISCUSSION

The ability of the internal structure of viable bones to adapt to the mechanical forces to which it is exposed is one of its most critical features. The trabecular bone architecture is optimized for load-bearing function and the bone enlarges in reaction to the applied mechanical force. The assessment of alterations in bone structure depends on trabecular bone reliant on trabecular bone rather than than cortical bone due to its relatively higher metabolic activity.[8,17] Utilization of FA in radiographs is both trabecular analysis of bone microstructure as well as alveolar bone mineral content of the content.[18,19]

The impacts of many systemic diseases and dental anomalies on the jaw have been researched in the literature using the fractal method. Lower FD values have been correlated with lower bone density.[3,11,14,16,20] Hukuk et al.[21] compared four different methods and found that FA is a distinctive technique especially in the detection of bone changes. Magat et al.[23]

compared FA assessments in DPR, cone-beam computed tomography (CBCT) and recommended using DPRs for FA of trabecular bone due to the higher radiation dose and lower image resolution of CBCT. In FA method using box counting procedure, FD values are between 1 and 2.[13,24] Values closer to 1 represent simple structures with fewer fractals, while values closer to 2 indicate more complex bone structures. Nevertheless, there is no consensus in the literature that trabecular complexity increases as FD values increase. The differences in FD values can be attributed to anatomical variability, the application of different FA techniques and the selection of different jaw regions. In the literature, FD values in FA studies with DPRs of pediatric patients were found to be in the range of 0.62-1.44 on average.[3,11,14,16] There are also studies suggesting that FD increases with age.[25,26] This present study, considering the pediatric patient group, DPRs were used because of their advantages such as low radiation dose, easy applicability and routine use, and the most important finding of essential findings of the study was that the mean condyle FD values increased significantly with age.

In this study, that irradiation was carried out according as to age and weight of the children and the minimal technical differences in DPRs (kVp, exposure time) were insignificant for FA. However, Shourt et al.[26] reported that form and dimension of the ROI can affect the FA data of alveolar bone. In the study by Lee et al.[27] it was determined that linear ROI selection was insufficient to characterize the trabecular structure. Günacar et al.[28] chosen ROIs in the form of circles of 15x15 pixels. In the study by Bulut et al.[3] a 64x64 pixel square ROI was selected in the mandibular condyle. These square ROIs in the trabecular bone have been widely utilized in previous studies.[11,12,14,16] Several important regions of the mandible such as the antegonial notch, condyle and ramus undergo changes depending on age and growth development potential. Enlow et al. reported that the patient's age and dental condition have an effect on these remodeling regions.[24,25] In our study, square ROIs of 40 x40 pixels were used within the cortical borders of the mandibular condyle. However, there was no conclusive result on how this difference in ROI shapes affected the FD.

In previous studies, it has been concluded that the forces transmitted to the mandibular condyle and mandibular bone and the advance in bone consistency of these regions are affected by occlusal forces, the amount of teeth in the mouth and especially the presence of molar teeth.[29,30] Bulut et al.[3] analyzed the trabecular structures of the condyles with FA in the DPRs of 159 children aged 6-13 years and found that FD increased with age, but there was not found difference between right and left FDs except at the age of 6 years. In the current study, it is thought that the masticatory function of children in the 9-12 age group increases more with the change in the existing tooth structure compared to the 6-8 age group, and since bone development increases with age, the FD value is therefore higher in the 9-12 age group. Nevertheless, unlike Bulut et al.[3] there was a statistically significant difference between right and left condyle FDs in all age groups.

Guagnelli et al.[31] reported DXA trabecular bone scores of lumbar and hand bones in healthy childhood aged 4-19 years and resulted that gender showed a poor correlation with trabecular bone score. In their study Bulut et al.[3] found no significant difference between the condyle FDs of children and gender. Kolcakoglu et al.[16] investigated the trabecular bone formation in the mandible in pediatric patients diagnosed with sleep bruxism and in a control group using FA on panoramic radiographs and found that the FDs of patients with sleep bruxism were higher than those of the group without bruxism. However, no correlation was observed between FD values and age and gender. In this study, similar to the literature, there was found no significant difference between the mean FD values of the right and left condyles between the genders in the same age group.

The density of trabecular bone in children is an important factor in orthodontic treatment planning. It has been hypothesized that individuals with more dense trabecular structure may require higher forces to achieve tooth movement. Hence, individual differences in trabecular structure may affect the orthodontic treatment process and the magnitude of the applied force.[32] During orthodontic treatment, decreased bone density can lead to increased tooth movement speed, which may necessitate enhanced anchorage to maintain stability. Though this present study concentrated solely on the condylar region, previous literature emphasizes the importance of cortical bone structure in children for both orthodontic treatment planning and monitoring of growth and development. The density and distribution of the trabecular structure directly affects the efficiency of tooth movement, treatment duration and the magnitude of force required. For this reason, a broader assessment of bone structure may contribute to the development of more precise and individualized approaches for orthodontic and skeletal growth-related treatments.[32,33]

Limitations

Limitations of that study include the fact that the effect of both the preferred chewing place and the current dmft/DMFT status on the anatomy and bone compensation of condyles was not investigated. Furthermore, it has been shown that the mandibular condyle and trabecular structure are affected by changes in hormonal patterns during adolescence and tend to increase gradually with age. In addition, the limitation of the present study is that only the condyle was evaluated. In future studies, it is recommended to include the current dentition status of groups aged 13 years and older in order to evaluate the changes in FD values by examining not only the condyle but also other regions in the study with the effect of both the permanent dentition stage and hormonal changes during adolescence.

CONCLUSION

FA is considered a useful method for detecting and evaluating changes in bone structure. In conclusion, FA of DPR in this study showed that FD values of the trabecular structure of mandibular condyles of children aged 6-12 years improved with age however, there was no difference according to gender.

ETHICAL DECLARATIONS

Ethics Committee Approval

Prior to the study, ethics clearance was received from the Non-interventional Clinical Researches Ethics Board of Ankara Medipol University (Date: 06.06.2023, Decision No: 63).

Informed Consent

Because the study was designed retrospectively, no written informed consent form was obtained from patients.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The authors declared that this study has received no financial support.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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