
Evaluation of the trabecular structure of the mandibular condyles by fractal analysis in patients with different dentofacial skeletal patterns

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Objective: An orthodontic malocclusion may affect the temporomandibular joint structures in susceptible individuals. This study aims to investigate the bone density of the mandibular condyles in patients presenting with different dentofacial skeletal patterns. *Methods:* Panoramic radiographs of 200 randomly selected patients with a skeletal and dental Class I, Class II division 1, Class II division 2 and Class III malocclusion were evaluated. Bone density of the right and left mandibular condyles was measured using fractal analysis. *Results:* No significant difference was detected between the right and left condyles in the various malocclusion groups. However, post-hoc tests showed that Class I patients had significantly higher FD values than Class III and Class II division 1 patients in both right and left condyles following intergroup comparisons. The only significant difference between the genders was detected in the left condyle of Class II division 1 patients, as male patients were found to have significantly higher FD values than females. *Conclusions:* The results of the present study showed that Class II division 1 and Class III patients displayed significantly lower fractal dimension (FD) values in their mandibular condyles when compared to Class I patients. This might be associated with the possible presence of a temporomandibular disorder in Class II division 1 patients which resulted in changes to condylar structure, and with less bone complexity in the temporomandibular joint of older Class III patients likely due to continued condylar growth. (Aust Orthod J 2021; 37: 93 - 99. DOI: 10.21307/aoj-2021-010)

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Introduction

Fractal analysis is used by radiologists as a dataset to differentiate bone morphology.³ The analysis is a statistical structure test that is derived from fractal mathematics and provides a detailed expression of complex shapes and structures.^{1,2}

A fractal dimension (FD) analysis describes the complexity of a structure by measuring similarities within the structure.^{4,5} An FD value increases as the complexity of the structure increases and therefore a high FD value indicates that a structure is more complex.^{4,5} The measurable features of bone are the arrangement of trabeculae, bone thickness and bone

density.⁶ The structure and layout of trabeculae is determined by porosity, bone thickness, and anisotropy.^{7,8} According to Wolff's Law, the internal structure of trabecular bone varies depending on its functional load, which therefore produces changes in bone density and the arrangement of the trabeculae.⁹ Trabecular loss occurs due to increased regional pressure in cases of mechanical overload or when age reduction in bone formation occurs in company with an acceleration in osteoclastic resorption.^{2,10} Analysing trabecular bone structure in order to evaluate bone health has found important application in areas of medicine.¹¹ The trabecular structure of alveolar bone

can be identified by FD since it shows self-similarity when viewed on radiographs at a certain resolution.^{9,12} It has been stated that fractal analysis of the alveolar trabecular bone is a diagnostic tool that can be used for objective analysis.¹³

By applying FD on 2D radiographs previous studies have identified changes in bone morphology^{1,14} and reported that higher fractal measurements indicate a complex bone structure with fewer trabeculae.^{15,16} The most used and suitable method in the application of fractal analysis is the box counting method¹⁴ defined by Russel et al.¹⁷

The temporomandibular joint (TMJ) consists of ligaments, an articular disc, attached masticatory muscles, and an articulation between the condyle and glenoid fossa.⁶ It is well known that the shape and function of the TMJ are closely related and applied functional loads have a significant morphological effect.¹⁸⁻²⁰ Earlier studies identified a significant relationship between occlusal features and joint morphology;¹⁹⁻²² however, additional studies do not support the correlations.²³⁻²⁵ Zhou et al.²⁶ found that the TMJ presented normal structure and function in patients presenting with Class III and Class II division 1 malocclusions, but was clearly structurally and functionally abnormal in Class II division 2 malocclusion cases. While TMJ symptoms and signs are less common in patients presenting with normal occlusions, some occlusal characteristics more commonly associated with a Class II malocclusion group increase the likelihood of TMJ symptoms and signs.²⁷

Therefore, the aim of the present study was to analyse and compare the FD values of the mandibular condyles in Class I, Class II division 1, Class II division 2 and Class III malocclusion subjects by investigating FD values on panoramic radiographs.

Material and methods

Panoramic radiographs taken from Bolu Abant Izzet Baysal University, Faculty of Dentistry, Department of Orthodontics archive were used to investigate the structure of mandibular condyles using fractal analysis. The research was approved by the Bolu Abant Izzet Baysal University Ethical Committee (Decision No: 2020/26).

The dataset included 200 randomly selected patients aged from 12 to 25 years. While orthodontic

dental casts were used for the classification of the malocclusion, and by using the ANB angle, an analysis was conducted on lateral cephalometric radiographs to determine the skeletal classification of the patients. An angle equal to and between 0 and 4 degrees was classified as a skeletal Class I, an ANB angle >4 degrees was classified as a skeletal Class II, while an angle <0 degrees was classified as a skeletal Class III. The patients were divided into four groups by their skeletal pattern and type of malocclusion as Class I (N = 50; 25 female and 25 male; 17.36 ± 3.65 years), Class II division 1 (N = 50; 25 female and 25 male; 15.86 ± 2.47 years), Class II division 2 (N = 50; 25 female and 25 male; 16.3 ± 2.35 years) and Class III (N = 50; 25 female and 25 male; 17.48 ± 3.6 years).

Subjects who had systemic diseases or pathology likely to affect bone metabolism, who presented with signs and symptoms of TMJ disease, who were using drugs that may have effects on bone metabolism or who had previously received orthodontic treatment, were not included. Panoramic radiographs were selected from those that displayed the TMJ visibly and clearly. The panoramic radiographs of all patients were obtained using a Vatech machine (PaX-Uni3D, Yongin, Republic of Korea) while the patient was seated and in natural head position.

FD values were calculated by using ImageJ software version 1.52 (National Institutes of Health, MD, USA). Initially, high-resolution radiographs were converted to .tif format files using IrfanView program (version 4.56, Irfan Skiljan, Wiener Neustadt, Austria).

FD analysis was conducted by using the box-counting method of White and Rudolph.¹⁴ Regions of interest (ROIs) were chosen so that both of the condyles remained within the cortical bone borders. Standardised ROIs were selected as equal sizes of 84 × 84 pixels.⁶ The ROIs were cropped and duplicated (Figure 1). To eliminate brightness variations, ROIs were blurred using a 'Gaussian blur' filter (Figure 2a). A subtraction of the blurred image from the first image was performed (Figure 2b) and a 128 gray value was added to every pixel location in the resulting image to ensure adequate discrimination of the trabecular structure and bone marrow space (Figure 2c). The resulting image was binarised, eroded, dilated, inverted and skeletonised in sequence (Figure 2d, 2e, 2f, 2g, and 2h). The skeletonised image was divided into squares using the 'Fractal Box Count' option in the

'Analyze' menu (Figure 3). By using the box-counting function, boxes of 2, 3, 4, 6, 8, 12, 16, 32 and 64 sized pixels were superimposed on the ROI. For each pixel size, the number of boxes including trabeculae and the total number of boxes were identified. Using the values, a logarithmic scale graph was created. The fractal value that indicated the degree of complexity of the structure was established according to the slope of the line on this graph.

All measurements were conducted by a single, experienced observer. The intra-observer reliability was analysed by re-evaluating 40 randomly selected panoramic images, two weeks after the first assessment.

Statistical analysis

Statistical analyses were made using the SPSS 22.0 software (SPSS Inc, IL, USA). The Student's *t*-test



Figure 1. Panoramic radiograph with selected and duplicated regions of interest (ROI).

was applied for intragroup comparison of fractal dimensions according to side and gender. One-way ANOVA and post-hoc Tukey tests were conducted for the comparison of the FD values between the groups. An intraclass correlation coefficient (ICC) was calculated to evaluate the intra-observer reliability. The level of statistical significance was set at 0.05.

Results

The intra-observer reliability was found to be excellent with an ICC of 0.974 (CI: 0.958–0.984).

Table I displays the intragroup comparisons of fractal dimensions between the right and left condyles. No significant difference was detected between the right and left condyles associated with the Class I, Class II division 1, Class II division 2 and Class III groups.

Intergroup comparisons of the FD values are provided in Table II. Significant differences were found in the right and left condyles between the groups. Post-hoc tests showed that Class I patients had significantly higher FD values compared with Class III and Class II division 1 patients in both right and left condyles.

An intragroup comparison of the fractal dimensions between male and female patients is shown in Table III. The only significant difference between the genders was detected in the left condyle of Class II division 1 patients, as male patients were found to have significantly higher FD values than the females of this group.

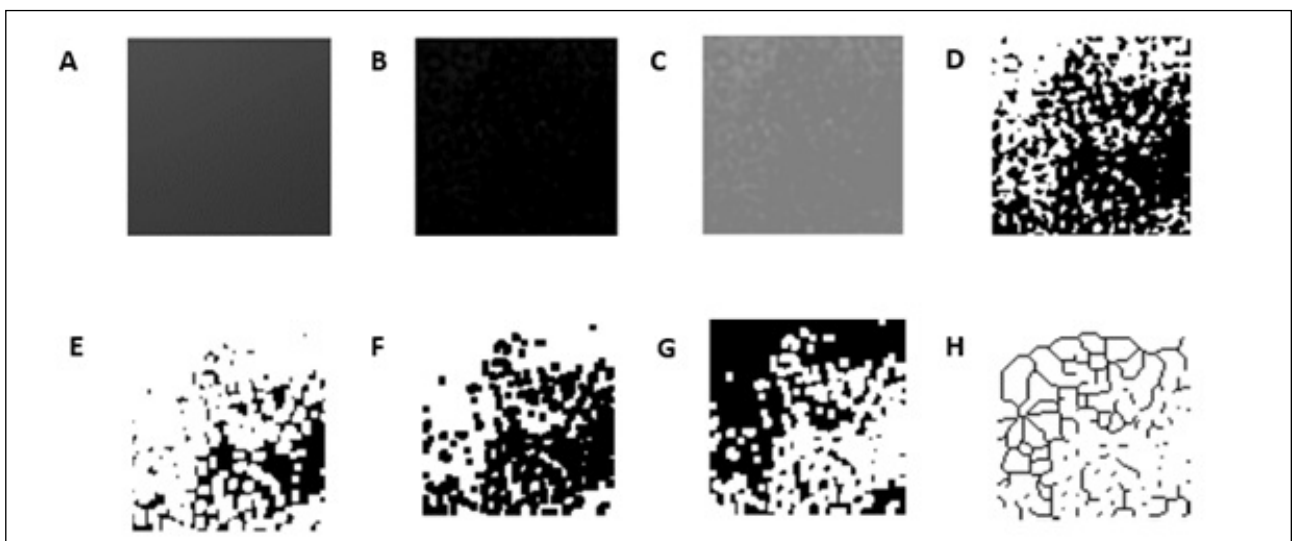


Figure 2. A, Filter of Gaussian blur. B, Subtracted image. C, Addition of 128 gray value. D, Binarisation. E, Erosion. F, Dilatation. G, Inversion. H, Skeletonisation.

Table I. Intragroup comparison of fractal dimensions between right and left condyles in skeletal Class I, II div 1, II div 2 and III groups using Student's *t*-test.

Group	FD (Mean \pm SD)		<i>p</i>
	Right TMJ	Left TMJ	
Class I	1.405 \pm 0.084	1.385 \pm 0.090	0.257
Class II division 1	1.350 \pm 0.092	1.333 \pm 0.088	0.362
Class II division 2	1.375 \pm 0.109	1.346 \pm 0.100	0.174
Class III	1.334 \pm 0.105	1.324 \pm 0.090	0.609

FD: fractal dimension; SD: standard deviation; TMJ: temporomandibular joint.

Table II. Intergroup comparison of fractal dimensions using One-way ANOVA and post-hoc Tukey tests.

Test	Right TMJ		Left TMJ	
One-way ANOVA (<i>p</i> value)	0.002		0.007	
Pairwise comparison by Tukey test (<i>p</i> value)	III	0.002	III	0.005
	II.1	0.026	II.1	0.027
	II.2	0.421	II.2	0.155
	II.2-III	0.157	II.2-III	0.623
	II.1-II.2	0.577	II.1-II.2	0.900
	II.1-III	0.850	II.1-III	0.956

TMJ: temporomandibular joint.

**Figure 3.** Fractal box-counting function.

Discussion

Fractal analysis has been used widely in orthodontics to investigate bone density around impacted canines,²⁸ to evaluate osteoclastic activity induced by orthodontic load,²⁹ to assess the mid-palatal suture to determine activity³⁰ and to identify the risk factors implicated in orthodontic relapse.³¹ A fractal analysis of the mandibular condyles has also attracted attention in patients with temporomandibular disorders⁶ and systemic diseases.³² However, to date, this is the first study to evaluate condylar FD values in patients presenting with different malocclusions.

The use of panoramic radiographs for performing fractal analysis on the mandibular condyles has been accepted as a valid method and is widely used for fractal assessment.^{6,33-35} Additionally, panoramic films require lower radiation doses and are routinely obtained before starting orthodontic treatment. Although cone beam computed tomography (CBCT) provides better anatomic visualisation than panoramic radiographs, it requires higher radiation doses for scan acquisition. Therefore, a CBCT scan was not additionally obtained as a routine record and so panoramic radiographs were used for condylar FD calculation in the present study. A box counting method was used for FD assessment, which is a common and accepted method of fractal analysis.^{1,36}

The intragroup comparisons showed that the FD values were not significantly different between right and left condyles in any of the groups examined in the present study. Although the difference was not significant, FD of the right condyle was higher than the left condyle in each group. It could be hypothesised that the reason for the higher FD values in the right condyle may be associated with the masticatory preference of the patients. In a previous study, the higher FD values were determined to be the result of the physical adaptation of the trabecular bone to high occlusal forces.⁶ In the current study, higher FD

Table III. Intragroup comparison of fractal dimensions between male and female patients using Student's *t*-test.

Group	Side	FD (Mean \pm SD)		<i>p</i>
		Male	Female	
Class I	Right	1.391 \pm 0.076	1.419 \pm 0.091	0.251
	Left	1.368 \pm 0.091	1.401 \pm 0.087	0.201
Class II division 1	Right	1.358 \pm 0.095	1.342 \pm 0.089	0.543
	Left	1.368 \pm 0.072	1.298 \pm 0.089	0.004
Class II division 2	Right	1.394 \pm 0.104	1.354 \pm 0.107	0.181
	Left	1.348 \pm 0.087	1.344 \pm 0.108	0.869
Class III	Right	1.356 \pm 0.097	1.312 \pm 0.110	0.141
	Left	1.346 \pm 0.090	1.302 \pm 0.087	0.083

FD: fractal dimension; SD: standard deviation

values may have been associated with higher occlusion forces during unilateral right side chewing, and the consequent structural anatomic adaptation to these forces on that side. However, as the design of the present study was retrospective and patients were evaluated based on their initial examination information, it was not possible to verify the chewing side preference for all patients. Therefore, further studies are needed to evaluate whether this relationship exists.

The present study showed significant differences in FD values between the groups in both right and left condyles. Post-hoc comparisons indicated that this difference was mainly the result of the differences between Class I – Class III and Class I – Class II division 1 subjects.

The FD values of the Class II division 1 and Class III groups were found to be significantly lower than the Class I group on both sides. The Class I patients had the highest FD values of the groups, followed by Class II division 2, Class II division 1 and Class III patients, in descending order.

By using fractal analysis in panoramic radiographs, Arsan et al.⁶ investigated the degenerative changes in the mandibular condyles of patients with TMJ diseases and found that FD was reduced in patients who suffered more severe degenerative changes.

There is no consensus regarding the relationship between a particular malocclusion and temporomandibular disorders. Egermark et al.³⁷ stated that correlations between signs and symptoms of temporomandibular disorders and different kinds of malocclusion are, in general, non-existent or weak. However, Henrikson et al.²⁷ indicated that subjects with a normal occlusion had fewer signs and symptoms of temporomandibular disorders, while some occlusal characteristics

that were common in the Class II group increased TMJ signs and symptoms. The significantly lower FD values in the Class II division 1 malocclusion group compared with the Class I group in the present study could be attributed to the presence of a possible temporomandibular disorder in Class II patients, which resulted in changes to condylar structure. Although no clinical symptoms and signs of TMJ disorder were observed in the patients included in the present study, the radiologic examination indicated differences in the trabecular structure of the condyles between the different malocclusions. Even if the patients did not have signs and symptoms of a TMJ disorder, the significantly lower FD values in the Class II division 1 patients may alert clinicians to a possible TMJ disorder that may develop in this group.

The loading of the temporomandibular joint was shown to be different between the various types of malocclusions. Subjects with a Class II division 2 malocclusion have been shown to have a greater loading of the temporomandibular joint.^{38,39} The second-highest FD value in the present study was observed in Class II division 2 patients, which could be attributed to the increased loading in these patients and a resultant physical adaptation of the trabecular bone.

The possibility of a temporomandibular disorder in this Class II group may have caused the group to have a lower FD value than the Class I group.

Higher FD values indicate a complex bone structure with denser and less porous trabeculae.³⁵ Most of the growth of the condyle and the glenoid fossa has been shown to be completed early. However, changes in the temporomandibular joint may continue in older patients with Class III relationships.¹⁸ The lowest FD

values in the Class III subjects in the present study might be associated with the less complex bone structure and porous trabeculae of the condyles in these patients who still continue to grow compared with the patients in the other groups. The FD effects of continued condylar growth in older patients with Class III malocclusion could not be investigated, as this study was limited to initial radiographs. Further studies are required on repeated radiographs at staged time intervals to examine the relationship between condylar growth and FD analysis.

The only significant difference in FD values between the genders in the present study was detected in the left condyles of Class II division 1 patients, as females had a lower FD value than males. Although the differences were not significant, female subjects had lower FD values than male subjects in all groups except Class I. The signs and symptoms of temporomandibular disorders have been shown in female patients more frequently than males.⁴⁰ Therefore, the reason for lower FD values in females may be related to their more common temporomandibular disorder experience.

Conclusion

The results of the present study revealed that Class II division 1 and Class III patients displayed significantly lower FD values in their mandibular condyles when compared with Class I patients. Fractal analysis could be used as a method for the differentiation of condylar trabecular morphology in patients presenting with different orthodontic malocclusions.

Conflicts of interest

The authors declare no conflicts of interest.

Financial interests

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