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Comparative fractal analysis of mandibular condyles in temporomandibular disorder and non-temporomandibular disorder patients using cone-beam computed tomography

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ABSTRACT

Introduction: Temporomandibular joint (TMJ) anatomy and microstructure is complex. Multifactorial disorders of the TMJ may affect the musculoskeletal and osseous structures of the joint. It is highly beneficial to detect these changes early in the development of temporomandibular disorders (TMDs) in order to prevent their progression. There are several pathological conditions that can affect the trabecular bone of the mandibular condyle in the TMJ. In order to analyse these changes, it is possible to measure them through the use of fractal dimensional analysis, as they are natural fractals.

Aim & objective: Fractal analysis was used in this study to examine the trabecular pattern of the mandibular condyle, with the objective of assessing fractal dimension changes in mandibular condyles for TMD diagnosis.

Methods: The 120 subjects are divided into two groups, a Control group (non-TMD's-60 each) and a Study group (TMD's-60 each). The study includes participants diagnosed with TMD's according to RDC/TMD Axis -I & Axis-II (Research diagnostic criteria,2014). Cone bean computed Tomography (CBCT) images are captured and converted into JPEG images. A fractal dimensional analysis is performed on the condylar portion of the trabecular bone. With Image J software version 1.51 program (National Institutes of Health, Bethesda, MD @; https://imagej.nih.gov/ij/download.html).

Results: The present study found that subjects with TMD had significantly lower fractal values than controls ($p < 0.001$ on right side and left side $p < 0.021$).

Conclusion: The study group had lower fractal values than the control group. This study in additional hypothesized fractal values for each type of TMD. The use of CBCT can enhance the diagnosis of TMD.

1. Introduction

Temporomandibular disorders (TMDs) are a type of craniofacial pain that can significantly affect an individual's quality of life. These disorders are characterized by masticatory dysfunction, with clinical signs and symptoms categorized based on the structures involved.[1,2] TMDs encompass both muscle and temporomandibular joint (TMJ) disorders, as classified by the American Academy of Orofacial Pain into masticatory muscle disorders and articular disorders.[3] Early detection of TMDs is crucial to prevent their progression into chronic conditions. However, clinical examination alone is insufficient for a comprehensive assessment of the TMJ's osseous and soft tissue components. Imaging techniques play a vital role in enhancing the diagnostic process.[4]

Advancements in imaging technology have significantly improved the diagnosis and prognosis of TMDs. Recent studies, such as those by Gaalaas et al.[5] and Arsan et al.,[6] have emphasized the importance of analysing the trabecular bone microarchitecture of the mandibular condyle, a region with higher metabolic activity compared to the cortical portion of the alveolar bone. The trabecular bone in the mandibular condyle plays a critical role in the temporomandibular joint's function and is closely linked to various metabolic and pathological processes that influence TMDs.[7–9]

The trabecular microarchitecture is a complex structure characterized as a natural fractal, consisting of self-similar geometric shapes, such

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as curves, lines, dots, and surfaces, that are independent of one another.[10] Fractal dimensional analysis (FDA), which quantifies these patterns through the fractal dimension (FD), has emerged as a valuable tool in evaluating the condition of trabecular bone. While panoramic radiographs provide broad area coverage for jawbone evaluation, their low resolution often results in missed early disease-related changes in trabecular bone.[11] This limitation can be addressed with three-dimensional cone-beam computed tomography (CBCT), which offers a larger field of view, higher diagnostic resolution, and adjustable image parameters for a more detailed study of the trabecular bone.

Cone-beam computed tomography (CBCT) has proven particularly useful for studying the microarchitecture of the mandibular condyle. It provides advantages such as reduced radiation exposure and enhanced diagnostic imaging compared to traditional computed tomography (CT).[12] CBCT scans allow for the evaluation of trabecular patterns in the mandibular condyle using fractal analysis, which measures the complexity and irregularity of bone structure.[6] This approach helps identify subtle changes in the trabecular bone that may not be visible through conventional methods, offering insights into both TMD and non-TMD conditions.

FDA has shown potential as a diagnostic tool for assessing the trabecular patterns of the mandibular condyle in CBCT scans. It is hypothesized that a significant difference exists in the fractal dimension of trabecular patterns between TMD and non-TMD groups, with the TMD group expected to exhibit lower fractal dimension values, reflecting altered bone architecture. The null hypothesis for this study is that there is no significant difference in the fractal dimension values between TMD and non-TMD groups. This study aims to explore the relationship between fractal dimensions and TMDs, enhancing our understanding of how these disorders impact mandibular bone structure.

2. Aims

To evaluate the changes in condylar trabeculae using fractal analysis on CBCT scans in temporomandibular disorder patients.

To compare the trabecular changes in the control (non-TMDs) and study group with temporomandibular disorder (TMDs).

3. Methodology

3.1. Study design

The subjects for this study were selected from G. Pulla Reddy Dental College and Hospital, Kurnool, Andhra Pradesh, Department of Oral Medicine and Radiology. Participants were divided into two groups: a control group (non-TMDs) consisting of 60 subjects, and a study group (TMDs) with 60 subjects. Patients (study group) were selected based on the presence of complaints related to temporomandibular disorder (TMD), and diagnoses were made in accordance with the TMD Research Diagnostic Criteria (RDC/TMD,2014). Control group consists of subjects without TMD symptoms. The study adhered to the World Medical Association's Helsinki Declaration (2013) and was approved by the Institutional Ethical Committee (GPRDCH/IEC/2018/012).

Group A consisted of participants younger than 20 years, Group B included those between the ages of 20 and 40, and Group C comprised individuals over 40 years of age. The fractal dimensions (FD) of these groups were compared, taking into account age and sex differences.

To calculate the sample size for a study involving Fractal Dimensional Analysis (FDA) in temporomandibular disorders (TMDs) and non-TMDs with a focus on trabecular patterns in mandibular condyles using CBCT (Cone Beam Computed Tomography), the appropriate sample size formula will depend on several factors. Since FDA typically involves quantitative data, here we will consider a formula suitable for comparing two independent groups (TMD and non-TMD groups) using a parametric approach (such as *t*-test or equivalent) to compare fractal dimensions.

For comparing two independent groups with continuous data, the formula is as follows:

$$n = \left(Z_{a/2} + Z\beta\right)^2 \cdot \left(2\sigma^2\right)$$

Where.

- n = sample size per group (TMD and Non-TMD)
- Zα/2 = Z-value corresponding to the significance level α (e.g., 1.96 for α = 0.05)
- Zβ = Z-value corresponding to the desired power (e.g., 0.84 for 80 % power)
- σ = estimated standard deviation of the fractal dimension values (σ = 0.3)
- d = expected difference in fractal dimensions (Cohen effect size = 0.3)

Using the formula:

$$n = (7.84).(0.18) \,/\, (0.3)^2 = 1.4112/0.09 = 15.68$$

Thus, for each group (TMD and Non-TMD), you would need at least **16 samples** for detecting a medium effect size with 80 % power.

3.2. Inclusion criteria

The study group consisted of individuals diagnosed with TMD symptoms based on the Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) Axis-I and Axis-II (2014).[1] The control group included participants without a history of TMD symptoms.

3.3. Exclusion criteria

Individuals with conditions known to interfere with bone turnover, or those taking medications that could alter bone metabolism, were excluded from the study. For example, individuals with osteoporosis, hyperparathyroidism, or Paget's disease, as well as those on medications like bisphosphonates or corticosteroids, were excluded, as these factors can significantly impact the trabecular bone structure and fractal analysis results.[13]

3.4. Clinical & radiographic evaluation

A clinical examination was performed according to the RDC/TMD diagnostic algorithms (2014).[2] Symptoms and observations were recorded on a standardized form, which includes a detailed questionnaire based on Axis-I of the RDC/TMD. A bimanual and bidigital palpation of the temporomandibular joint (TMJ) was performed, and the following were assessed: mouth opening patterns (such as deviations or deflections), pain during unassisted and assisted opening/closing, lateral and protrusive jaw movements, and any joint sounds or crepitus. To confirm the presence of crepitus and joint sounds, auscultation was also performed. Tenderness was assessed by applying standardized pressure with the index and third fingers. Extraoral muscles were palpated with 2 lbs. of pressure (1 lb. for the posterior mandibular and submandibular regions), and intraoral muscles were palpated with 1 lb. of pressure.

The RDC/TMD diagnostic algorithm was used to classify the study group into various subtypes: Group I (Ia. Myofascial pain, Ib. Myofascial pain with limited opening), Group II (IIa. Disc Displacement with reduction, IIb. Disc Displacement without reduction with limited opening, IIc. Disc Displacement without reduction without limited opening), and Group III (IIIa. Arthralgia, IIIb. Osteoarthritis, IIIc. Osteoarthrosis).[14]

The Carestream 9100 CBCT unit (Carestream Dental, Asia LLC.2015 manufacturer: Atlanta, GA, USA) was utilized to acquire high-resolution

CBCT scans of the right and left TMJs in a closed-mouth and relaxed position (The term 'relaxed position' refers to the natural, unstrained position of the mandible, where the teeth are not in contact, and the muscles surrounding the temporomandibular joint (TMJ) are in their neutral state. This position allows for accurate imaging of the condylar morphology without muscle contraction or occlusal interference).[15] Imaging was performed at 120 kVp and 3.8 mA, with a scan time of less than 12seconds and a field of view (FOV) of 8 × 8 cm which allowed for the imaging of one TMJ at a time. Consequently, bilateral TMJ imaging was achieved by performing two consecutive scans: one for the right condyle and one for the left condyle. The condyle, articular fossa, and eminence of the TMJ were aligned in the sagittal plane in multiplanar reconstructed images (coronal and axial). The CBCT scans were reconstructed using parallel and perpendicular planes to create the image volume. The images were analysed in the axial, sagittal, and coronal planes to ensure comprehensive assessment of the condylar structure. The coronal slice from the axial view was specifically chosen for analysis, as the condyle is widest at the mediolateral side in this plane. The region of interest (ROIs) are selected as suggested by previous studies.[6,15] The voxel size of the images was [0.3mm], which ensured sufficient resolution for accurate measurement and evaluation of the trabecular bone patterns in the mandibular condyles.

CBCT images (CS imaging software, 2015) obtained were converted into DICOM (Digital Imaging and Communications in Medicine) format and subsequently saved as JPEG images.[6] The images were examined on LED backlit LCD laptop screen with a HD resolution(1280x1024) in a dimly lit room. To assess intra-observer reliability, one observer reviewed the FD twice within a one-week period. For inter-observer reliability, the analyses conducted by two independent observers were compared. Both observers were experienced oral and maxillofacial radiologists, each having more than four years of expertise in interpreting CBCT scans.[16]

3.5. Fractal dimensional analysis

The method for fractal analysis, as described by White and Rudolph,[17] was employed to analyse the JPEG images. These images were imported into ImageJ software (version 1.51, National Institutes of Health, Bethesda, MD; http://imagej.nih.gov/ij/download.html) for fractal dimensional analysis. A 64x64 pixel area from the center of the condyle, excluding cortical bone, was selected as the region of interest (ROI). A Gaussian filter was applied to the image to reduce brightness variations caused by the different thicknesses of bone and soft tissue. The filtered image was then subtracted from the original, and a threshold of 128 was applied to differentiate and outline bone marrow spaces and trabeculae. To minimize noise, the binarized image underwent erosion and dilation processes. Finally, the image was inverted and skeletonized to visualize the trabeculae and bone marrow (Fig. 2)

Fractal box-counting was employed to quantify the final image using ImageJ software. The fractal dimension (FD) was calculated for each skeletonized image using the box-counting method,[18] also known as the Minkowski-Bouligand dimension. This method is based on the relationship between various box sizes and the corresponding number of boxes needed to cover the complex regions of the image. The analysis was conducted with equal-sized square tiles, with box sizes of 2, 3, 4, 6, 8, 12, 16, 32, and 64 pixels. A logarithmic scale was used to plot the number of boxes and the trabecular boundaries against the box sizes. The fractal dimension of the trabecular structure in the condyle was then determined from the slope of the data points, with representative fractal box-counting graphs shown in Fig. 3.

In the study group, degenerative osseous changes in the condyle were assessed using the Muir and Goss method (see Fig. 1). Six types of degenerative changes were identified, including flattening, concavities, erosion, sclerosis, osteophytes, and subchondral cysts. Each type of change was graded as follows: 0 for no demonstrable changes, 1 for mild changes, and 2 for gross changes.[4]

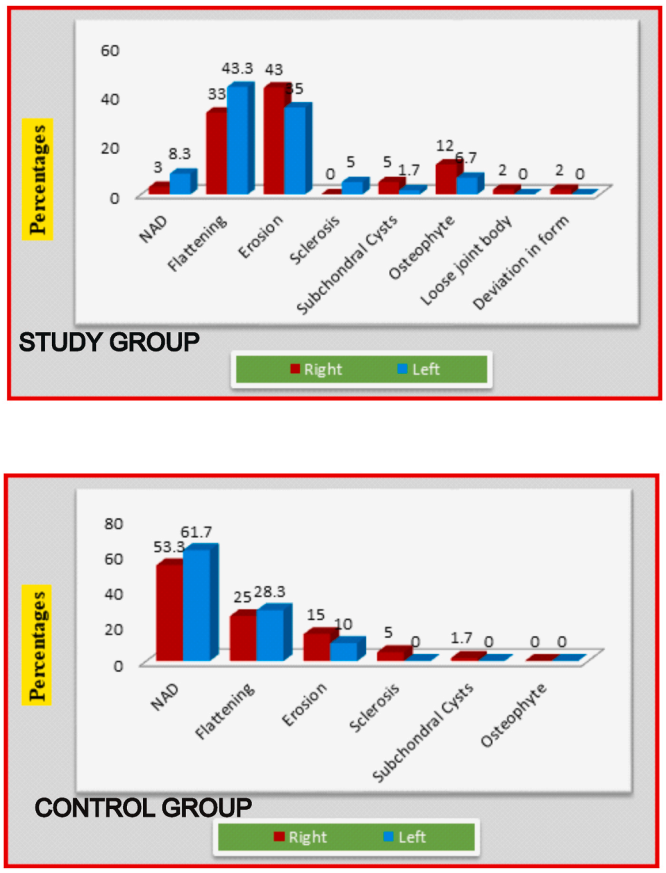

Fig. 1. Graphical representation of Condyle osseous changes among study and control group.

3.6. Statistical analyses

The parameters were tabulated and then subjected for statistical analysis. The analysis was done by using SPSS (IBM, Statistical Package for the Social Science, software version 23). Independent sample 't' test is carried out for the sample analysis. Normality was assessed using tests such as the Shapiro-Wilk test or by visualizing histograms and Q-Q plots. Homogeneity of variances was checked using Levene's test. One-way Anova variance test is carried out for non-parametric sample distribution (Kruskal Wallis H-test value performed). Anova variance test is done to correlate the degenerative changes with fractal analysis. A "p" value is set at <0.05 was considered as statistically significant. Chi square test is done to find the correlation between different variants.

4. Results

In this study, changes in the trabecular bone pattern of patients suffering from Temporomandibular Disorders (TMDs) were assessed by calculating the fractal dimension of CBCT images and comparing them to the values of healthy controls (120 subjects).

The study group included patients who presented to the Department of Oral Medicine and Radiology with symptoms such as pain and discomfort, and were diagnosed with various TMDs. The control group consisted of individuals without any TMD symptoms. The age and sex distributions of the study group and control group are presented in Table 1. The one-way Anova variance for distribution of sample is carried out (Kruskal-Wallis H-test was successfully performed for statistically significant distribution of sample).

Regarding the TMD subtypes, Myofascial pain was most prevalent in Group A, with 67 % of individuals in this group diagnosed with it. This was followed by disc displacement with reduction in the left TMJ (14 %)

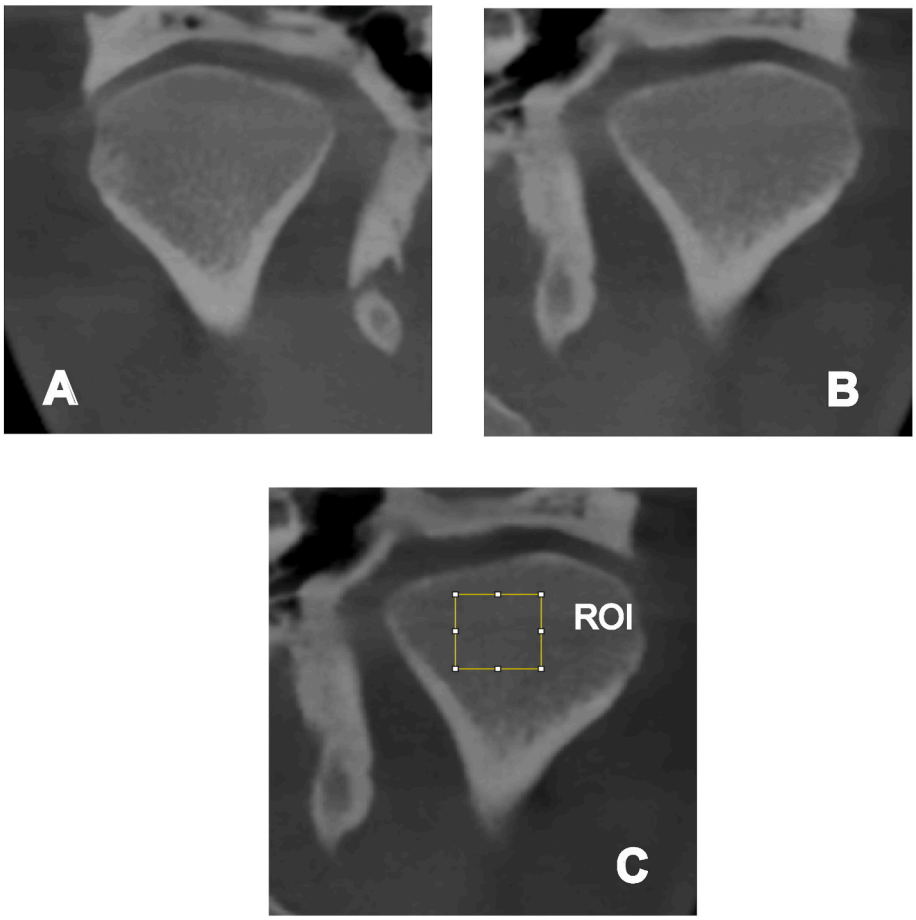

Fig. 2. Bilateral TMJ coronal section captures a. Right TMJ b. Left TMJ c. ROI (region of interest) selection in Image J version 1.51 (National Institutes of Health, Bethesda, MD; https://imagej.nih.gov/ij/download.html).

and right TMJ (9 %). In Group B, disc displacement with reduction in the right TMJ was most common (25 %), followed by Myofascial pain (21 %). In Group C, Myofascial pain and unilateral osteoarthritis of both the right and left TMJ were observed with equal frequency (20 % each) (see Table 1).

When analysing gender differences, 39 % of females had Myofascial pain, followed by disc displacement with reduction on the left side (16 %) and right side (11 %). In males, Myofascial pain was more prevalent (32 %), followed by disc displacement with reduction on the right side (16 %) and osteoarthritis of the left TMJ (12 %). Females were found to be more likely to suffer from TMDs than males, as shown in Table 1.

The condylar osseous changes in both the study and control groups are shown in Fig. 1. In both groups, flattening was the most common degenerative change, followed by erosion. However, the frequency of flattening (43.3 %) and erosion (35 %) was higher in the study group than in the control group. In the control group, the majority of subjects exhibited no degenerative changes (53.3 % on the right side and 61.7 % on the left side. (graphical representation of these mandible condylar Osseous changes are represented in Fig. 1).

Table 2 signifies these degenerative condylar changes in study group and their comparisons with fractal analysis which showed a significance as grade of degeneration change according to Muir and Goss method.[4] There statistically significant relationship seen on right side of the mandible condyle (p value = 0.029).

Comparison of fractal dimension values between the study and control groups, broken down by age, sex, and side of the condyle (right and left TMJ), is presented in Table 3. Where age and sex does not show any statistical significance (chi square test for sex distribution The p-value (0.0849)). Statistically significant correlations were observed between the fractal values of the study and control groups on both the right and left sides of the condyle.

Table 4 provides a detailed overview of the hypothesized constant values used for the diagnosis of temporomandibular disorders (TMDs) in both the healthy group and the study group affected by TMDs. These values represent the fractal dimensions, which serve as quantitative indicators of changes in the trabecular bone structures within the condylar regions. In the context of each diagnostic category, the fractal value reflects the alterations in the microarchitecture of the trabecular bone caused by the presence of TMDs. The comparison between the healthy and TMD groups highlights the extent of structural changes in the condylar regions, aiding in the differentiation and understanding of TMD-related bone modifications.

5. Discussion

In this study, we aimed to evaluate the fractal analysis of mandibular condyles in patients diagnosed with temporomandibular disorders (TMDs) and in individuals without TMDs. Specifically, we sought to compare the trabecular patterns in the mandibular condyles between these two groups and assess whether fractal dimension (FD) can serve as a reliable diagnostic marker for TMDs. Additionally, we aimed to investigate the relationship between the fractal patterns and the clinical characteristics of TMDs, such as myofascial pain, disc displacement, and osteoarthritis.

Several studies have demonstrated that TMD symptoms often begin in children and adolescents, and if left untreated, these symptoms may progress to chronic conditions, affecting both quality of life and overall health. Based on this prevalence, the participants in our study were

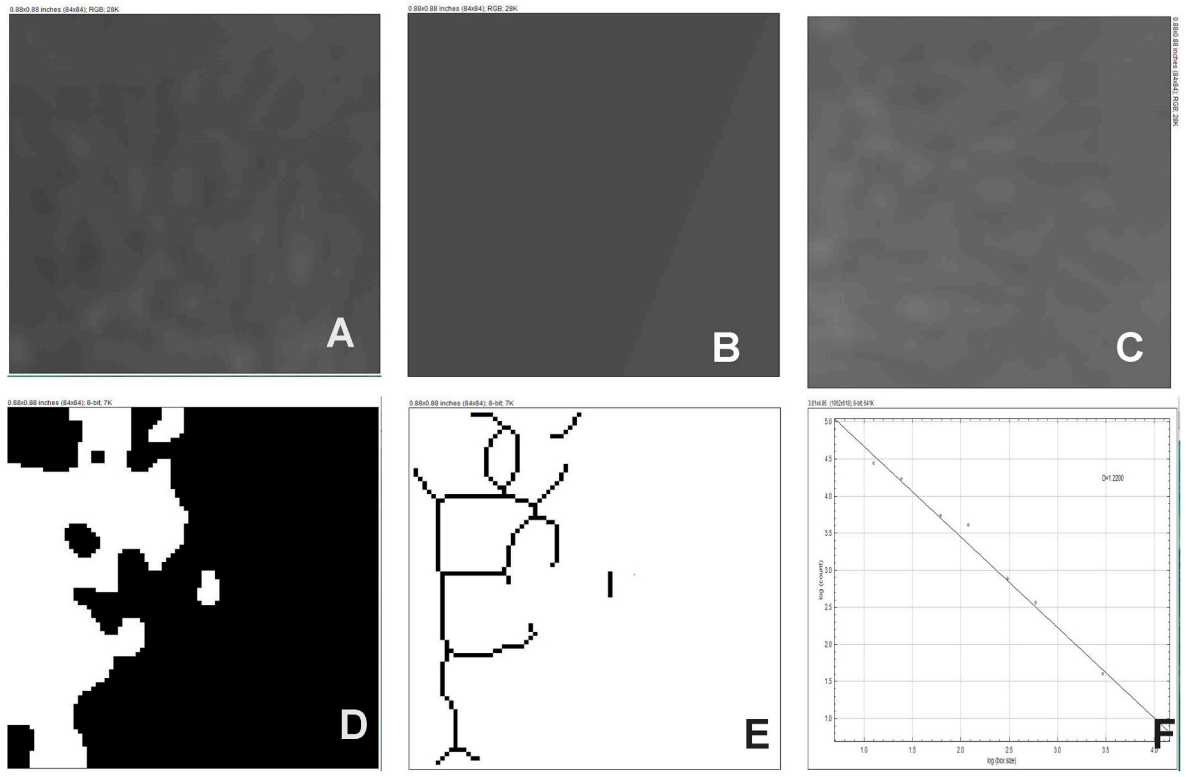

Fig. 3. Image Processing (a) ROI selection-right TMJ (b) Gaussian blur (c) Add (25bit) (d) Binarization (e) Skeletonization (f) Logarithmic scale graph for fractal value.

Table 1
Percentage of Distribution of age groups, Males and Females in TMD Diagnosis.

Study group	Group A(<20 years)			Group B(20–40 years)			Group C(>40 years)			Males (%)			Females (%)		
	Right TMJ	Left TMJ	Both	Right TMJ	Left TMJ	Both	Right TMJ	Left TMJ	Both	Right TMJ	Left TMJ	Both	Right TMJ	Left TMJ	Both
Myofascial pain (Ia)	0	0	67	0	0	21.0	0	0	20.0	0	0	32.0	0	0	39.0
Myofascial pain with limited opening (Ib)	0	0	0	0	0	4	0	0	0	0	0	4.0	0	0	3.0
Disc displacement with reduction of TMJ(IIa)	0	14.0	0	25.0	14.0	0	10.0	10.0	0	4.0	8.0	0	11.0	16.0	0
Disc displacement without reduction of TMJ(IIb)	0	1.7	0	0	0	0	0	0	0	0	4.0	0	0	4.0	0
Disc displacement without reduction with limited opening (IIc)	0	0	0	4	0	0	0	0	0	0	4.0	0	0	0	0
Arthralgia of TMJ(IIIa)	0	5.0	0	7.0	14.0	0	0	10.0	0	0	16.0	8.0	0	8.0	11.0
Osteoarthritis of TMJ(IIIb)	0	0	0	0	7	4.0	20.0	20.0	10.0	8.0	20.0	12.0	3.0	3.0	6.0
Total %										40 %			60 %		

categorized into three distinct age groups[19–21] allowing us to examine potential age-related differences in mandibular condyle fractal patterns. To diagnose TMDs, we utilized the **Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD, 2014)**[2,14] Our results indicated that **myofascial pain** was the most common condition, accounting for 35 % of cases in the study group, followed by **disc displacement with reduction**, **arthralgia**, and **osteoarthritis**. These findings align with those reported by D. Manfredini et al.,[22] who observed that 50.2 % of patients had group I disorders (myofascial pain), 38.6 % had group II disorders (disc displacement), and 50.2 % had group III disorders (arthralgia, osteoarthritis, osteoarthrosis). Similarly, studies by List T et al.[23] and Yap Au et al.[24] in Asian populations also reported comparable trends, with myofascial pain being the most prevalent condition among the majority of TMD cases. In our study, we observed that the majority of patients under 20 years of age were diagnosed with myofascial pain (67 %), followed by disc displacement with reduction (23 %). Fewer individuals (5 %) were diagnosed with arthralgia and disc displacement. These findings are consistent with those of Al-Khotani A et al.,[25] who found that myofascial pain was the most common diagnosis in adolescents (15 %), followed by disc displacement with reduction, arthralgia, and osteoarthrosis. Bertoli FM et al.[26] also observed that 34.9 % of Brazilian adolescents and young adults suffer from TMD, with myofascial pain being the most frequent (10.3 %), followed by disc displacements and reductions (8 %) and arthralgia (3.5 %).

In individuals aged 20–40 years, disc displacement was the most common diagnosis (39 %), followed by myofascial pain (21 %), arthralgia (21 %), and osteoarthritis (11 %). Among the elderly, osteoarthritis (30 %), myofascial pain (20 %), and disc displacement (20 %) were prevalent. These results align with the findings of Manfredini D

Table 2
Fractal values in Study and control compared in age groups, sex, right and left condyle of TMJ.

Parameters	Frequency	Mean ± SD	Std error	t Value	P Value
STUDY GROUP					
Right condyle					
Group A	21	1.32 ± 0.13	0.02	1.009	0.371**
Group B	27	1.37 ± 0.10	0.01		
Group C	12	1.37 ± 0.12	0.03		
Males	24	1.25 ± 0.16	0.03	0.487	0.628**
Females	36	1.26 ± 0.11	0.01		
Left condyle					
Group A	21	1.32 ± 0.13	0.03	0.055	0.946**
Group B	27	1.32 ± 0.13	0.02		
Group C	12	1.34 ± 0.09	0.02		
Males	24	1.26 ± 0.13	0.02	1.025	0.310**
Females	36	1.29 ± 0.10	0.01		
CONTROL GROUP					
RIGHT					
Group A	20	1.33 ± 0.11	0.02	2.401	0.100**
Group B	24	1.39 ± 0.09	0.01		
Group C	16	1.32 ± 0.14	0.03		
Males	25	1.39 ± 0.06	0.01	0.480	0.635**
Females	35	1.33 ± 0.14	0.02		
LEFT					
Group A	20	1.33 ± 0.12	0.02	0.104	0.902**
Group B	24	1.33 ± 0.13	0.02		
Group C	16	1.32 ± 0.12	0.03		
Males	25	1.34 ± 0.12	0.02	3.256	0.002*
Females	35	1.32 ± 0.12	0.02		
Right Condyle					
Study	60	1.26 ± 0.13	0.097	4.235	<0.001*
Control	60	1.35 ± 0.11			
Left Condyle					
Study	60	1.28 ± 0.11	0.051	2.347	0.021*
Control	60	1.33 ± 0.12			

Independent sample 't' Test and chi square test performed for sex distribution: *P < 0.05 (significant), **p > 0.05 (Not significant).

Table 3
Changes in fractal dimension in relation to degenerative changes among study group.

Parameters	No of Patients	Mean ± SD	Std error	F Value	P Value
Right					
0	3	1.36 ± 0.08	0.04	2.569	0.029*
1	20	1.25 ± 0.13	0.02		
2	21	1.29 ± 0.12	0.02		
3[a]	10	1.23 ± 0.10	0.03		
4[a]	3	1.10 ± 0.16	0.09		
5	2	1.32 ± 0.12	0.09		
6	0	–	–		
7	0	–	–		
8[a]	1	0.93	–		
Left					
0	5	1.24 ± 0.10	0.04	0.635	0.596**
1	22	1.28 ± 0.11	0.02		
2	20	1.26 ± 0.13	0.02		
3[a]	13	1.31 ± 0.09	0.02		

ANOVA test: *P < 0.05 (significant), **p > 0.05 (Not significant).
[a] Degeneration grade (0 = no changes, 1 = mild changes&2 = gross changes) more than 2 values indicates sum of two or more osseous changes according to Muir and Goss.[8]

et al.,[27] who analysed age-related trends in TMDs, showing that muscle disorders and disc displacements were more common in younger patients, while osteoarthritis and arthralgia became more prevalent as age increased.

Female patients represented the majority (60 %) of those diagnosed with TMDs in our study. This finding is consistent with research by Manfredini D et al.,[27] who observed that 73 % of TMD patients were female, as well as by Chaurasia A et al.,[28] who reported a similar female-to-male ratio in their cohort of 1009 patients aged 6–80 years.

Table 4
Hypothesized Fractal values for diagnosis.

	Right		Left	
	No of TMJ	FD Value	No of TMJ	FD Value
Healthy	60	1.38	60	1.35
Myofascial pain (Ia)	22	1.26	22	1.27
Myofascial pain with limited opening (I b)	4	1.28	4	1.27
Disc displacement with reduction of TMJ (IIa)	17	1.29	17	1.27
Disc displacement without reduction of TMJ(IIb)	2	1.22	2	1.16
Disc displacement without reduction with limited opening (II c)	4	1.21	0	1.34
Arthralgia (IIIa)	10	1.24	10	1.33
Osteoarthritis (III b)	9	1.20	9	1.28

Regarding condylar osseous changes observed on CBCT, flattening and erosion were the most common changes seen in both the study and control groups. Specifically, in the study group, flattening was observed in 33 % of cases on the right side (R) and 43.3 % on the left side (L), while erosion was seen in 46 % on the right side and 35 % on the left side. In the control group, most individuals exhibited no degenerative changes (53.3 % R, 61.7 % L), with flattening (25 % R, 28.3 % L) and erosion (15 % R, 10 % L) being the next most common changes. These findings suggest that degenerative changes in the condyle are more common in TMD patients, particularly flattening and erosion, which are typically associated with advanced age. Talaat W et al.[29] also found a higher prevalence of condylar irregularities in TMD patients (41.3 %) compared to controls (15.12 %), which is consistent with our results.

Degenerative changes in the mandibular condyle, including flattening, erosion, and osteophytes, were particularly prevalent in patients with TMD, supporting the notion that such changes are associated with the pathophysiology of TMD. Alves N et al.[30] found similar results, with 56.26 % of TMD patients showing sclerosis, 52 % flattening, and 52 % erosion on CBCT scans. These findings further support the notion that TMD patients experience degenerative changes as they age, leading to a progressive increase in osteoarthritic changes in the mandibular condyle. Dermilap KO et al.[13] also reported similar findings, noting that patients taking bisphosphonates had higher fractal dimension (FD) values than controls, indicating differences in bone turnover that could affect the results of fractal analysis.

Our study found a significant correlation between fractal dimension (FD) values and the presence of degenerative changes in the TMJ, with the study group (TMD patients) showing lower FD values than the control group. This is consistent with the findings of Bayrak S et al.,[31] Belgin CA et al.[32] reported significantly lower FD values in patients with TMD compared to healthy controls. Similar findings are noticed by Kumar SS et al.[33] inreview of the literature. The decreased FD values in the study group suggest that degenerative changes in the condyle reduce its structural complexity, which can be assessed using fractal analysis.

TMJ morphological changes are clinically significant due to constant mechanical and biochemical stress. In TMD, early evaluation of bone function through trabecular patterns can help monitor disease progression. Our study found lower fractal values in TMD patients, particularly on the right side, which aligns with clinical observations. Further research is needed to confirm these findings, standardize fractal values for TMD subtypes, and validate results through randomized longitudinal studies.

6. Limitations

While our study supports the potential use of fractal analysis as a diagnostic tool for TMDs, especially for detecting subtle bone changes, it is important to acknowledge certain limitations. For instance,

confounding factors such as age, gender, and medication use (e.g., corticosteroids or bisphosphonates) could influence the fractal values and may need to be controlled for in future studies. Additionally, the lack of longitudinal data in our study limits the ability to assess the long-term reliability and predictive value of fractal analysis for TMD diagnosis. Despite these limitations, our study demonstrates that CBCT and fractal analysis can be valuable tools for identifying degenerative changes in the TMJ, offering a non-invasive method for early diagnosis and monitoring of TMD progression.

Ethical clearance

The study complied with the World Medical Association's Helsinki Declaration (2013) and received approval from the Institutional Ethical Committee (GPRDCH/IEC/2018/012.

Research ethics

We further confirm that any aspect of the work covered in this manuscript that has involved human patients has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.

Intellectual property

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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