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FRACTALS AND LACUNARITY ANALYSIS OF BONE TRABECULAR PATTERN AROUND MANDIBULAR THIRD MOLARS USING CBCT SCAN -A RETROSPECTIVE STUDY

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Abstract:

AIM: To assess the bone trabecular pattern around mandibular third molars (MM3) using Fractals and lacunarity analysis.

OBJECTIVE: To measure bone surface area (BSA), bone marrow surface area (BMSA), bone fractal dimension (BFD), bone marrow fractal dimension (BMFD) & lacunarity of MM3 using ImageJ software & to compare among the groups of MM3.

MATERIALS AND METHODS: This study was a retrospective cone-beam computed tomography (CBCT) study. A total of 105 CBCT images, divided into Group A: 35 impacted, Group B: 35 developing & Group C: 35 functional MM3 were analysed. Three regions of interest (ROI) of size 45×45-pixel were cropped around MM3 using Microsoft office picture manager software. The BSA, BMSA, BFD, BMFD & lacunarity were measured using ImageJ software.

RESULT The mean BSA & BFD values were greater in impacted MM3 (1438.78±39mm^2 & 1.4243±.018) followed by developing (1369.39±95mm^2 & 1.3526±.10) & functional MM3 (1273.31±29 mm^2 & 1.2386±.032) and the difference was statistically significant (P<o.o5) showing bone surface is higher and bone marrow surface is lower in impacted MM3 which is vice versa in Functional MM3. Lacunarity was higher in functional molars (0.6017±0.012) indicating

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larger lacunae space followed by developing (0.5311±.058) and impacted molars (0.4857±0.018) with smaller gaps or lacunae space inside the trabecular bone.
CONCLUSION: From the present study, the density of trabecular bone around MM3 by fractals and lacunarity analysis method demonstrate that there is an increased bone surface in impacted molars compared to functional molars. Therefore, speculated that bone density may play a local etiologic role in impaction of tooth.
KEYWORDS: fractals, lacunarity, bone trabecular pattern, mandibular third molars, CBCT

INTRODUCTION:

Fractal is a mathematical shape derived from the Latin word "fractus," meaning "fractured" or "broken" [1]. Self-similarity, which refers to an endless nesting of structure on all scales when a substructure resembles a superstructure in the same form, is an important characteristic feature of fractals. Basically, a fractal is a pattern that repeats indefinitely, and every fragment of a fractal, no matter how zoomed in or out, closely resembles the entire image. Fractal analysis is the technique for the evaluation of these fractal characteristics by delineating complex shapes and structural patterns and transforming it into a numerical value as fractal dimension (FD) [1,2]. Higher FD values indicates complexity, whereas lower FD indicates simplicity of the analyzed structure.

The most significant use of fractals in dentistry is for evaluating bone structure. This is because fractal analysis is a quantitative method of measuring trabecular structure, and the oral environment provides a testing ground for the evaluation of bone quality [1]. A complex network of trabeculae that vary in thickness and direction makes up trabecular alveolar bone [2]. Their textures may differ as a result of the varied occlusal stresses that the teeth exert on the jaw bones during mastication.

Lacunarity is a measurement of how the fractals fill the space and describes the spatial distribution of lacunae or gaps [3]. Low lacunarity is due to the uniformity of gap sizes i.e., geometric objects are homogeneous whereas high lacunarity indicating heterogenous objects. So lacunarity is considered as a scale dependent indicator of heterogeneity or homogeneity of an object [4].

Of all the teeth in the dental arch, the mandibular third molar (MM3) is by far the most frequently impacted tooth. A number of issues, including mechanical obstructions (such cysts, tumors, hyperplasia, and local infections), trauma, vitamin deficiencies, malnutrition, hormonal imbalances, syndromes and various dental and mandibular morphologic characteristics like the result of inadequate interproximal reduction due to lack of forwarding movement of dentition, insufficient space between the second molar and the anterior border of the ramus and the vertical direction of condylar growth may result in MM3 impaction. In addition to these components, studies have also documented that shorter mandibular length, increased crown size, third molar angulation and gonial angle have all been linked as an etiologic factor for mandibular third molar

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impaction but not the trabecular structure of the mandible [5].

Various imaging techniques like periapical radiography, occlusal, panoramic radiography and CBCT has been used for determining the impaction of MM3. Recent studies have used CBCT-based fractal-dimension analysis to measure changes in bone microarchitecture [6]. It has been established that FD analysis is beneficial for assessing the trabecular architecture on panoramic and periapical images. But only a few research have demonstrated how FD can be used for examination of CBCT images. The advantages of CBCT include three-dimensional image, a much lower radiation dose, less image distortion, less superimposition, higher resolution when compared to other conventional two-dimension imaging modalities [7]. In CBCT, Grayscale measurements of bone density may differ between centers depending on the equipment utilized and the locations used. To get around this, FD analysis might be a more trustworthy approach than the standard Hounsfield unit analysis [6].
With this background, purpose of this study's use of fractals and lacunarity analysis was to determine the bone trabeculation morphology as assessed by bone surface area and FD around MM3 using CBCT images was a probable cause of MM3 impaction.

MATERIALS AND METHODS:

STUDY DESIGN:

The present study was conducted retrospectively in the Department of Oral Medicine and Radiology, Vivekanandha dental college for women, Tiruchengode, Namakkal district, Tamil Nadu.The study attained the ethical clearance from the Institutional review board (VDCW/IEC/361/2023). A total of 105 standardized CBCT images that met the criteria were collected from various centers of Tamil Nadu and Vivekanandha dental college for women which is further divided equally into three groups:
Group A: 35 Impacted MM3
Group B: 35 Developing MM3
Group C: 35 Functional MM3

CRITERIA FOR MANDIBULAR THIRD MOLAR SELECTION:

The tooth is said to be:

- Impacted – If it is below the level of occlusion and with complete root formation
- Developing - If it is without complete root formation
- Functional – If it is fully erupted to the level of occlusion with complete root formation

INCLUSION CRITERIA:

- Radiographs of patients admitted for CBCT evaluation of head and neck region.
- Age group between 17 – 40 years.
- CBCT images without any artefacts.
- Images with clearly identifiable mandibular third molar region

EXCLUSION CRITERIA:

- CBCT images with head trauma, fracture involving angle of mandible or the mandibular third molar region.
- CBCT images with missing mandibular third molars.
- Presence of periodontitis, cystic lesions or tumors in third molar region.

METHODOLOGY:

Three regions of interest (ROI) of size 45×45 pixel around MM3 were cropped from the curvilinear plane of CBCT scans using MICROSOFT OFFICE PICTURE MANAGER SOFTWARE. (Fig.1)
The three ROIs are
ROI 1: Anterior ramus of mandible (at a point tangent to the level of occlusion)
ROI 2: Dental region (next to CEJ of mandibular third molar tooth)
ROI 3: Antegonial region (superior to antegonial notch)
The cropped image is then imported to IMAGEJ software 1.54d: Java 1.8.0_345 [64 bit] (National Institutes of Health, Bethesda, MD, USA) for processing and analysis of Bone surface area (BSA), Bone marrow surface area (BMSA), Bone fractal dimension (BFD), Bone marrow fractal dimension (BMFD) & Lacunarity (Fig. 2). The image of Red Green Blue (RGB) scale or any different scale is converted into 8-bit image because only 8-bit image can be analysed by IMAGEJ software.

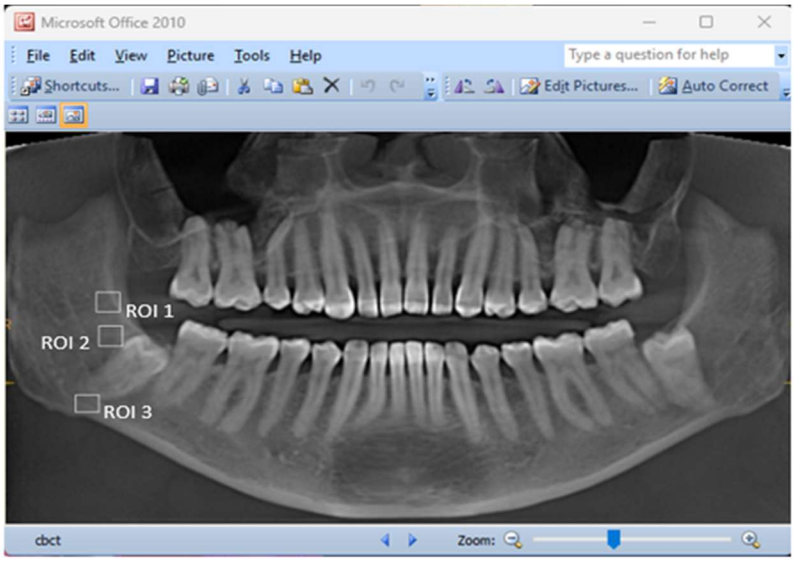


Fig.1: Three ROIs cropped (45×45 pixel) around MM3 using MICROSOFT OFFICE PICTURE MANAGER SOFTWARE.

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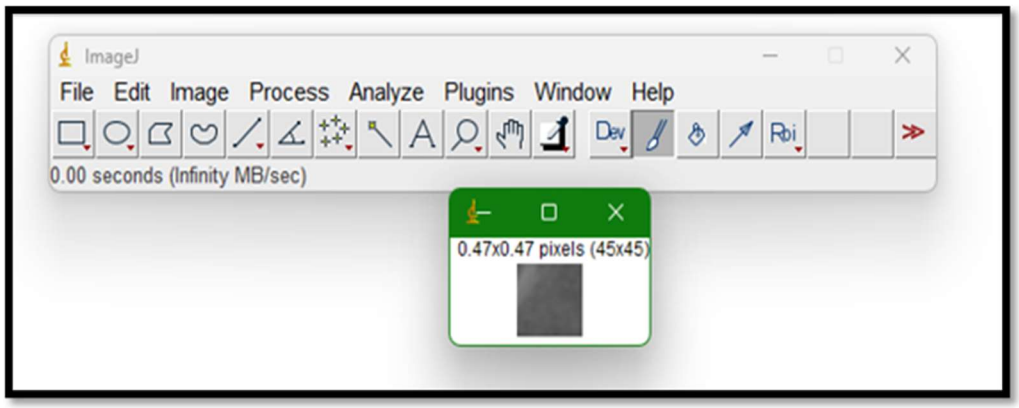


Fig.2: Cropped image opened using IMAGEJ software

Shown in Fig:3

- From the original cropped image (Fig.3a) duplicate image prepared (Fig.3b)
- A "Gaussian filter" (r=35) was used to remove the density difference caused by soft tissue in the image and to make sharper difference more evident (Fig.3c)
- This Gaussian filtered image is "subtracted" from the original cropped image (Fig.3d).
- The constant grayscale value of 128 is "added" to each pixel of the image to reveal the density difference in image & to separate bone marrow cavities and bone trabeculation (Fig.3e)
- The "threshold" of the image is adjusted to get the image in two colour format black and white (fig.3f).
- The image was converted into "Binary" to get evident trabeculae (Fig.3g)
- The binarized image was "Eroded" to remove the noise in image (Fig.3h)
- The image then "Dilated" to expand the areas and to highlight lines to more visibility (Fig.3i)
- With the "Invert" feature the image was then inverted, in which the white areas turn black and black turns white. (Fig.3j)
- Finally using the skeletonize feature the bone trabecular structure transformed into complex lines. (Fig.3k)
- For Bone marrow analysis "inversion" of the image is done before the binarization (shown in Fig.4 a-l)

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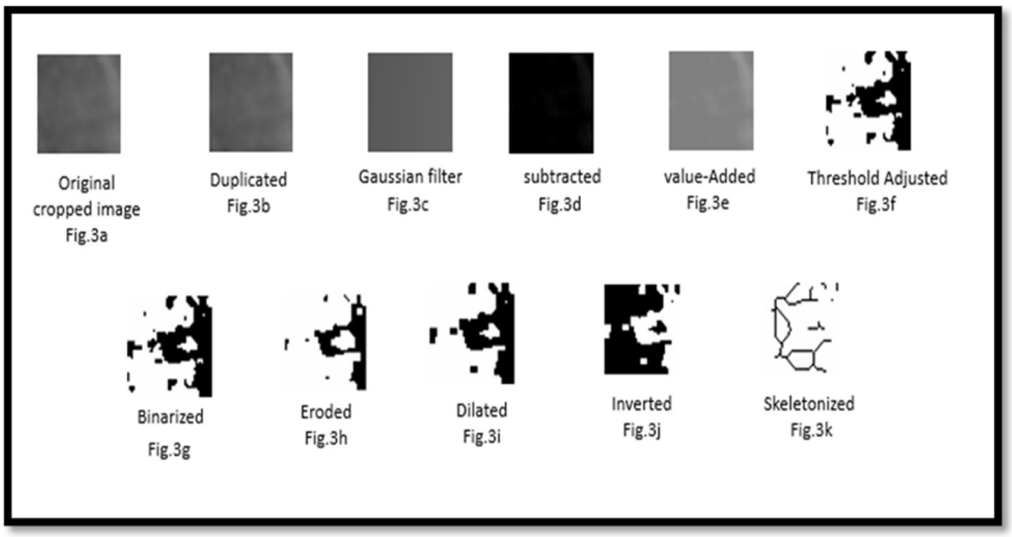


Fig.3: Steps in image processing for BSA & BFD analysis

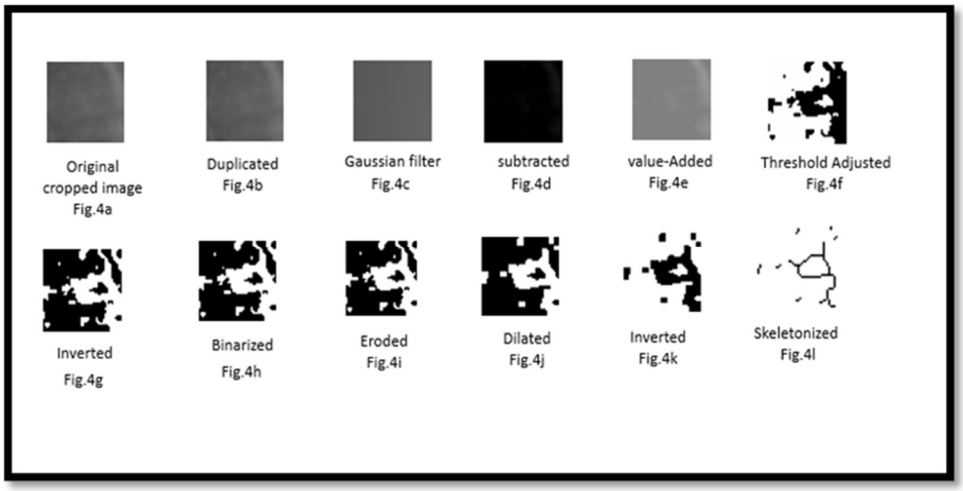


Fig.4: Steps in image processing for BMSA & BMFD Analysis

The skeletonized images (Fig.3k,4l) of bone & bone marrow were then analyzed for BFD & BMFD using the "Fractal box count" method. The image was divided into squares of 2, 3, 4, 6, 8, 12, 16, 32, and 64 pixels using the 'Box-counting' tool which calculated the number of squares that included these complex trabecular lines. Each pixel size was estimated separately, and the overall number of frames was then determined. A logarithmic scale was used to plot the number of plates that were counted versus the total number of plates. In the graph, a line is drawn through each data point. The FD value, which indicates the complexity of the studied image, is given by the slope of the drawn line (Fig.5). A bony region with 100% bone content would have a fractal value of 2, while a region with 0% bone content would have a fractal value of 1. The Area of the images (BSA & BMSA) were measured using the area fraction feature available in the software.

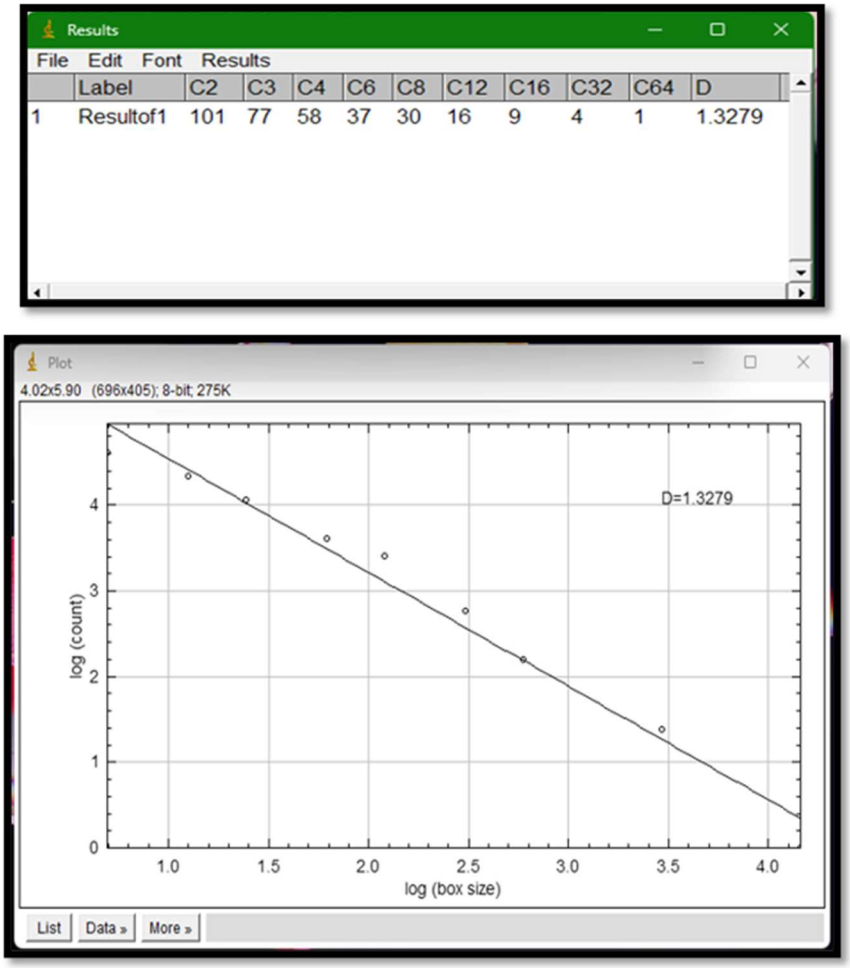


Fig 5: Box counting method with graph for measuring fractal dimension. Image divided into squares of 2, 3, 4, 6, 8, 12, 16, 32, and 64 pixels using the 'Box-counting' tool to measure fractal dimension, Graph with a line drawn through each data point in Fractals

A plugin called FracLac was used to calculate lacunarity. The FracLac plugin offers options for the box counting method and sliding box method for lacunarity analysis. The box counting method of the FracLac plugin was used to calculate lacunarity. (Fig.6)

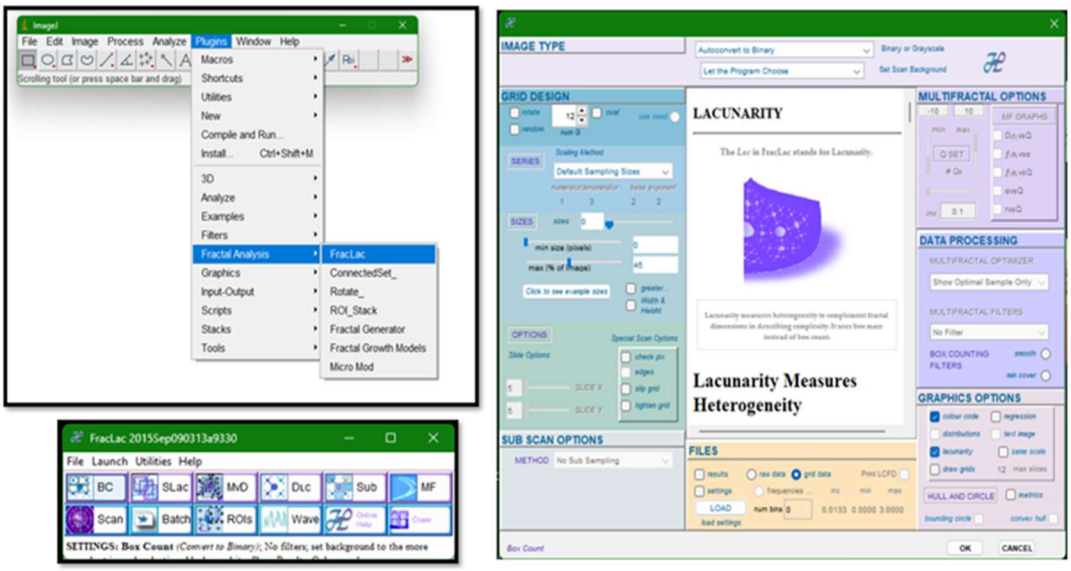


Fig.6: FracLac plugin used to calculate the lacunarity in IMAJEJ software

All measurements were carried out for the second time by the same investigator after a week interval to assess intraobserver variability. The data obtained subjected to statistical analysis using Statistical Package for Social Sciences (SPSS) software version 25.0 (IBM, Chicago, USA). Comparison between the three groups done using one way ANOVA followed by Tukey's HSD post hoc test. Intraclass correlation coefficient (ICC) is used to access the Intraobserver variability. Level of significance was set at 5% ($p < 0.05$ = Statistically Significant)

RESULT:

Intra-observer reliability test (Table.1) was assessed by comparing the values obtained in the first evaluation and values reassessed after a week. The correlation values attained are greater than 90%. This demonstrates that the values acquired in the current investigation have a high degree of reliability and reproducibility.

Table 1: Correlation between the first and second measurements using Intraclass correlation coefficient

		N	*Intraclass coefficient (ICC)*
Pair I	Bone Surfacer Area - A	15	0.990
	Bone Surfacer Area - B	15	
Pair II	Bone Marrow Surface Area - A	15	0.975
	Bone Marrow Surface Area - B	15	
Pair III	Bone fractal - A	15	0.981
	Bone fractal - B	15	

Pair IV	Bone marrow fractal - A	15	0.988
	Bone marrow fractal - B	15	
Pair V	Lacunarity – A	15	0.944
	Lacunarity – B	15	

Table 2 shows the comparison of mean bone surface area (BSA), bone marrow surface area (BMSA), bone fractal dimension (BFD), bone marrow fractal dimension (BMFD) & lacunarity among the groups of impacted, developing and functional MM3 using one way ANOVA test. The BSA & BFD was higher in impacted MM3 (1438.78±39mm2 & 1.4243±.018) followed by developing (1369.39±95mm2 & 1.3526±.10) and functional MM3 (1273.31±29 mm2 & 1.2386±.032) (Graph 1,2) whereas BMSA & BMFD are higher in functional MM3 (2819.64±40 mm2 & 1.3494±.023) followed by developing (2713.13±109mm2 & 1.3446±.021) and impacted MM3 (2614.55±40 mm2 & 1.3263±.025) (Graph 3,4). All these values are statistically significant. This indicates that there is increased BSA & BFD in impacted MM3 causing the tooth to impact and increased BMSA & BMFD in functional molars which is the reason for the eruption of the tooth.

Lacunarity values was higher in functional molars (0.6017±0.012) indicating larger lacunae space followed by developing (0.5311±.058) and impacted molars (0.4857±0.018) with smaller gaps or lacunae space inside the trabecular bone. (Graph 5)

Table 2: Comparison of mean BSA, BMSA, BFD, BMFD and lacunarity among groups of MM3 using one way ANOVA test

	N	Impacted molars Mean±SD	Functional molars Mean±SD	Developing molars Mean±SD	P value
Bone surface area (BSA)	35	1438.78±39 mm^2	1273.31±29 mm^2	1369.39±95 mm^2	<0.001**
Bone marrow surface area (BMSA)	35	2614.55±40 mm^2	2819.64±40 mm^2	2713.13±109mm^2	<0.001**
Bone fractal dimension (BFD)	35	1.4243±.018	1.2386±.032	1.3526±.10	<0.001**
Bone marrow fractal	35	1.3263±.025	1.3494±.023	1.3446±.021	<0.001**

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dimension (BMFD)					
Lacunarity	35	0.4857±0.018	0.6017±0.012	0.5311±.058	<0.001**

Table 3 show the pairwise comparison of BSA, BMSA, BFD, BMFD and lacunarity values individually with three different groups of impacted, developing and functional MM3 using Tukey's HSD post Hoc test. All the values are statistically significant except for BMFD between functional & developing MM3 and developing and functional MM3.

Table 3: Pairwise comparison of BSA, BMSA, BFD, BMFD and lacunarity between three groups of MM3.

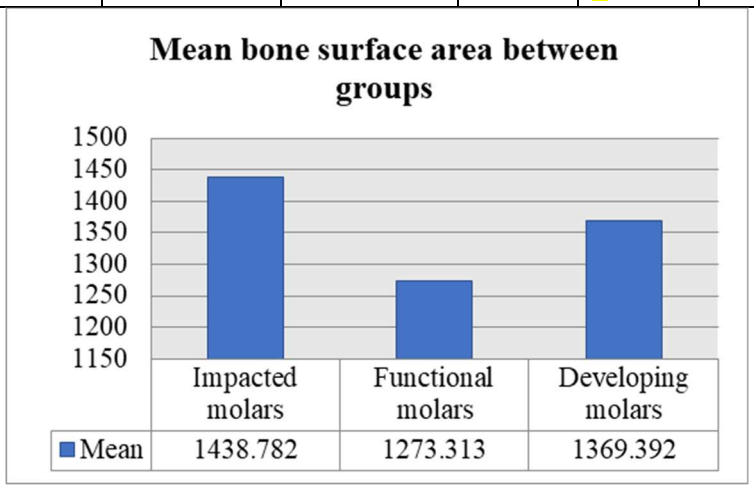
	(I) groups	(J) groups	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval	
						Lower Bound	Upper Bound
Bone surface area (BSA)	Impacted molars	Functional molars	165.4685*	14.861	<0.001	130.1212	200.8160
		Developing molars	69.39029*	14.861	<0.001	34.0429	104.7377
	Functional molars	Impacted molars	-165.4685*	14.861	<0.001	-200.8160	-130.1212
		Developing molars	-96.07829*	14.861	<0.001	-131.4257	-60.7309
	Developing molars	Impacted molars	-69.39029*	14.861	<0.001	-104.7377	-34.0429
		Functional molars	96.07829*	14.861	<0.001	60.7309	131.4257
Bone Marrow surface area (BMSA)	Impacted molars	Functional molars	-205.0968*	17.065	<0.001	-245.6864	-164.5073
		Developing molars	-98.58086*	17.065	<0.001	-139.1704	-57.9913
	Functional molars	Impacted molars	205.0968*	17.065	<0.001	164.5073	245.6864
		Developin	106.51600	17.06	<0.00	65.9264	147.105

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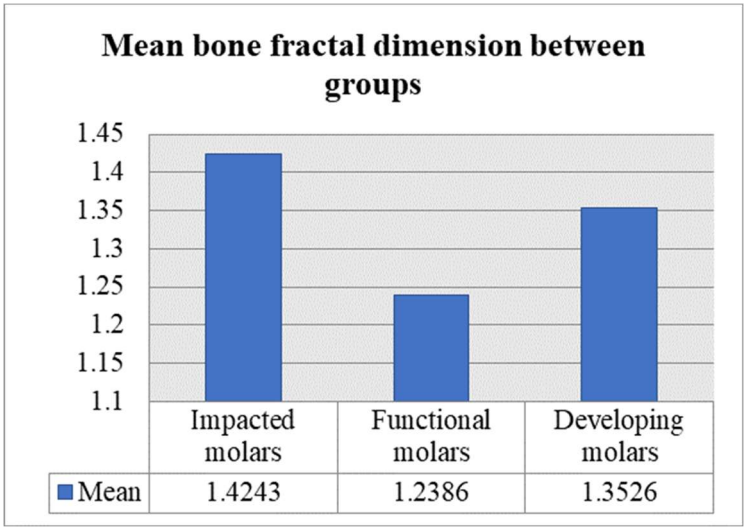
		g molars	*	5	1		6
	Developing molars	Impacted molars	98.58086*	17.065	<0.001	57.9913	139.1704
		Functional molars	-106.5160*	17.065	<0.001	-147.1056	-65.9264
Bone fractal dimension (BFD)	Impacted molars	Functional molars	.18571*	.01481	<0.001	.1505	.2209
		Developing molars	.07171*	.01481	<0.001	.0365	.1069
	Functional molars	Impacted molars	-.18571*	.01481	<0.001	-.2209	-.1505
		Developing molars	-.11400*	.01481	<0.001	-.1492	-.0788
	Developing molars	Impacted molars	-.07171*	.01481	<0.001	-.1069	-.0365
		Functional molars	.11400*	.01481	<0.001	.0788	.1492
Bone marrow fractal dimension (BMFD)	Impacted molars	Functional molars	-.02314*	.00566	<0.001	-.0366	-.0097
		Developing molars	-.01829*	.00566	.005	-.0318	-.0048
	Functional molars	Impacted molars	.02314*	.00566	<0.001	.0097	.0366
		Developing molars	.00486	.00566	.668	-.0086	.0183
	Developing molars	Impacted molars	.01829*	.00566	.005	.0048	.0318
		Functional molars	-.00486	.00566	.668	-.0183	.0086
Lacunarity	Impacted molars	Functional molars	-.11600*	.00869	<0.001	-.1367	-.0953
		Developing molars	-.04543*	.00869	<0.001	-.0661	-.0248
	Functional molars	Impacted molars	.11600*	.00869	<0.001	.0953	.1367
		Developing molars	.07057*	.00869	<0.001	.0499	.0912
	Developing molars	Impacted molars	.04543*	.00869	<0.001	.0248	.0661

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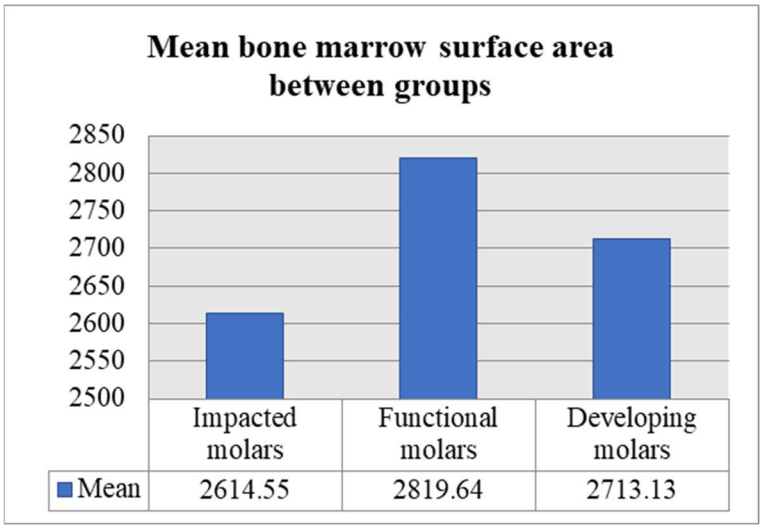
		Functional molars	-.07057*	.0086 9	<0.00 1	-.0912	-.0499



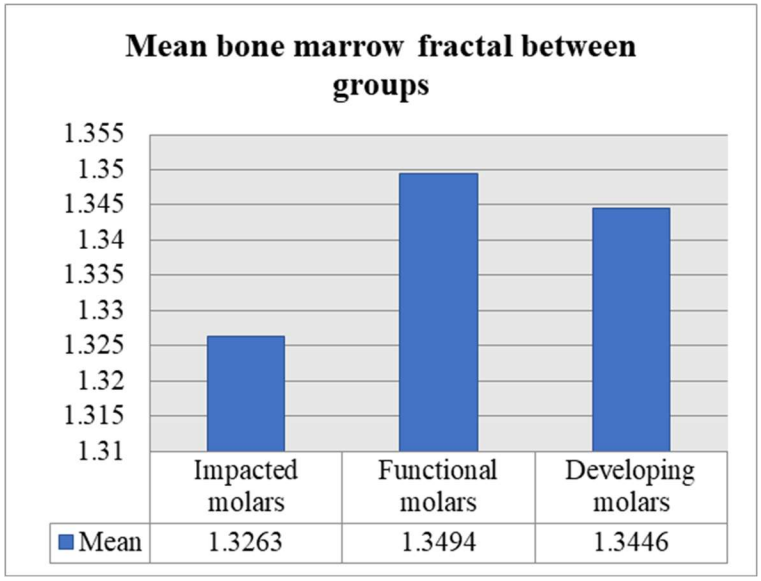
Graph 1: Mean bone surface area



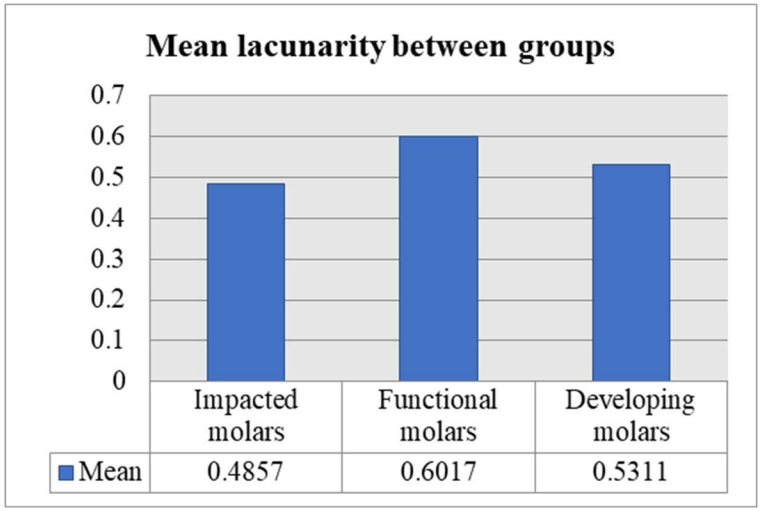
Graph 2: Mean bone fractal dimension between groups



Graph 3: Mean bone marrow surface area between groups



Graph 4: Mean bone marrow fractal between groups



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Graph 5. Mean lacunarity between groups

DISCUSSION:

The development of third molars typically occurs between the ages of 17 and 24 and its eruption usually happens at an average of 20years. The term "tooth impaction" refers to the failure of teeth to erupt within these anticipated times [8]. The rate of mandibular third molar impaction in the dental arch is the greatest of any tooth impaction except for maxillary third molars. Due to this, we included MM3 of individuals aged 17 years and above in our study group.

The current study evaluated the bone microarchitecture around MM3 retrospectively using BSA, BMSA, BFD, BMFD and lacunarity measurements. According to the findings, we may conclude that BSA & BFD was greater and BMSA & BMFD was lesser around impacted molars when compared with the not impacted molars. The current study utilized FD analysis in a manner similar to the study conducted by Arvind TRP et al [6]., & Servais et al [7]., and the same finding was reported by these authors who studied bone densities surrounding maxillary impacted canines. In the study done by Abazi Y et al [9]., & Köseoğlu Seçgin C et al [10]., used Hounsfield Units & grey scale values respectively for Bone density measurement around maxillary impacted canines and showed the similar results i.e., in comparison to the unimpacted side, the impacted side's maxillary alveolar bone area and bone density are higher.

Monu Yadav et al [11]., observed that fractal dimension of the mandibular third molar's trabecular bone was shown to be significantly variable, and it may be utilized to forecast the pattern of tooth eruption. In contrast, Gonca M et al [5]., found that there was no statistically significant correlation between impaction of molars and FDs of microstructure of bone.

Numerous applications of fractal dimension analysis have been made in dentistry, particularly in dental implant planning, implant osseointegration, mandibular trabecular bone changes in patients with bruxism and periodontitis [12-15]. Therefore, its ability to determine trabecular patterns in terms of BFD and BSA can be beneficial to calculate bone densities.

The use of CBCTs to measure bone density has been strongly criticized, with multiple studies suggesting that before grayscale readings can be properly transformed into Hounsfield units (HUs), the machine needs to be calibrated with the proper artifacts [16]. As a result, FD analysis rather than grayscale value is better suited for drawing conclusions about the evaluation of bone quality.

In a study using direct digital periapical images of the mandibular posterior region in dentate and edentulous patients, Yasar and Akgünlü [4] evaluated FD and lacunarity and found that the trabecular bone textures in dentate and edentulous areas varied. According to them, FD and lacunarity can be used to distinguish between different bone formations. Basavarajappa S et al [3]., investigated FD and lacunarity of mandibular bone of tobacco users in digital panoramic radiographs and stated that lower FD and higher lacunarity was noted in smokeless tobacco users

and these results indicate that the use of FD and lacunarity analysis can be a potential prognostic method for evaluating the quality of the bone and for detecting osteoporotic changes.

In our study increase in lacunarity values was noted in functional molars followed by developing and impacted molars stating that there is heterogenous bone pattern in non-impacted region with higher lacunae spaces compared to impacted region.

Among the groups taken in our study, increased BSA, BFD and decreased BMSA, BMFD & lacunarity seen in impacted molars followed by developing and functional molars. It indicates that there is more complex bone trabecular structure in impacted region when compared to completely erupted region. In case of developing tooth, it may undergo impaction if there is higher BSA, BFD values as that of impacted tooth. Therefore, molar impaction may also be the result of complex bone structure around it relative to completely erupted molars. Further research is required to confirm the fact that microarchitecture of bone has a local etiologic role in impaction of the tooth

CONCLUSION:

Our investigation of the CBCT images of patients with impacted molars revealed a substantial difference in the mandibular alveolar bone's density, as measured by trabecular bone area and FD, which is greater in the impacted side than in the non-impacted side. Additionally, our data showed that the bone marrow area was lesser surrounding the impacted molar than it was around the erupted molar. As a result, we made the assumption that increased bone density might be a local etiologic factor in tooth impaction.

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