Radiographic Assessment of Mandibular Bone Trabeculae Using Fractal Dimension Analysis For Optimizing Treatment Planning, A Cross-sectional Analysis

Ewansiha GO[1], Abubakar MK[2], Yahaya A[3], Iya S[1], Ogbozor BE[1], Ahmad IS[4], Bamgbose BO[5]

Correspondence: Yahaya A[3]

Email: *abdulmanany@gmail.com*

[1]Department of Oral and Maxillofacial Radiology, Aminu Kano Teaching Hospital, Kano-Nigeria

[2]Medical Centre/Department of Community & Preventive Dentistry, Faculty of Dental Sciences, Federal University Gusau, Zamfara-Nigeria

[3]Department of Child Dental Health, Faculty of Dentistry, Bayero University & Aminu Kano Teaching Hospital Kano-Nigeria

[4]Aminu Kano Teaching Hospital, Kano-Nigeria

[5]Department of Oral Diagnostic Sciences, Faculty of Dentistry, Bayero University & Aminu Kano Teaching Hospital Kano-Nigeria

Key words: Fractal dimension, Trabecular bone, Mandible, Panoramic radiography, Bone assessment, Treatment planning.

ABSTRACT

Background

Early detection of mandibular bone changes is critical for preventing complications during dental surgeries. Radiographic assessment of mandibular trabeculae using visual index assessment and fractal dimension (FD) analysis represents a significant advancement in dental diagnostics. These approaches enhance the identification of individuals at risk of low bone mass and facilitate the monitoring of bone changes, thereby optimizing treatment planning.

Objective

This study aimed to visually assess changes in the trabecular pattern of the mandible on digital panoramic images and compare these changes with fractal dimension analysis to support optimal treatment planning.

Methods

This retrospective cross-sectional study was conducted in the Department of Oral Diagnostic Sciences, Aminu Kano Teaching Hospital, Kano. Two regions of interest (ROIs)—between the interdental region of the second premolar and first molar—were analyzed on both sides of the mandible using dedicated software for visual and FD assessment. Data on age, sex, trabecular pattern type, and FD values were recorded. Statistical analyses, including Chi-square, independent t-test, and ANOVA, were performed to assess associations among variables.

Results

A total of 412 digital panoramic images were analyzed, comprising 219 (53.2%) males and 193 (46.8%) females, with a mean age (SD) of 35.3 (11.9) years. Sparse trabecular patterns were more prevalent among females (56.0% right; 50.3% left), while significantly higher FD values were observed in males ($p = 0.02$ right; $p = 0.006$ left). Both visual assessment and FD analysis identified sparse trabecular patterns on the right (51.7%, 51.9%) and left (44.2%, 48.3%) sides. Agreement between methods was moderate on the right and fair on the left side of the mandible (Kappa = 0.47 and 0.36, respectively).

Conclusion

Both visual index and FD assessment methods effectively identified sparse trabecular patterns, though neither alone is entirely sufficient. A combined approach yields more reliable data for improved treatment planning.

INTRODUCTION

Research on mandibular bone trabeculae has gained increasing attention due to its relevance in radiographic assessments that support clinical decision-making. The mandible, a robust arch-shaped and the only mobile facial bone, comprises trabecular bone enclosed between two cortical plates. Compared to the maxilla, the mandible exhibits relatively stable bone mineral density (BMD), with the posterior region typically demonstrating denser cortical bone and the anterior region showing denser trabeculation. In contrast, the posterior region is characterized by wider, more irregular trabeculae.[1–6] Assessing bone thickness and density—key indicators of bone quality—permits both quantitative and qualitative evaluations of bone structural integrity.

Radiomorphometric tools such as the Trabecular Bone Pattern Index (TBPI), Mandibular Cortical Index (MCI), and densitometric analyses serve as valuable screening techniques for evaluating mandibular bone health. Based on image processing technologies, dual-energy X-ray absorptiometry (DXA)—the gold standard for BMD assessment—can predict the risk of osteoporotic fractures.[7–9] Other imaging modalities, including cone-beam computed tomography (CBCT), intraoral radiographs, and panoramic radiography, are also employed.[10,11] Moreover, fractal analysis, expressed as fractal dimension (FD), offers a cost-effective and accessible method to quantitatively analyze trabecular complexity using the box-counting technique described by White and Rudolph.[2,3,12–14]

Mandibular surgical planning is complicated by the bone's anatomy, functional load, and aesthetic implications. While computer-assisted planning enhances diagnostic precision, its limited adoption is due to high costs and training requirements.[15,16] A more feasible approach in resource-limited settings is panoramic radiography, which captures comprehensive dental and maxillofacial structures in a single image.[9,17] Assessing BMD—shaped by age, sex, race, nutrition, body mass, smoking, alcohol use, corticosteroid therapy, and physical activity—is essential in planning procedures such as implant placement, bone grafting, orthodontic interventions, and orthognathic surgery.[5,9,17] Trabecular patterns have been categorized visually into sparse, heterogeneous, and dense patterns.[7,9,18] Dense trabeculation suggests normal BMD, while sparse patterns are associated with poorer treatment outcomes.[9,13,17–19]

Several studies have demonstrated the utility of morphometric parameters—such as trabecular pattern and bone density—for identifying individuals at risk of low bone mass using panoramic radiographs.[12,18–22] However, there is limited literature from our environment. This study hypothesized that the mandibular trabecular pattern, as observed on digital panoramic images, could offer clinical insight into bone mass risk during treatment planning. The study therefore assessed mandibular trabecular patterns and compared visual assessments with fractal dimension analysis to optimize surgical planning.

METHODS

Study Design and Setting

This descriptive retrospective study utilized digital panoramic radiographs obtained for various diagnostic purposes from the Oral and Maxillofacial Radiology Unit, Department of Oral Diagnostic Sciences, Aminu Kano Teaching Hospital, Kano—a tertiary hospital in Northwestern Nigeria. Ethical clearance was obtained from the institution's Research Ethics Committee (NHREC/28/01/2020/AKTH/EC/3938). All images were anonymized to ensure confidentiality. Images were retrieved via purposive-consecutive sampling from the hospital's Picture Archiving and Communication System (PACS) over a two-year period (April 2021–March 2023). All panoramic radiographs were acquired using a Planmeca ProMax S3 Pan/Ceph® unit (70 kVp, 12.5 mA, 11.0 s exposure, dose area product = 71.7 mGy·cm²). The images were saved in DICOM format and evaluated using Planmeca Romexis viewer software (version 3.8.0). The study was conducted and reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines and in adherence to the Declaration of Helsinki.

Participant Selection

Inclusion Criteria

- Patients aged ≥20 years
- Presence of full permanent dentition
- Absence of artifacts in the selected region of interest (ROI)

Exclusion Criteria:

- Mandibular anatomical or pathological defects
- History of metabolic bone disease or metastasis
- Alcoholism or smoking history
- Prior mandibular fractures or orthodontic treatment
- Use of corticosteroids, TNF-α inhibitors, or antiresorptive therapy

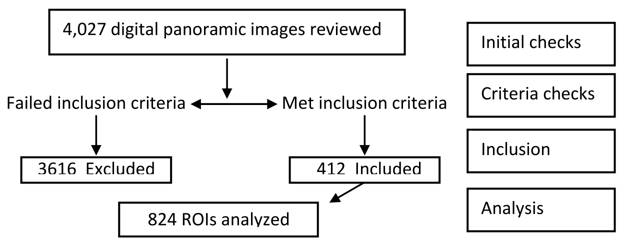
Variables

Dependent variable: Fractal dimension value

Independent variables: Age, sex, and trabecular pattern

STROBE FLOW CHART

Only 412 radiographs that met the inclusion criteria were included and 824 regions of interest, analyzed.



Data Collection and Measurements

Data collection occurred over two months. Three observers—an oral and maxillofacial radiologist, a radiologist, and a senior resident—conducted a pilot evaluation of 10 randomly selected panoramic images that met the inclusion criteria. From each image, an experienced oral and maxillofacial radiologist selected one ROI in the interdental region between the second premolar and first molar on both mandibular sides. These

ROIs represented the three trabecular pattern categories according to the visual index proposed by Lindh et al.[23] and modified by Jonasson et al.[24] (see Figure 1).

Figure 1: Reference radiographs for the assessment of trabecular pattern. 1. sparse 2. heterogeneous 3. dense trabecular patterns

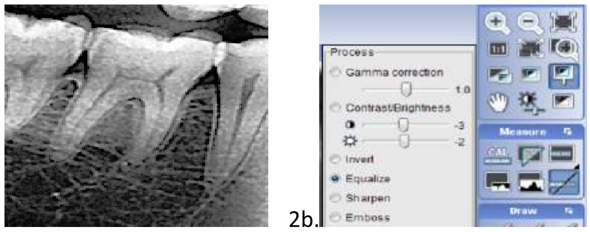
Data Validity, Reliability, and Bias-Minimizing Steps

To ensure consistency and minimize bias across observations, the third observer (a senior resident) was supervised by an oral and maxillofacial radiologist. A training session on the use of the visual index assessment and fractal dimension (FD) analysis was conducted by the radiologist using Romexis Viewer and ImageJ software. Both visual index assessment and FD analysis were independently performed on each side of the mandible for 10 selected images by the third observer, repeated five times per side, and subsequently re-evaluated by the oral and maxillofacial radiologist to confirm consistency with established protocols. Expert opinions from the oral and maxillofacial radiologist and radiologist were used to standardize the visual index grading of the trabecular pattern as sparse, heterogeneous, or dense. Each image's region of interest (ROI) was compared against reference images, and all data were recorded using a Microsoft Excel spreadsheet.

Visual Assessment Protocol

The visual index assessment was carried out by a single observer (senior resident) using Romexis software, with each result crosschecked against the reference images. The trabecular bone pattern was evaluated on post-processed digital panoramic images at two mandibular sites: the interdental region between the second premolar and the mesial root of the first molar, excluding the lamina dura. These locations, designated as ROI1 (right) and ROI2 (left), were selected based on evidence suggesting that the posterior mandible demonstrates less variation in bone pattern, shape, and function, making it a suitable site for radiographic evaluation of trabecular bone patterns on panoramic images.[4-7]

Images were assessed on a 15.6-inch LED HP monitor (TOA4F4V, 930HDD, Intel® Core i3-5005U, 1366 × 768 resolution, 4 GB RAM, 2 GHz processor) with landscape orientation, under subdued lighting, and running Windows 10. Using the toolbar functions in Romexis Viewer, each ROI was equalized and contrast-adjusted to enhance geometric detail, allowing subtle gray-level variations within the trabecular network to be more conspicuous—features often obscured at standard viewing settings, as illustrated in Figures 2a and 2b.

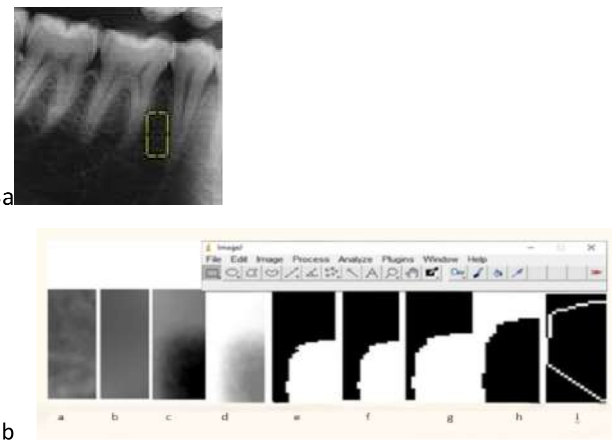


2a. 2b.

Figure 2

Figure 2a illustrates a cropped section of the left mandibular region of interest (ROI) from a digital panoramic image, as assessed using the visual index method. The observer compared this ROI with reference radiographs to evaluate and categorize the trabecular bone patterns. Figure 2b displays the operational toolbars of the Romexis viewer used to enhance image quality during the assessment process.

A written instruction was provided to guide the observer in grading the trabecular pattern using a 3-point scale based on comparison with the reference images. Patterns with wider intertrabecular spaces were classified as sparse (Grade 1), those showing a combination of sparse and dense trabeculae were termed heterogeneous or mixed (Grade 2), and patterns characterized by numerous trabeculae were categorized as dense (Grade 3).



3a

3b

Figure 3

Figure 3a shows the region of interest (ROI) located between the interdental area of the mandibular second premolar and the mesial root of the first molar, as seen on digitized panoramic images.

Figure 3b is a screenshot of the image analysis workflow using ImageJ, consisting of the following steps:

a. Duplicate

b. Filter

c. Subtract

d. Add intensity (128)

e. Make binary

f. Erode

g. Dilate

h. Invert

i. Skeletonize

Concise concept of fractal analysis

The term fractal is derived from the Latin word fractus, meaning "fractured" or "broken." It describes an entity that exhibits self-similarity across different scales, such that its parts are indistinguishable from the whole.[3,12,25] This concept underpins the calculation of the fractal dimension (FD), a mathematical method used to quantify complex geometric structures—such as bone texture, vascular networks, and cell shapes—that cannot be adequately measured by conventional parameters like length, area, or volume.[14,26,27] Since Mandelbrot introduced the concept of fractal geometry, it has found broad applications in scientific fields, particularly in image processing, where patterns with fractional dimensions—such as bone trabeculae—exhibit irregularities that defy Euclidean geometry.[13,26,27]

Fractal analysis, expressed as FD, employs statistical texture analysis to evaluate trabecular bone architecture based on variations in pixel intensity[22]. Several methods exist for calculating FD, including the Hausdorff dimension, Minkowski–Bouligand method, mass-radius method, and the widely used box-counting method (also known as the Kolmogorov dimension).[28–29] The box-counting method involves overlaying grids of various box sizes (2, 3, 4, 6, 8, 12, 16, 32, and 64 pixels) to count the number of boxes required to cover the structure[2]. A double logarithmic plot is then generated, with the number of boxes on the y-axis and box sizes on the x-axis. The FD value (Figure 4) is determined from the slope of the linear regression line fitted to the plotted data.[2–3]

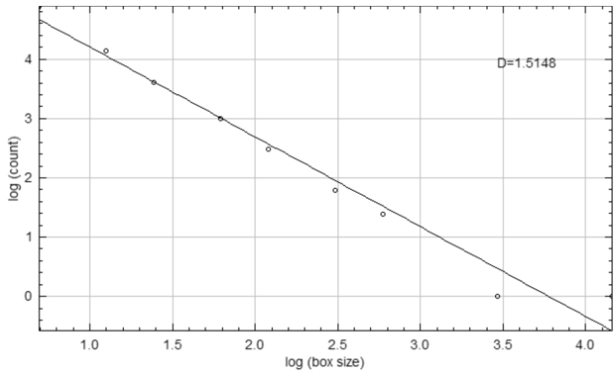


Figure 4: A double logarithm scale of fractal box analysis of skelotonized images

Data Analysis

The extracted database was subjected to statistical analysis using IBM SPSS Statistics for Windows, version 29.0 (IBM Corp., Armonk, NY, USA). Quantitative variables were presented as means and standard deviations, while qualitative variables were described using frequencies and percentages. The normality of continuous variables was assessed using the Shapiro-Wilk test. The Chi-square test was employed to evaluate the statistical significance of categorical variables. Independent t-tests and one-way ANOVA were used to compare the mean fractal dimension (FD) values between two regions of interest (ROIs) and across age groups, respectively. The Kappa statistic was used to assess the agreement between visual index assessment and FD analysis. A p-value of less than 0.05 was considered statistically significant.

Results

Out of 4,027 digital panoramic images reviewed, 412 were selected for analysis, resulting in 824 ROIs—corresponding to the right and left sides of the mandible. The demographic analysis showed that 219 (53.2%) were male and 193 (46.8%) were female, all aged 20 years and above, with a mean age of 35.3 ± 11.9 years. Male subjects were significantly older than their female counterparts, with a mean age difference of 3.2 years (p = 0.007) as shown in Table 1.

Table 1: *Age and Sex distribution of study partiipants*

Sex	n (%)	Age (years)			
		Min	Max	Mean	SD
Male	219 (53.2)	20	81	36.8	12.1
Female	193 (46.8)	20	89	33.6	11.4
Total	412 (100)	20	89	35.3	11.9

Mean difference of 3.2 years (95% CI: 0.89 – 5.5 years; p = 0.007) t = 2.728; SD: Standard deviation

The age distribution of the study population revealed a clear predominance of younger individuals, with the 20–29 age group being the most represented among both sexes. This was followed by the 30–39 and 40–49 age groups. A progressive decline in the number of participants was observed with increasing age, as illustrated in Figure 5.

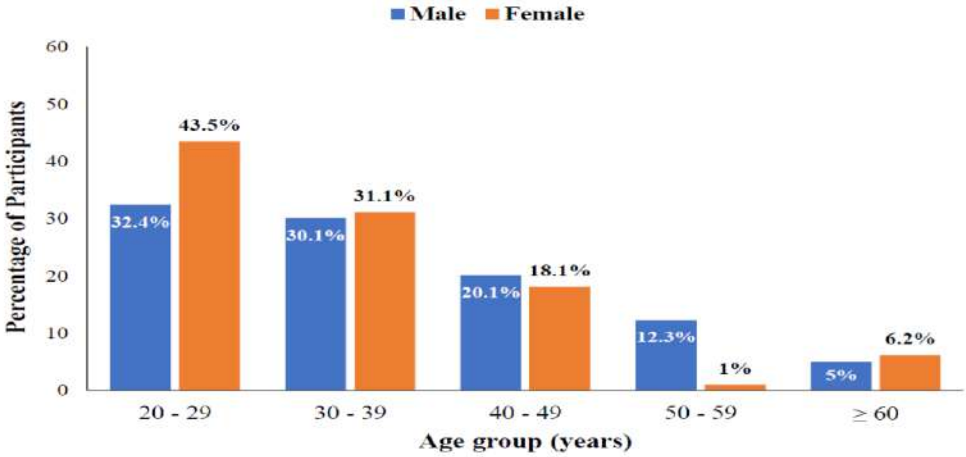


Figure 5: Age distribution of study participants by sex

Morphological Evaluation of Mandibular Trabecular Pattern Using Visual Index

The overall distribution of trabecular bone patterns, assessed using the visual index and matched with reference images, showed that sparse trabecular patterns predominated in the right mandible (51.7%). In contrast, the left mandible displayed a more balanced distribution between sparse (44.2%) and heterogeneous (43.2%) patterns. No statistically significant differences were observed in trabecular bone patterns of the right mandible between males and females (p = 0.26). However, in the left mandible, statistically significant sex-related differences were noted: males exhibited more heterogeneous and dense trabecular patterns, whereas females showed a higher prevalence of sparse patterns (Table 2). An age-related trend in trabecular bone pattern distribution was observed, with the oldest age group (≥60 years) demonstrating a high prevalence of sparse patterns in the right mandible (82.6%, p = 0.08). No statistically significant differences were observed among age groups for the left mandible (Table 2).

Table 2: *Visual Index of Trabecular Bone Pattern in Right and Left Mandibles*

	Right Mandible, n (%)			Left Mandible, n (%)		
	Sparse	**Mixed**	**Dense**	**Sparse**	**Mixed**	**Dense**
All	213 (51.7)	151 (36.6)	48 (11.6)	182 (44.2)	178 (43.2)	52 (12.6)
Sex						
Male	105 (47.9)	87 (39.7)	27 (12.3)	85 (38.8)	100 (45.7)	34 (15.5)
Female	108 (56.0)	64 (33.1)	21 (10.9)	97 (50.3)	78 (40.4)	18 (9.3)
	$\chi2$ = 2.665, df = 2, P-value = 0.26			$\chi2$ = 6.820, df = 2, P-value = 0.03		
Age						
20 – 29	81 (52.3)	59 (38.1)	15 (9.7)	69 (44.5)	68 (43.9)	18 (11.6)
30 – 39	57 (45.2)	52 (41.3)	17 (13.5)	55 (43.6)	50 (39.7)	21 (16.7)
40 – 49	44 (55.7)	24 (30.4)	11 (13.9)	30 (38.0)	40 (50.6)	9 (11.4)
50 – 59	12 (41.4)	13 (44.8)	4 (13.8)	16 (55.2)	9 (31.0)	4 (13.8)
≥ 60	19 (82.6)	3 (13.0)	1 (4.3)	12 (52.2)	11 (47.8)	0
	$\chi2$ = 14.213, df = 8, P-value = 0.08			$\chi2$ = 9.109, df = 8, P-value = 0.33		

P-value estimated using Chi-square test ($\chi2$)

FD Analysis of Right and Left Mandibular Trabeculae

Fractal Dimension (FD) Analysis of Mandibular Trabecular Bone

The fractal dimension (FD) analysis of trabecular bone in the right and left mandibles across sex and age groups (Table 3) revealed comparable overall mean FD values between the right [1.15 ± 0.36] and left [1.17 ± 0.38] sides, suggesting similar trabecular bone complexity bilaterally. Independent t-tests and one-way ANOVA were employed to assess sex- and age-related differences in FD values. Statistically significant sex-related differences were observed in both the right (p = 0.02) and left (p = 0.006) mandibles, with males exhibiting higher mean FD values than females. Age-related differences were statistically significant in the right mandible (p = 0.003), whereas no significant differences were found in the left mandible across age groups.

Table 3: *Distribution of Right and Left MandibularBone Trabeculae FD Values*

		Right Mandible		Left Mandible	
		Range	**Mean ± SD**	**Range**	**Mean ± SD**
All		0.18 – 1.97	1.15 ± 0.36	0.002 – 1.96	1.17 ± 0.38
Sex					
	Male	0.18 – 1.97	1.19 ± 0.38	0.02 – 1.96	1.22 ± 0.39
	Female	0.40 – 1.87	1.11 ± 0.35	0.002 – 1.83	1.12 ± 0.35
		t = 2.279, P = 0.02		t = 2.777, P = 0.006	
Age					
	20 – 29	0.18 – 1.88	1.08 ± 0.36	0.002 – 1.84	1.13 ± 0.38
	30 – 39	0.72 – 1.96	1.20 ± 0.36	0.02 – 1.90	1.21 ± 0.38
	40 – 49	0.30 – 1.97	1.18 ± 0.38	0.52 – 1.96	1.22 ± 0.37
	50 – 59	0.76 – 1.81	1.30 ± 0.33	0.65 – 1.83	1.20 ± 0.37
	≥ 60	0.59 – 1.66	1.03 ± 0.33	0.73 – 1.59	1.05 ± 0.30
		F = 4.020, P = 0.003		F = 1.78, P = 0.13	

P-value estimated using Independent t-test for sex, and one-way ANOVA (F) for age.

Post-hoc Analysis of Age-related Differences in the Right Mandible

Post-hoc analysis revealed highly statistically significant age-related differences in FD values of the right mandible. The 50–59 age group demonstrated significantly higher mean FD values [1.30 ± 0.33] compared to the youngest age group (20–29 years) [1.08 ± 0.36]. In contrast, age-related differences in the left mandible were not statistically significant (p = 0.13), although the highest mean FD value was observed in the 40–49 age group [1.22 ± 0.37]. A comparative analysis between the visual index assessment and FD analysis, as illustrated in Figure 6, showed a predominance of sparse trabecular bone patterns. This pattern was observed in 51.7% of right mandibular images based on the visual index and 51.9% based on FD analysis. For the left mandible, sparse patterns were observed in 44.2% (visual index) and 48.3% (FD analysis). Heterogeneous trabecular patterns were less frequent, occurring in 36.6% of right and 24.8% of left mandibular images.

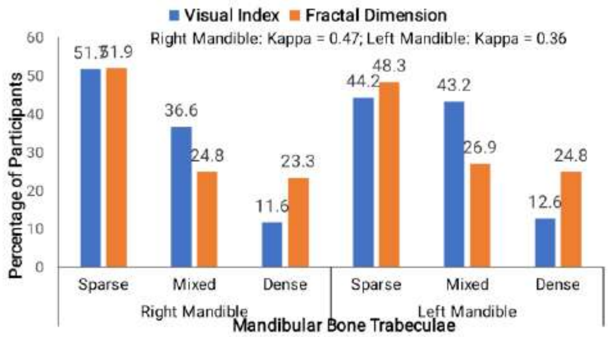


Figure 6. Comparison of visual index assessment and FD analysis methods for evaluating mandibular bone trabeculae.

Agreement between the two methods was assessed using Kappa statistics, showing moderate agreement for the right mandible (κ = 0.47) and fair agreement for the left mandible (κ = 0.36). Both methods were effective in identifying sparse trabecular patterns; however, discrepancies were more pronounced in the classification of heterogeneous and dense trabecular patterns.

DISCUSSION

Findings:

The findings of this study showed that the sparse trabecular pattern was effectively identified when both the visual index and FD analysis were used, with a prevalence of 51.7% and 51.9%, respectively. The prevalence of sparse trabecular distribution was higher among female participants, noticeable on both the right (56%) and left (50.3%) sides of the mandible using the visual index assessment. Similar prevalence rates of sparse mandibular trabecular patterns in the literature range from 2.2% to 48%.[7,29] This is particularly noted among older individuals and postmenopausal women. These findings highlight the role dental clinicians can play in identifying individuals at high risk of fractures, including populations of women with low BMD—a condition also prevalent in men over 50 years—through visual index assessment of mandibular trabecular patterns on conventional radiographs.[18,23,30]

These visual assessments, exemplified by the index proposed by Lindh et al.,[23] represent a straightforward and rapid clinical approach to evaluating bone microstructure, providing qualitative information about bone density and architecture. For example, changes in mandibular trabeculae, observed as sparse trabeculation on dental radiographs, can serve as indicators of more extensive skeletal bone loss, low BMD, and increased fracture risk elsewhere in the body.[9,31] An animal study has shown that the mandible reflects overall skeletal conditions and undergoes rapid bone turnover, making it a sensitive site for detecting early changes in bone loss and mineral content, although such rapid turnover has not been demonstrated in humans.[7,31]

Measurement indices (visual index vs. fractal analysis) were assessed and compared. Despite its usefulness, visual index assessment is subjective, requiring a minimum 30% change in bone mineral content for visual recognition. It should therefore be combined with other objective methods such as DXA (the gold standard for BMD measurement) or high-resolution quantitative CT (HR-QCT). Fractal analysis, based on non-Euclidean geometry, offers a technique that may improve the radiographic diagnostic accuracy of complex biological structures such as trabecular bone. It can detect changes of less than 30% in bone structure.[14,23,26,32]

Fractal analysis has diverse applications in dentistry, including the study of implant stability, quantifying the complexity of trabecular bone, periodontitis, fracture risk in osteoporosis, bruxism, and bone alterations following orthodontic treatment.[12,33] Trabecular bone density is considered a key indicator of bone health, with denser trabeculae suggesting healthy bones, while sparser patterns are associated with higher fracture risk.[9,18,19]

Side predilection of the sparse trabecular pattern was also assessed. The sparse pattern was more common in the right mandible, though no tentative evidence exists to support this laterality. Further multivariate studies with enhanced geometric detail are required to clarify whether this observation reflects a genuine underlying effect or a chance finding. Geraets et al.[18] noted that human perception of sparse trabecular patterns depends more on average gray values in the ROI than on internal geometric features. Sparse trabeculation should not be overlooked because it may signify clinical abnormalities like impaired bone formation and increased fracture risk.[31] A systematic review found significantly higher fracture risk in women with sparse trabeculation identified via visual assessment on dental radiographs.[8]

Right vs. left side predilection was further evaluated. A higher prevalence of sparse trabecular patterns (56% and 50.3% for right and left mandibles, respectively) was consistent among female participants. Factors such as age and hormonal changes, particularly among postmenopausal and elderly women, are known to influence bone morphology. Estrogen deficiency post-menopause is a key contributor. In line with our findings, Motwani et al.[34] reported that 46% of postmenopausal women showed sparse trabecular patterns using digital intraoral periapical radiographs. Bone loss is believed to begin with trabecular bone due to its large endosteal surfaces and progresses to cortical bone loss.[7,13,31]

Proposing a hypothesis to explain right-left differences in bone trabeculation

Using the visual index, we found no statistically significant age-related difference in trabecular patterns, but observed a marked right-left variation. Mandibular bone loss is influenced by multiple factors such as age, sex, hormonal status, medications, nutrition, lifestyle, and mechanical loading. These factors contribute to significant regional variations. Mavropoulos et al.,[35] using an animal model, emphasized the role of mechanical forces in bone remodeling. They showed that soft diets reduce masticatory force and subsequent bone stimulation, leading to decreased mandibular bone density. Conversely, orthodontic forces increase bone density in targeted regions. Based on this, we hypothesize that the observed right-left differences may stem from individual chewing side preferences or frequent soft diet intake among older participants. This aligns with Wolff's law, which states that bone remodels in response to mechanical stress.[36]

Dense trabecular pattern as seen in our study calls for caution among clinicians in interpreting "normal" BMD. Although dense trabecular patterns were classified as indicative of normal BMD in this study, literature suggests caution. Excessive insertion torque in dense bone may lead to marginal bone loss and implant failure due to over-compression. Therefore, lower torque values are advised during implant placement in such individuals.[37,38] Nicolielo et al.[39] hypothesized that both extreme ends of trabecular density—very sparse or very dense—are linked with higher risk of early implant failure, while intermediate types are more favorable for implant survival.

A significant sex-based difference ($p = 0.03$) in trabecular patterns was found, with males exhibiting more heterogeneous and dense patterns. This aligns with reports in literature[7,40] indicating that males tend to show denser, more complex, and stronger trabecular patterns compared to females.

FD pattern and assessment of mandibular trabecular complexity were also conducted. We applied FD analysis using the box-counting method[14,22] on digital panoramic images to evaluate mandibular trabecular complexity and identify individuals at risk of low bone density. Higher FD values denote more complex geometric patterns. Mean FD values in healthy bone range from 1.10 to 1.83.[41] Yaşar and Akgünlü[28] reported a mean FD of 1.3623 in dentate regions, demonstrating significant differences in FD between dentate and edentulous areas due to masticatory load changes.[2,28] Our study reported mean FD values of 1.15 and 1.17 for the right and left mandibles, respectively, consistent with literature.[28,41] Although significant morphometric differences were noted between male and female mandibles, data on microstructural differences in our region are scarce. A CBCT-based study reported higher mean FD values in men (1.02) compared to women (0.97), supporting our finding of sex-based differences.[42]

Implications

- Sparse trabeculation should not be overlooked, as it may indicate impaired bone formation and high fracture risk.
- Sparse mandibular trabeculation may offer a rapid method to identify individuals, particularly women, at risk of osteoporosis/osteopenia using dental radiographs.
- Our findings support prudence during treatment planning for osteotomy, implant placement, and orthodontic procedures in males.

Trade-offs (Limitations)

- Being a single-center study, potentially limits generalizability. However, the large sample size and rigorous measures to ensure validity and minimize bias mitigate this concern.
- Visual assessment remains subjective and may vary between observers.
- Regional variations in trabecular patterns within the same mandible complicate the establishment of standardized evaluation criteria.
- FD analysis on 2D images may inadequately capture the full geometric complexity of mandibular microstructures.
- Limited ROIs may not reflect all dynamic changes in mandibular bone structures.

Take-home (Conclusion):

Both the visual index and FD analysis effectively identified sparse trabecular patterns. However, notable variance was seen between the two methods in identifying complex trabecular structures. This suggests that while both methods have merit, neither is universally suitable for all trabecular pattern types. A combination of clinical anamnesis, radiographic evaluation, and imaging software may be necessary for comprehensive assessment during treatment planning.

Expectations for Future Research:

Future studies should adopt a multicenter design with a broader range of ROIs.

Recommendations:

While FD offers a promising and objective method for evaluating mandibular trabecular structures, future studies should integrate more clinical variables and advanced radiographic modalities.

Conflicts of interest:

The authors declare no conflicts of interest.

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