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Research Article

FRACTAL ANALYSIS OF TRABECULAR BONE PATTERN IN THE MANDIBLE AS AN INDICATOR OF OSTEOPOROSIS IN WOMEN - A CLINICAL STUDY

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ABSTRACT

Objectives: The objectives of this study were to estimate and compare the measurement of trabecular bone pattern in the mandible of normal and osteoporotic volunteers.

Methods: A 43 female volunteers were selected as osteoporotic (n=43) group and 30 as normal (n=30) group with age ranging from 25 to 60 years were enrolled based on bone mineral densitometer (BMD) in the calcaneus bone. A detailed case history followed by digital periapical radiograph was performed. The mandibular trabecular bone pattern in these volunteers was determined using Image J software, after standardizing the pixel size and locations of the region of interest for three different regions between the two groups. Statistical analysis using independent t-test and Pearson coefficient was performed.

Results: Results showed a significant difference in mean BMD values between the groups (0.52 in normal and −3.22 in osteoporotic). There are no significant differences in mean fractal dimension values between the groups (0.83 in normal and 0.82 in osteoporotic). Pearson correlation coefficient shows no significant correlation between the groups at three sites (p>0.001).

Conclusion: Although trabecular bone microstructure on an intraoral radiograph plays a key role in defining osteoporosis, the present study did not show any significant difference in its architecture between normal and osteoporotic individuals as defined by BMD. Therefore, further studies should be performed using better-standardized resolution strategies and different estimation methods to gain more insight.

Keywords: Dental radiograph, Osteoporosis, Densitometry, Trabecular bone, Fractals.

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INTRODUCTION

Osteoporosis is a skeletal disorder characterized by compromised bone strength predisposing a person to an increased risk of fracture [1]. Measurements of bone mineral densitometer (BMD) are done by various methods such as dual-energy X-ray absorptiometry (DEXA) scan, bone biopsy, and other adjuncts include quantitative ultrasound calcaneal (QUS), computed tomography (CT), and magnetic resonance imaging. Numerous studies have shown that DEXA scan though being the gold standard method for detecting osteoporosis has its own limitations which prevent it from being used in the mass screening of osteoporosis. Compared to DEXA, QUS offers wider accessibility, portability, ease of handling, economical, and does not emit ionizing radiation [2].

Trabecular bone has a branching pattern in which bone remodeling is more and is the significant indicator of osteoporosis [3]. However, osteoporosis is not only characterized by a decrease in density but also by structural changes in the architecture of trabecular bone. The inner aspect of alveolar bone appears spongy having spicules, trabecular, and lamella which give its typical structure. Lattice pattern has an accurate expression of the internal bony medullary cavity on intraoral periapical radiograph [4]. Many studies have been carried out to determine the quality of alveolar bone of which fractal analysis is accurate, easily available, and economical [5]. In fractal dimension (FD), morphometric analysis along with mathematical processing is done using a radiographic image. There are many counting algorithms in the fractal analysis, of this box-counting method was used to analyze the trabecular pattern.

Digital radiography made with digital sensors facilitates image manipulation, reduced patient exposure, relatively inexpensive, and viewing the minute details of the image. These images are stored on the computer and shared for the benefit of patient management [6]. Although many studies have been performed using fractal analysis to determine osteoporosis, many authors have not demonstrated the roles of standardized resolution and location of the region of interest (ROI) [7]. With this background, the aim of our study was to compare and estimate the measurements of the trabecular bone using standardized pixel dimension and defined regions of interest in both the groups. The present study is unique wherein osteoporosis screening was done using calcaneus BMD instead of DEXA to enroll the study participants.

METHODS

Study group

The study was performed in the oral medicine and radiology department which was approved by Ethical Committee Review Board and informed written patient consent was obtained from all the subjects. A mass screening for osteoporosis was done for 1 week using QUS device in women with age ranging between 25 and 60 years. A total of 43 were in the osteoporotic group in which 13 were excluded: 10 due to systemic diseases and medications and 3 were not willing to participate in the study and 30 were included in the control group. Patients with systemic conditions such as a chronic renal disease, anemia, hyperthyroidism, long-term steroid medications, Paget's disease, and dental conditions such as periapical and periodontal pathologies were excluded.

BMD evaluation

BMD evaluation was done using the bone densitometer CM-200 machines at calcaneus region. It is based on the measurement of ultrasound pulse penetration. For estimation, the participants were recommended to place the calcaneus bone of the right leg in the foot compartment of CM-200 devices (Fig. 1). The software of the CM-200 devices will evaluate the BMD of the calcaneus bone. The measurement results were determined by T-score criteria set by the World Health Organization (WHO) which was graphically presented on the device

Asian J Pharm Clin Res, Vol 11, Issue 2, 2018, 157-160

monitor. T-score >−1 is normal; T-score between −1.1 and −2.5 is osteopenia; and T-score ≤ −2.5 is osteoporosis [8]. The volunteers were then subjected to oral examination to evaluate the dental status.

Radiographic evaluation

The Satelec Acteon X-ray machine with exposure parameters of 0.250 mA and 70 kVp was used. PSP sensor was used to record the digital periapical radiograph using paralleling technique. The films were processed and the images were stored in BMP (Bitmap) format. The images were digitized by 8-bit image type and 300 dpi spatial resolution by a logarithmic algorithm. All images were analyzed using Image J version 1.32j, public domain software developed by National Institute of Health (US). A pixel size of 34×30 was fixed and was used in all the ROI. Three regions of interest were selected. The regions of interest include: (i) D1-apical area of mandibular premolar tooth, (ii) D2-interproximal area between molar and premolar, and (iii) D3-posterior to the last mandibular molar and superior to the inferior alveolar nerve canal. The three ROI selection on the periapical radiograph was done using the criteria of measuring 2.5 mm from the root apices or mesially or distally [9]. The ROI was cropped to binary image and skeletonized image using white and Rudolph method [10]. The skeletonized image indicates the bone pattern (Fig. 2). This image was then converted into the widths of the square boxes with 2, 3, 4, 6, 8, 12, 16, 32, and 64 pixels. Finally, FD value (D-value) (Fig. 3) were calculated.

Statistical analysis

Data analysis was performed using SPSS 22.0 software. Independent t-test was used to calculate the mean values between the groups of variables. Pearson correlation coefficient analysis was used to calculate the linear relationship between variables of the two groups.

RESULTS

Table 1 summarizes the mean BMD and FD of the study groups. The mean BMD T-score in control groups was 0.52 and in study groups was -3.22. The mean FD value in control groups was 0.83 and in study groups was 0.82. A significant difference in the BMD values was found between the groups (p<0.001).

Table 2 summarizes the FD values of the study subjects according to three sites with no significant differences between the groups (p>0.001). Table 3 summarizes the correlation coefficient at the three sites between the groups with no significant differences.

DISCUSSION

The present study aimed at estimating and comparing the measurements of trabecular bone pattern in the mandible of normal and osteoporotic conditions. Osteoporosis is "a systemic skeletal disease characterized by low bone mass and micro-architectural deterioration of bone tissue, with a consequent increase in bone fragility and susceptibility to fractures" [11]. The evaluation of BMD by DEXA scan is the gold standard method for assessing the osteoporotic risk (WHO, 2003). Most of the studies have used calcaneal BMD less frequently in comparison to DEXA [7]. Studies on calcaneus BMD have a great advantage compared to other skeletal bones, and the measurements are not affected by local factors such as spinal deformation and fractures [12]. A study by Martini *et al*. proved that calcaneus BMD is an accurate and cost-effective technique in the diagnosis of osteoporosis [13]. Therefore, the present study, to the best of our knowledge, is the first one in which osteoporosis screening was done using calcaneus BMD instead of DEXA to determine the study group. None of the study participants were known osteoporotic.

Lindh *et al*. showed that the bone remodeling is more extensive in the trabecular bone than in the compact bone which is the manifestation of osteoporosis. It is not clear what structure give rise to the trabecular pattern. A study by Bender *et al*. showed that the posterior regions of mandible did not alter in radiographic appearance of trabeculae when influenced by the muscle activity or the occlusal forces [14]. Most of the clinical studies have not taken into consideration the odds of trabecular bone architecture changes by anatomical variations, various imaging methods, and different estimation methods for measuring FD. Our study is the first in the literature which has aimed at standardizing the pixel size at 34×30 and location of ROI by taking three different sites: D1, D2, and D3, respectively.

Fig. 1: Bone mineral densitometer CM-200 device

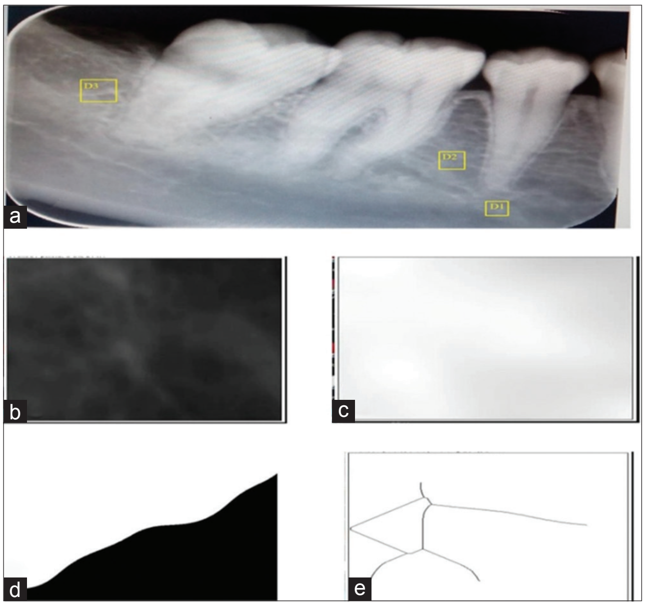

Fig. 2: (a) Region of interest, (b) blurred image, (c) grayscale image, (d) binary image, and (e) skeletonized image

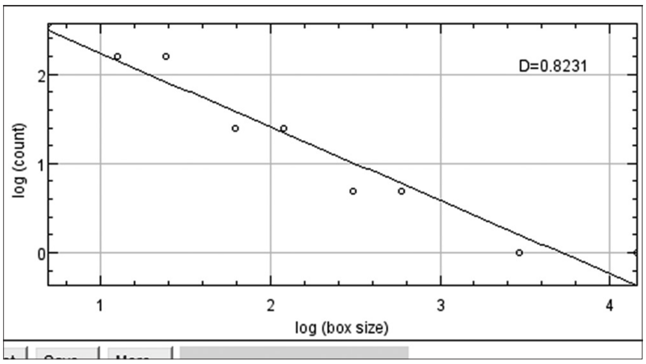

Fig. 3: Shows fractal dimension values calculated from the slope of the line fitted to the data points

Table 1: Mean BMD and FD values of the study groups

Variables	Group	Mean±SD	T	p
FD: D1	Osteoporotic	0.82967±0.099116	0.254	0.800
	Normal	0.83633±0.104138		
FD: D2	Osteoporotic	0.84367±0.131477	0.123	0.903
	Normal	0.84733±0.097872		
FD: D3	Osteoporotic	0.82367±0.128129	0.337	0.738
	Normal	0.83433±0.116993		
BMD	Osteoporotic	−3.22333±0.550350	12.377	<0.001
	Normal	0.52500±1.564738		

N: 30 Normal group, N=30 osteoporotic group, FD: Fractal dimension, BMD: Bone mineral densitometry. D1: Apical region of mandibular premolar tooth, D2: Interproximal area between molar and premolar, D3: Posterior to the last mandibular molar and superior to the inferior alveolar nerve canal, SD: Standard deviation

Table 2: FD values of the study subjects according to three sites

Site	Normal - FD values	Osteoporosis - FD values	p
D1	0.83	0.82	0.800
D2	0.84	0.84	0.903
D3	0.83	0.82	0.738

FD: Fractal dimension, D1: Apical region of mandibular premolar tooth, D2: Interproximal area between molar and premolar, D3: Posterior to the last mandibular molar and superior to the inferior alveolar nerve canal

Table 3: Correlation coefficient between the three sites

Fractal dimension	All	Osteoporotic	Normal
FD: D1			
Correlation	0.093	−0.330	0.291
p	0.479	0.075	0.118
FD: D2			
Correlation	0.011	−0.232	0.101
Significant (2-tailed)	0.932	0.217	0.595
FD: D3			
Correlation	0.168	0.203	0.312
Significant (2-tailed)	0.200	0.282	0.093

FD: Fractal dimension, D1: Apical region of mandibular premolar tooth, D2: Interproximal area between molar and premolar, D3: Posterior to the last mandibular molar and superior to the inferior alveolar nerve canal

The use of digital periapical radiograph helps in the assessment of trabecular bone which could be a cost-effective tool for identifying individuals at risk of osteoporosis. Several methods have been developed to estimate the trabecular bone density from radiographs; fractal analysis holds the greatest value in determining the trabecular complexity and bone structure. Amer *et al.* stated that different regions in periapical radiograph revealed significant differences in the FD values [15]. Yasar *et al*. suggested that FD value did not show significant differences in the trabecular bone pattern [16]. These results are conflicting. Hence, the present study was performed using standardized resolution and ROI. Several attempts have been made for the reliability of FD estimation with different algorithmic methods. Box-counting method, despite being the commonly used one has several limitations like magnification factor [9]. Matheus *et al.* showed that FD value did not change by tile counting method. Images influenced by various spatial resolutions produce different FD values [3]. Cha *et al.* and Geraets and van der Stelt mentioned that the use of different methods of estimation for fractal analysis could be a problem, as its diagnostic accuracy becomes questionable [17,18]. The results can change based on the techniques used to determine FD. Brewer demonstrated the roles of resolution and quantization as limiting factors in the estimation of FD [19]. Many studies have shown that the problem in the fractal analysis of binary images is the effect of noise [9]. Since no estimation methods work well universally, the relative discrepancies of all estimating techniques need to gain insights [20]. In our study using digital images, FD values did not change when spatial resolution is the same by box-counting method. Therefore, each imaging modality has its own non-linear artifacts such as resolution and quantization. FD analysis of cone beam CT images warrants further investigations, as only one study has used this imaging modality [7].

Our study has merits and drawbacks. Due to the strength, we have standardized the pixel size and locations of ROI at three different sites in calculating FD values. This suggests that each site is not influenced by local factors such as occluding teeth and masticator forces. Consequently, the limitations such as roles of resolution, quantization, and different methods of estimation of FD values were questionable. The imaging modality is also a factor since we used two-dimensional (2D) images which have noise and sampling frequency as drawbacks. Therefore, three-dimensional (3D) images should be used for better quality of images and determination of FD values.

CONCLUSION

FD values of the trabecular bone assessed by digital images, box-counting method, standardized pixel size, and three different ROI did not show any significant differences between osteoporotic and normal volunteers. Further, multi-centric studies should be performed with larger sample size, 3D techniques along with the measurements of biochemical markers such as serum alkaline phosphatase and calcium to give an overview of the bone turnover, which could also be cost-effective and simple. This can give a better insight into using QUS and periapical radiographs as osteoporosis indicators in mass screening.

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