



## FRACTAL ANALYSIS USING CONE BEAM COMPUTED TOMOGRAPHY (CBCT) FOR DETECTING OSTEOPOROSIS.

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### ABSTRACT

Osteoporosis is a systemic disorder of bone characterized by a reduction in bone mass and deterioration of bone micro architecture. Cone Beam Computed Tomography (CBCT) is now being commonly prescribed as they offer more information as compared to conventional 2D radiographs. The aim of our in-vitro study was to examine fractal dimension (FD) changes on mandibular trabecular bone during simulated osteoporosis and evaluate fractal dimension in each region of interest on CBCT images and compare the same with Dual energy X-ray absorptiometry (DEXA) values. Twelve specimens were obtained from three cadaveric mandible bones subjected to decalcification at various time intervals to simulate osteoporosis. CBCT and DEXA scans were made before and after processing the samples. Grand average fractal dimension at each decalcification stage was calculated and correlation analysis was performed to quantify the relationship at each stage between FD and BMD. There was a significant difference in the FD and BMD values, p value ( $p < 0.05$ ). FD values at each stage of periodic decalcification were not significantly correlated with the BMD measurements. Further research related to fractal dimension requires a careful choice of method for calculating it, and that the fractal dimension which detects changes in trabecular structure, but may not be a descriptor of decalcification of trabecular bone.

**KEYWORDS:** Osteoporosis, Cone Beam Computed Tomography (CBCT), Dual energy X-ray absorptiometry (DEXA) Fractal dimension (FD), Bone mineral Density (BMD).

### INTRODUCTION

“Osteoporosis” as a term was first described in 1950s as ‘too little bone’ by Fuller Albright.<sup>[1]</sup> Osteoporosis is a systemic disorder of bone characterized by a reduction in bone mass and deterioration of bone micro architecture. Bone strength is primarily determined by integration of both bone density and quality. Due to micro architectural deterioration there is enhanced bone fragility and consequent increase of risk factors for fractures as mentioned in NIH Consensus Development Panel.<sup>[2]</sup> It predominantly affects elderly population with significant morbidity and mortality. It is postulated that ageing populations worldwide will be accountable for rise in the incidence of osteoporosis, especially in postmenopausal women. Bone quality is estimated by both mineral assay and bone micro architecture. Estimation of micro architectural structure has been a difficult proposition.

Trabecular bone is the most common site in the jaw bones for osteoporosis. Trabecular bone represents a complex structural pattern. One of the techniques used to

study and describe such complex shapes and structures is Fractal analysis; which is expressed numerically as Fractal Dimension (FD). The term ‘Fractal’ in literal sense means ‘broken’ or ‘fracture’. In a fractal each fragmented structure can reproduce the whole structure at all levels of magnification. Trabecular bone is also a fractal structure.

Various oral signs and features observed on routine dental radiographs have been suggested as possible indicators of osteoporosis. Dental radiographs commonly prescribed for routine dental procedures are two dimensional panoramic radiographs and intra-oral periapical radiograph which are assessed for signs like teeth present mentioned by Taguchi A<sup>[3]</sup>, mandibular cortical width described by Taguchi A, Swei Y<sup>[4]</sup>, alveolar bone resorption, morphologic classification of inferior cortex<sup>[3],[4]</sup> and to predict any latent osteoporosis in a patient Kwang-Joon Koh.<sup>[5]</sup> However, Cone Beam Computed Tomography (CBCT) is now being commonly prescribed as it offers more information as compared to

conventional 2D radiographs in cases like preoperative planning of endosseous dental implantation procedures, dentoalveolar trauma, craniofacial trauma such as zygomaticomaxillary or mandibular fractures, assessing the morphological changes in the temporomandibular joints and for pathologies associated with paranasal sinuses. It is an established and widely used tool in Oral-Maxillofacial imaging for orthognathic surgeries associated with correction of craniofacial deformities and Orthodontic assessment for comprehensive information regarding inclination of teeth and position of impacted and supernumary teeth where accurate image geometry is essential and also to determine the bone quality. Fractal analysis has been performed on two dimensional radiographs to assess the trabecular structure. The work of Ruttimann *et al*<sup>[6]</sup>; Southard *et al*<sup>[7]</sup> on intraoral periapical radiographs and Caligiuri *et al*<sup>[8]</sup> on digital lumbar spine radiographs; demonstrated that the fractal dimension may be a useful morphometric descriptor of bone quality. Whereas, the work of KI Lee<sup>[9]</sup> using intraoral periapical radiographs and Kwang-Joon Koh<sup>[5]</sup> using panoramic radiograph concluded that these imaging modalities might not be adequate to detect osteoporosis. The results of earlier studies are mixed and given this ambiguity it was important to do this study using a different imaging modality. Thus, the aim of our in-vitro study was to examine fractal dimension changes on mandibular trabecular bone during simulated osteoporosis and evaluate fractal dimension in each region of interest on CBCT images and compare the same with Dual energy X-ray absorptiometry (DEXA) values.

## MATERIAL AND METHODS

### 1. Preparation and Image acquisition

Twelve specimens were obtained from three cadaveric mandible bones. Each section was thoroughly rinsed with distilled water and air dried. A small hole was drilled in each specimen above the area of interest for purpose of reproducibility of that area in order to observe trabecular changes prior and after each stage of decalcification. CBCT and DEXA scans were made before and after processing the samples.



**Figure 1** Mounting of bone specimen on a jig for obtaining CBCT scan.

Cone Beam computed tomography scans were obtained on Kodak 9000c machine with small Field of View (FOV) 5 x 3.7 cm and with an isotropic voxel size of 0.076 mm. The specimens were radiographed by

securely fastening on a special jig and reproducible radiographs were obtained [Figure 1].

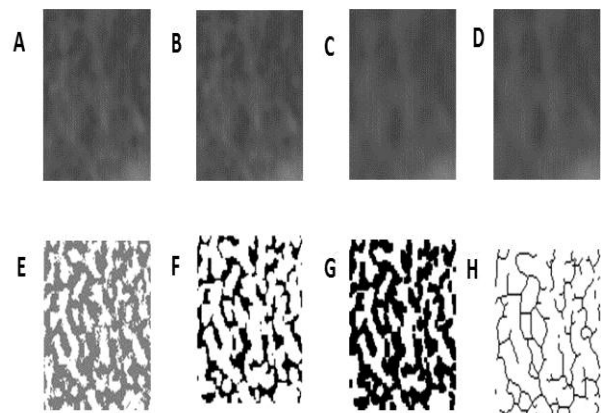
Bone specimen was subjected to progressive partial decalcification in fresh solution of 0.1N hydrochloride solution at cumulative timed period of 30, 60 and 90 minutes. After each decalcification period, solutions were collected and specimens washed in distilled water, dried and then radiographed as well as subjected to DEXA scan.

CBCT images were viewed on HP Compaq LE 1911, 19" VGA LCD display (Hewlett Packard Company, 3000 Hanover Street, 94304 – 1185, USA) at a 1280x800 resolution using the Kodak dental imaging software (version 6,12,10,0 copyright Carestream Health Inc., 150 Veronal Street, Rochester, NY 14608, USA).

According to the criteria from the WHO, DEXA scans were interpreted as Bone mineral Density (BMD) values ranging from 0.2 to 1.6.

### 2. Fractal and statistical analysis

After obtaining CBCT images of each specimen, one slice in paraxial section was used for each selecting the Region of Interest (ROI). Slice thickness was 0.2mm. ROI was the cancellous bone in cross section plane. Each selected ROI was photographed in CS3D Imaging software then processed to grayscale and resampled to the size of 45.16X45.16mm (128X128 pixels) on Adobe Photoshop 7.0 software. Then the image was saved in BMP format. Fractal dimension was carried out using Image J software as shown in figure 2. The transferred cropped ROI was filtered using Gaussian blur, sigma=3 to remove the fine and medium scale variations in image brightness and then saved again. Then, the original ROI and the blurred one were subtracted from each other and multiplied by one and added 128. Then, the resultant image was converted to binary image with threshold at grey level of 128. The binary image was eroded and dilated three times to reduce the noise.



**Figure 2** Image processing procedures. A.ROI (128x128 pixels), B. Gaussian blurred image, C subtraction image, D. Multiplication and addition image, E. Binary image, F. eroded image. G. dilated image, H. skeletonized image.

Using Image J software, the fractal dimensions (FDs) of the outlined image will be calculated by Box Counting function as described by Maha Eshak Amer.<sup>[10]</sup> Initially, the Image is converted by square grid of equally sized tiles; widths of the square boxes are 2, 3, 4, 6, 8, 12, 16, 32 and 64 pixels. Subsequently, the number of the counted tiles will be plotted against the total number of tiles in a double logarithmic scale. Finally, FD calculated from the slope of the line fitted on data points.

The SPSS 10.0' software (SPSS Inc., IBM Company Headquarters, Chicago IL) was used for storing and analyzing data. Grand average fractal dimension at each decalcification stage was calculated and correlation analysis was performed to quantify the relationship at each stage between FD and BMD.

## RESULTS

The mean FD value was 1.219 prior to decalcification and 0.731 after simulating osteoporosis. The mean BMD was 1.213 and 0.615 respectively. The images of the trabecular bone showed fractal behavior. All bone specimens showed decreased fractal dimension on progressive decalcification. BMD values also decreased following decalcification. Significant changes of fractal dimension, calculated by mathematical morphology operations combined with box counting, as well as BMD values obtained with DEXA scan could be noted (Table 1). There was a significant difference in the FD and BMD values, p value ( $p < 0.05$ ). FD values at each stage of periodic decalcification were not significantly correlated with the BMD measurements (TABLE 2).

**TABLE 1: Values and Mean  $\pm$ SD of twelve specimens obtained prior to decalcification and after each stage of decalcification.**

SPECIMEN	0 min		30 min		60 min		90 min	
	FD	BMD	FD	BMD	FD	BMD	FD	BMD
1	1.26	1.21	1.26	0.80	0.90	0.70	0.90	0.66
2	1.26	1.10	0.89	0.73	0.83	0.66	0.63	0.64
3	1.07	1.21	0.89	0.72	0.84	0.67	0.77	0.61
4	1.34	1.20	0.85	0.79	0.80	0.67	0.74	0.68
5	1.27	1.32	0.93	0.88	0.82	0.79	0.73	0.61
6	1.23	1.32	0.89	0.71	0.81	0.62	0.80	0.61
7	1.27	1.21	0.95	0.77	0.90	0.63	0.79	0.61
8	1.25	1.22	0.94	0.82	0.88	0.76	0.79	0.62
9	1.01	1.00	1.24	0.70	0.90	0.54	0.65	0.51
10	1.29	1.12	1.22	0.69	0.91	0.51	0.68	0.50
11	1.26	1.21	0.95	0.70	0.90	0.66	0.65	0.63
12	1.12	1.43	0.89	0.72	0.82	0.70	0.65	0.68
<b>MEAN VALUES</b>	1.219	1.213	0.991	0.753	0.860	0.660	0.731	0.615
<b>STANDARD DEVIATION</b>	0.098	0.110	0.151	0.059	0.042	0.080	0.082	0.059

FD- Fractal Dimension.

BMD- Bone Mineral Density.

**TABLE 2 Co-relation of Fractal Dimension (FD) and Bone Mineral Density (BMD) values at each stage of decalcification.**

Study Parameter		FD 0 min	FD 30 min	FD 60 min	FD 90 min
<b>BMD 0 min</b>	Pearson Correlation	0.14	-0.54	-0.53	0.21
	P Value	0.67	0.07	0.08	0.52
<b>BMD 30 min</b>	Pearson Correlation	0.41	-0.19	-0.22	0.46
	P Value	0.18	0.59	0.49	0.13
<b>BMD 60 min</b>	Pearson Correlation	0.20	-0.51	-0.39	0.28
	P Value	0.53	0.09	0.21	0.38
<b>MD 90 min</b>	Pearson Correlation	0.28	-.61(*)	-0.53	0.23
	P Value	0.38	0.04	0.08	0.47

FD- Fractal Dimension.

BMD- Bone Mineral Density.

## DISCUSSION

Fractal analysis appears to be a useful method for estimating the bone density on dental radiographs as described by Geraets WG<sup>[11]</sup>, Jolley L<sup>[12]</sup> and Amer ME.<sup>[13]</sup> In fractal analysis, there are different methods for calculating the FD, which can be used to compare normal bone with osteoporotic bone. A tile counting described by Heo MS<sup>[14]</sup> or box counting algorithm described by Chen SK<sup>[15]</sup> and Ergün S.<sup>[16]</sup> has been mainly used to quantify the trabecular pattern by counting the trabecular bone and bone marrow interface. In present study we have used Box counting using Image J software as this software is easily available and simple to use. A higher box counting volume indicates a more complex structure. Southard et al<sup>[7]</sup> found that the average FD decreased from 1.26 to 1.1 on the radiographs of 10 decalcified human alveolar bone Kwang-Joon Koh<sup>[5]</sup>, demonstrated that the FD on the panoramic radiographs decreased in the osteoporosis group compared with the normal group this in corroboration with the present study where both FD and BMD values decrease on progressive decalcification as compared to the values obtained prior to decalcification process. However, Ruttimann and Ship<sup>[6]</sup> reported that the FD increased with decalcification. The variance of the results in the studies mentioned could be due to anatomical variations, discrepancies in the methods, techniques for measuring the FD, or the differences in selecting the regions to be measured.

Trabecular bone has a branching pattern that exhibits fractal properties of self similarity that is a small fragment from the bone image will show same pattern at level of magnification. Because of this phenomenon, application of fractal geometry and measurement FD can be applied to determine trabecular complexity and bone structure. There is some loss of image information in the digitization process as mentioned in the work by Chen SK<sup>[17]</sup>; however, the major concern of inhomogeneity in the scanning process should have a limited effect on the results. ROI 45.16X45.16mm (128X128 pixels) was cancellous bone selected from the cross section images from the Inter Radicular area.

Periapical area was avoided because it is prone to alteration in trabecular bone pattern caused by odontogenic inflammatory conditions such as periapical abscess or granuloma. Skeletonization was done for the ROI to recognize trabecular pattern as separate from the background, the intensity of which became zero after applying the skeleton method.

Mean FD values of all the non decalcified samples was  $1.219 \pm 1$  SD and BMD was 1.213. FD values decreased after each period of decalcification and it is significantly correlated with  $p < 0.05$ . However, no significant correlation has been obtained BMD and FD values after each period of decalcification with p value more than 0.05. Similar result of non significant correlation between FD and BMD values was demonstrated in study

performed by Kwang-Joon Koh<sup>[5]</sup> to evaluate the trabecular pattern on panoramic radiographs to predict age related osteoporosis in postmenopausal women, as well as Southard et al<sup>[7]</sup> in the study using radiographs of decalcified human alveolar bone. In our study probably small sample size and other confounding factors may have resulted in non significant correlation of FD and BMD values. However, method described in the present study is simple, cost effective and non invasive to detect the trabecular bone pattern subjected to osteoporotic changes.

## CONCLUSION

Cone Beam Computed Tomography has evolved as a popular imaging modality by general dentist for various treatment procedures like Implant surgery, Orthognathic surgery and other invasive procedure where determination of bone quality has become mandatory. Fractal being non invasive and in expensive tool does hold promise in analyzing bone trabecular structure.

In conclusion, the results of this study indicate that further research related to fractal dimension requires a careful choice of method for calculating it, and that the fractal dimension which detects changes in trabecular structure, but may not be a descriptor of decalcification of trabecular bone.

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