대한구강악안면방사선학회지 2004; 34 : 179-83

The influence of X ray beam angulation on the fractal analysis of trabecular architecture in human dry mandible using standardized tile counting method

Kyung-Hee Lee, Sun-Bok Lee, Chang-Hyeon An*, Min-Suk Heo, Won-Jin Yi, Kyung-Hoe Huh,
Moo-Soon Park, Sam-Sun Lee, Soon-Chul Choi

Department of Oral and Maxillofacial Radiology, Dental Research Institute, and BK21, College of Dentistry, Seoul National University

**Department of Oral and Maxillofacial Radiology, College of Dentistry, Kyungpook National University*

ABSTRACT

Purpose : The purpose of this study is to examine the effects of X-ray beam angulation on the fractal dimension of trabecular bone structure of human dry mandible using the tile counting method.

Materials and Methods : We divided 5 human dry mandibles into an angle and a molar groups depending on the regions and deciding the region of interest (ROI). When contrasted with the ROI, the inferior cortex was appointed to be low and the lines perpendicular to the buccal cortex were appointed to be the standard angle. Direct digital intraoral radiographs were obtained from 9 different projection angles. We analyzed statistically the fractal dimension using the tile counting method.

Results : There was a statistically significant difference in the fractal dimension of the regions and the mandibles, but there was no statistically significant difference in the fractal dimension according to the X-ray beam angulation.

Conclusion : There is no statistically significant effect of the angle of the projection on the fractal dimension of trabecular bone structure of a human dry mandible according to the tile counting method. (***Korean J Oral Maxillofac Radiol 2004; 34 : 179-83***)

KEY WORDS : Fractals; Mandible; Radiography, Dental, Digital

The condition of bone is critical for the retention of the teeth. Dentists regularly take radiographs which have high resolution, in hopes that it might contain significant amounts of information on bone quality. Fractal dimension, which is a measure of the complexity of an object,[1,2] has been utilized as a possible diagnostic indicator of osteoporosis.[3-10] Fractal dimension offers a potential mean of detecting changes in the bone mineral content with dental radiography. Ruttimann et al.[11] estimated fractal dimension from radiographic images of mandibular alveolar bone before and after partial decalcification. They concluded that fractal dimension was changed after acid-induced demineralization, irrespective of the projection angle used to produce the radiographs. Since this research, there have been many published researches stating that there is a significant interrelationship among the fractal dimension of bone, the bone mineral content, and osteoporosis in dental radiograph.[12-16] There have also been reports on how fractal dimension can be an indicator in local bone changes due to periodontitis[17,18] after implant fixation[19] or surgery,[20] bone remodelling and so on. Lately, fractal dimension provided additional information beyond bone mineral density in correlation with biomechanical properties. But it must be noted that fractal dimension of bone is technique dependent[8,14] and fractal dimension of bone should be carefully designed with individual methods thoroughly evaluated.[19,21]

There has been some controversy on the effect of the projection angle on fractal analysis in the evaluation of bone property. Ruttimann et al.[11] concluded that the projection angle had no significant effect on the fractal dimension; Buckland-Wright et al.[22] stated that fractal analysis appears to be independent of projection geometry. However, in the research of Southard et al.[12] the specimens of human maxillary alveolar process bone were subjected to a -5-degree, 0-degree, and 5-degree altered projection angle. It was said that the results showed that every bone sample fractal dimension changed significantly with angular change. Chen and Chen[23] also quoted that the fractal dimensions changed significantly

---

*This study was supported by a grant of the Korea Health 21 R & D Project, Ministry of Health & Welfare, Republic of Korea. (01-PJ5-PG1-01CH12-0002)
Received October 7, 2004; accepted October 29, 2004

Correspondence to : Prof. Soon-Chul Choi
Department of Oral and Maxillofacial Radiology, College of Dentistry, Seoul National University 28, Yeongeon-dong, Jongno-gu, Seoul, 110-749, Korea
Tel) 82-2-2072-2622, Fax) 82-2-744-3919, E-mail) raychoi@snu.ac.kr

with projection geometry in a simulated alveolar bone model.

Ideally, the fractal dimension is insensitive to small variations in the projection angle. If the fractal dimension changes significantly to small variations in the projection angle, then its clinical value is questionable.

Therefore, the purpose of this research is to identify whether there is a statistically significant difference in the fractal dimension of a human dry mandible following a 10-degree alteration of the projection angle.

Materials and Methods

1. Material sampling

This study is based on 5 human dry mandibles, of unknown age, without any disease. Each mandible was classified into the angle region and molar region on both sides (Fig. 1).

2. Image acquisition

A direct digital intraoral radiographic system (Jupiter CDX-2000HQ, Biomedisys Corp., Seoul, Korea) and x-ray unit (Heliodent DS, Siemens Corp., Munchen, Germany) were used for the image acquisition. The images were acquired using the image taking method widely used in the clinics. Each mandible was fixed as a separate region using the specially devised positioning device. The distance between X-ray source and buccal cortex was fixed at 40 cm. A 40 × 30 mm CCD sensor was placed under the mandible. We fixed the tube current at 7 mA , the peak tube voltage at 70 kVp, and the exposure time at 0.16 sec. In each region, we appointed the inferior cortex of the mandible to face downward, and the projection angles that were perpendicular to the buccal cortex to be the standard angle, obtaining the image acquisition of 9 projection angles (standard, upper, upper-right, right, lower right, low, lower-left, left, upper-left) inclining it in 8 different directions of 10 degrees. The obtained digital images were in whole 180 pieces and the size was 3.57 × 2.73 cm (812 × 620 pixels). The image resolution was 577.7 dpi and the size of the pixel was 0.044 mm.

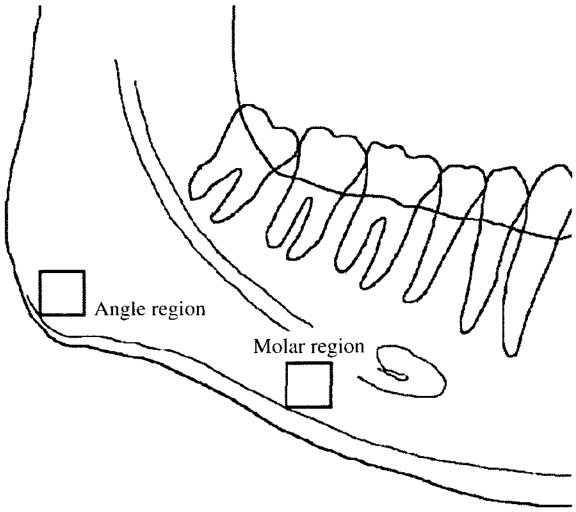

Fig. 1. Selection of ROI. 180 × 190 pixel sized ROI in bone trabecular structure were chosen from both sides of angle and molar regions.

3. Image processing

For the image processing, the pixel was set at 180 × 180 (7.92 × 7.92 mm), and the region of interest (ROI) was established in the identical anatomic location for each region (Fig. 1). For the angle region, the ROI was set adjacent to the inferior cortex of the mandibular angle, and that for the molar region, adjacent to the inferior cortex under the first molar.

Image processing was performed automatically by an automatic image analysis macro which was prepared by the Scion image program ver4.1 (Scion Corp., Frederick, Maryland, USA). This macro had been based on a Pentium 4 based personal computer. The image processing is a partially revised form of a known image process[24] that extracts the radiographic trabecular bone pattern (Fig. 2). After duplicating the ROI, we gained the blurred image using the Gaussian filer (sigma = 10 pixels, kernel size = 31 × 31 pixels), subtracted it from the ROI, added a 128 gray level, and finally ended up with the standard image. This standard image was low frequency noise subtracted image from the ROI and the mean gray level of the standard image was standardized at 128. We converted this standard image into a binary image based on the 128 gray level, extracted the outline, and obtained an outline image. We then obtained the fractal dimension by the tile counting method from the tiles of the outline image, sized from 3 pixels (0.132 mm) to 9 pixels (0.396 mm).

4. Statistical analysis

In order to analyze the effects exerted by the mandibles, the projection angles, and the regions on the fractal dimension, we carried out the ANOVA test and the paired sampled t-test, and conducted the Duncan test in order to find out whether there was any significant difference in each region according to each mandible.

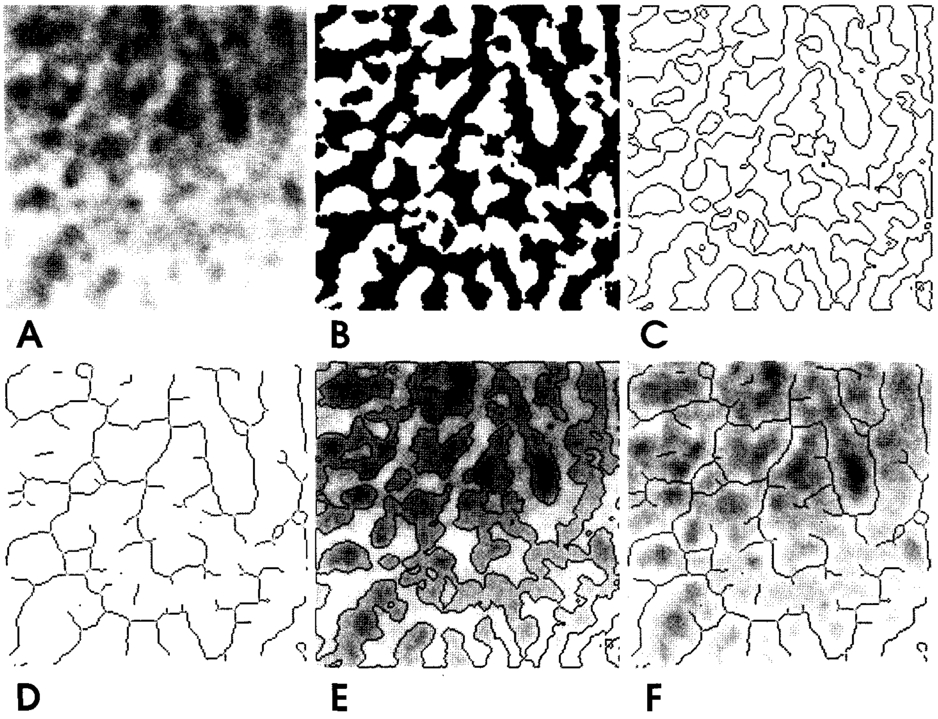

Fig. 2. A, ROI in bone trabecular structure from direct digital intraoral radiograph. B, Binary image. C, Outline image. D, Trabecular structure is skeletonized E, Addition of images A and C. F, Addition of images A and D.

Table 1. Mean value of fractal dimensions of human dry mandibles

Regions	Mandibles	Fractal dimensions									
		St.	Up	UR	Rt.	LR	Low	LL	Lt.	UL	Total
Angle	Mandible 1	1.32	1.33	1.38	1.32	1.38	1.29	1.32	1.30	1.33	1.33±0.03†
	Mandible 2	1.44	1.46	1.46	1.44	1.44	1.46	1.42	1.41	1.40	1.44±0.03†
	Mandible 3	1.38	1.42	1.41	1.40	1.36	1.36	1.40	1.41	1.42	1.39±0.03†
	Mandible 4	1.29	1.26	1.27	1.23	1.27	1.26	1.25	1.25	1.28	1.26±0.05†
	Mandible 5	1.33	1.32	1.35	1.31	1.30	1.35	1.32	1.30	1.32	1.32±0.06†
	Total	1.35	1.36	1.37	1.34	1.35	1.34	1.34	1.34	1.35	1.35±0.07*
Molar	Mandible 1	1.30	1.34	1.35	1.31	1.28	1.32	1.33	1.27	1.30	1.31±0.05‡
	Mandible 2	1.36	1.35	1.35	1.35	1.36	1.37	1.38	1.38	1.41	1.37±0.04‡
	Mandible 3	1.40	1.34	1.33	1.37	1.37	1.35	1.36	1.34	1.30	1.35±0.05‡
	Mandible 4	1.26	1.23	1.29	1.28	1.28	1.28	1.25	1.27	1.24	1.26±0.07‡
	Mandible 5	1.28	1.31	1.32	1.24	1.24	1.26	1.28	1.33	1.28	1.28±0.05‡
	Total	1.32	1.31	1.33	1.31	1.31	1.31	1.32	1.32	1.31	1.32±0.06*

*, †, ‡ : $p<0.05$

Results

After carrying out the Univariate Analysis of Variance of the fractal dimension with the mandibles, projection of angles and regions as the variables, it was found out that there were no statistically significant differences according to the projection of angles. According to the regions and the mandibles, there were some statistically significant differences in the fractal dimension ($p<0.05$) (Table 1). Even in the analysis of the groups that were divided into the angle region and the body region, there were no statistically significant differences in the fractal dimension according to the projection angles, though there were some statistically significant differences according to the different mandibles. As a result of carrying out the Duncan test (Table 2), in the angle region, the degree of statistically significant difference was divided into 4 groups, and decreased in the order of mandible number 4, 5 and 1, 3, and 2, and in the body region, they were divided into 3 groups decreasing in the statistically significant difference order of mandible 4 and 5, 5 and 1, and 3 and 2.

Table 2. Duncan test

Mandibular angle group

Mandible	N	Subset 1	Subset 2	Subset 3	Subset 4
No. 4	18	1.2617			
No. 5	18		1.3233		
No. 1	18		1.3311		
No. 3	18			1.3941	
No. 2	18				1.4363
Sig.		1	0.601	1	1

Mandibular body group

Mandible	N	Subset 1	Subset 2	Subset 3
No. 4	18	1.2644		
No. 5	18	1.2814	1.2814	
No. 1	18		1.3114	
No. 3	18			1.3524
No. 2	18			1.3669
Sig.		0.325	0.086	0.401

Discussion

The image processing measuring the morphometric features of the trabecular architecture in the digitized radiography of White et al.[24] was the method used in this research. The fractal dimension was obtained by employing the tile counting method using the outline image. All this was carried out semi-automatically by a program written by the macro Scion image program ver4.1.

In this research, there were no statistically significant differences according to the angle of projection on the whole, and in the angle regions, as well as the molar regions, On the other side, apart from the angle of projection, there were statistically significant differences according to the mandibles and the regions. From existing researches that have dealt with the relationship between the angle of projection and the fractal dimension, it has been known that in general situations, the fractal dimension is not effected by the angle of projection.[11,22] However, in the research of Southard et al.[12] as a result of altering the projection angle to −5 degrees, 0 degree, and 5 degrees to specimens of the human maxillary alveolar process bone, every bone sample fractal dimension changed significantly with angular change. Also, Chen and Chen[23] stated that the fractal dimensions changed significantly with projection geometry in simulated models of alveolar bone. Two explanations could account for this difference. First, they used a different technique (line-line basis,[12] power spectra[23]) to estimate fractal dimension, and this difference in technique could partially account for the difference in fractal dimension estimation. Another explanation is they examined the alveolar bone[12] or simulated alveolar bone,[23] whereas we examined the basal bone, or mandibular angle or body region.

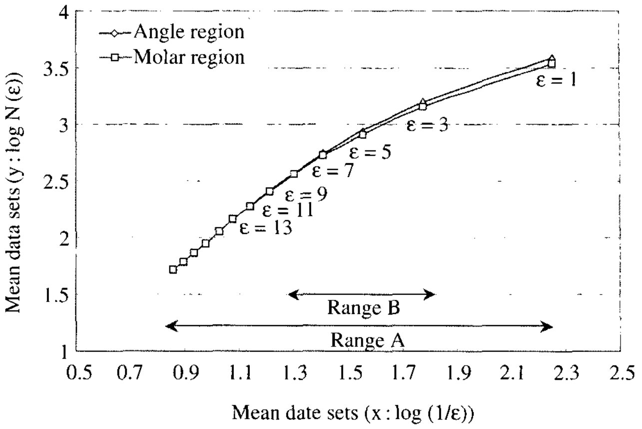

Fig. 3. Richardson plot. ε means the size of tile and N(ε) means the number of tiles containing any part of structure. Range A is the fractal curve, and Range B shows the fundamental significant range of scale.

When the mandibles were divided into an angle region and a molar region according to the regions, there were statistically significant differences in the fractal dimensions of each mandible ($p < 0.05$). In the angle region group, the average fractal dimension increased in the order of mandible number 4 (1.2617), 5 (1.3233), 1 (1.3311), 3 (1.3941), and 2 (1.4363), and in the molar region the average fractal dimension increased in the same order with mandible number 4 (1.2644) leading the way, followed by mandible number 5 (1.2814), 1 (1.3114), 3 (1.3524), and 2 (1.3669). After conducting the Duncan test, in the angle region, 4 groups showing statistically significant differences were classified, decreasing in the order of number 4, 5 and 1, 3, and 2, and in the molar region, 3 groups showing statistically significant differences were classified, decreasing in the order of 4 and 2, 2 and 5, 1, and 3. It must be noted that in comparison to the results in both the angle region and the body region, where there were no significant differences in the fractal dimension according to the projection angle, such results are noteworthy. On both sides of the angle region and the molar region, that the order of the average fractal dimension of the mandible was identical, is thought to be owed to careful consideration of the differences of each mandible when the fractal analysis was applied.

When planning the fractal analysis of the human mandible, the fractal dimension of bone should be carefully designed. The fractal analysis employed in this research is based on the tile counting method, widely known as an easy and powerful fractal analysis technique. The most important difference between former researches that employed the tile counting method and the present one, is that the range of scale related to tile counting is limited. Fig. 3 shows the Richardson plot, drawn from tile size ranging from (ε) 1 to 23 pixels. In another research that was carried out at the same time as this one, it was concluded that limiting the range of scale when obtaining the fractal dimension has a greater fundamental significance than from the whole range of the tile size (Range A), and that the range of scale of a dry, human mandible is from 3 pixels (0.132 mm) -9 pixels (0.396 mm), which was accordingly applied in this research. In the fractal analysis that was thus designed, whether there were any changes in the fractal dimension according to small variations in the projection angle show big differences in clinical value. If small variations in the projection angle beneficially alter the fractal dimension, there will be a lot of effort invested in trying to record and maintain the projection angle during clinical application. We have come to the conclusion that there is no difference in the fractal dimension according to small variations in the projection angle (10 degrees). Also, according to the different mandibles and regions, there were statistically significant differences in the fractal dimension. Such results are thought to have originated in that the fractal analysis that we have designed effectively reflect the bone property of each and every sample that was used.

We believe that in further developed researches in the future, those examining and interpreting the relationship between 3D trabecular bone structure, bone property and the fractal analysis will be in need.

References

1. Mandelbrot BB. The fractal geometry of nature. 3rd ed. New York : Freeman; 1983.
2. Peitgen HO, Jürgens H, Saupe D. Fractals for the classroom : part 1 introduction to fractals and chaos. 2nd ed. New york : Springer? Verlag; 1993. p. 209
3. Majumdar S, Weinstein RS, Prasad RR. Application of fractal geometry techniques to the study of trabecular bone. Med Phys 1993; 20 : 1611-9.
4. Caligiuri P, Giger ML, Favus M. Multifractal radiographic analysis of osteoporosis. Med Phys 1994; 21 : 503-8.
5. Weinstein RS, Majumdar S. Fractal geometry and vertebral compression fractures. J Bone Miner Res 1994; 9 : 1797-802.
6. Lin JC, Grampp S, Link T, Kothari M, Newitt DC, Felsenberg D, et al. Fractal analysis of proximal femur radiographs: correlation with bio-mechanical properties and bone mineral density. Osteoporos Int 1999; 9 : 516-24.
7. Jiang C, Giger ML, Chinander MR, Martell JM, Kwak S, Favus MJ. Characterization of bone quality using computer-extracted radiographic features. Med Phys 1999; 26 : 872-9.
8. Majumdar S, Lin J, Link T, Millard J, Augat P, Ouyang X, et al. Fractal analysis of radiographs: assessment of trabecular bone structure and prediction of elastic modulus and strength. Med Phys 1999; 26 : 1330-40.
9. Lee KI, Choi SC, Park TW, You DS. Fractal dimension calculated from two types of region of interest. Dentomaxillofac Radiol 1999; 28 : 284-9.
10. Benhamou CL, Poupon S, Lespessailles E, Loiseau S, Jennane R, Siroux V, et al. Fractal analysis of radiographic trabecular bone texture and bone mineral density: two complementary parameters related to osteoporotic fractures. J Bone Miner Res 2001; 16 : 697-704.
11. Ruttimann UE, Webber RL, Hazelrig JB. Fractal dimension from radiographs of peridental alveolar bone. A possible diagnostic indicator of osteoporosis. Oral Surg Oral Med Oral Pathol 1992; 74 : 98-110.
12. Southard TE, Southard KA, Jakobsen JR, Hillis SL, Najim CA. Fractal dimension in radiographic analysis of alveolar process bone. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1996; 82 : 569-76.
13. Law AN, Bollen AM, Chen SK. Detecting osteoporosis using dental radiographs: a comparison of four methods. J Am Dent Assoc 1996; 127 : 1734-42.
14. Hildebolt CF. Osteoporosis and oral bone loss. Dentomaxillofac Radiol 1997; 26 : 3-15.
15. Pothuaud L, Lespessailles E, Harba R, Jennane R, Royant V, Eynard E, et al. Fractal analysis of trabecular bone texture on radiographs: discriminant value in postmenopausal osteoporosis. Osteoporos Int 1998; 8 : 618-25.
16. Southard TE, Southard KA, Krizan KE, Hillis SL, Haller JW, Keller J, et al. Mandibular bone density and fractal dimension in rabbits with induced osteoporosis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2000; 89 : 244-9.
17. Shrout MK, Roberson B, Potter BJ, Mailhot JM, Hildebolt CF. A comparison of 2 patient populations using fractal analysis. J Periodontol 1998; 69 : 9-13.
18. Cha SY, Han WJ, Kim EK. Usefulness of fractal analysis for the diagnosis of periodontitis. Korean J Oral Maxillofac Radiol 2001; 31 : 35-42.
19. Wilding RJ, Slabbert JC, Kathree H, Owen CP, Crombie K, Delport P. The use of fractal analysis to reveal remodelling in human alveolar bone following the placement of dental implants. Arch Oral Biol. 1995; 40 : 61-72.
20. Heo MS, Park KS, Lee SS, Choi SC, Koak JY, Heo SJ, et al. Fractal analysis of mandibular bony healing after orthognathic surgery. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2002; 94 : 763-7.
21. Geraets WG, van der Stelt PF. Fractal properties of bone. Dentomaxillofac Radiol 2000; 29 : 144-53.
22. Buckland-Wright JC, Lynch JA, Rymer J, Fogelman I. Fractal signature analysis of macroradiographs measures trabecular organization in lumbar vertebrae of postmenopausal women. Calcif Tissue Int 1994; 54 : 106-12.
23. Chen SK, Chen CM. The effects of projection geometry and trabecular texture on estimated fractal dimensions in two alveolar bone models. Dentomaxillofac Radiol 1998; 27 : 270-4.
24. White SC, Rudolph DJ. Alterations of the trabecular pattern of the jaws in patients with osteoporosis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1999; 88 : 628-35.