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Evaluating Mandibular Cortical Index Quantitatively

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ABSTRACT

Objectives: The aim was to assess whether Fractal Dimension and Lacunarity analysis can discriminate patients having different mandibular cortical shape.

Methods: Panoramic radiographs of 52 patients were evaluated for mandibular cortical index. Weighted Kappa between the observations were varying between 0.718-0.805. These radiographs were scanned and converted to binary images. Fractal Dimension and Lacunarity were calculated from the regions where best represents the cortical morphology.

Results: It was found that there were statistically significant difference between the Fractal Dimension and Lacunarity of radiographs which were classified as having Cl 1 and Cl 2 (Fractal Dimension P:0.000; Lacunarity P:0.003); and Cl 1 and Cl 3 cortical morphology (Fractal Dimension P:0.008; Lacunarity P:0.001); but there was no statistically significant difference between Fractal Dimension and Lacunarity of radiographs which were classified as having Cl 2 and Cl 3 cortical morphology (Fractal Dimension P:1.000; Lacunarity P:0.758).

Conclusions: FD and L can differentiate Cl 1 mandibular cortical shape from both Cl 2 and Cl 3 mandibular cortical shape but cannot differentiate Cl 2 from Cl 3 mandibular cortical shape on panoramic radiographs. (Eur J Dent 2008;2:283-290)

Key words: Mandibular cortical index; Panoramic radiography; Fractal Dimension; Lacunarity; Digital image analysis.

INTRODUCTION

Osteoporosis is a condition characterized by a loss in bone mineral density and there is micro-architectural deterioration in bone tissue leading to fractures.[1] The patient is defined as osteoporotic when t-score of skeletal BMD is 2.5 standard deviations below the average peak bone density achieved in young adults matched by gender and race.[1,2] As osteoporosis and fractures are more difficult and costly to treat than to prevent, several health care interventions have been proposed to identify those people who may be at risk and who could benefit from preventive interventions.[3] Bone densitometry is used in the diagnosis of osteoporotic patients.[4] however currently available scientific evidence does not justify the use of bone densitometry as a screening tool in the asymptomatic population because of both its poor discriminatory power to detect those who will fracture from those who

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will not, and its cost if used indiscriminately.[5] The most reasonable health care strategy for bone densitometry provision seems to be its indication in a selective approach.[4,6,7]

The dentist is often the most regularly visited doctor in the elderly population whom are also under the risk of osteoporosis and associated fractures, and dental radiographs are the most frequently used imaging modalities for these patients. The Food and Drug Administration and American Dental Association recommend screening radiography for every newly edentulous patient because of high prevalence of findings such as root fragments and radiolucencies.[8] Panoramic radiography is commonly used in large intuitional settings as a method of screening partially and fully edentulous patients. It is reported that in Japan 10 million panoramic radiographs are taken annually,[9] and it is reported that between 1998 and 1999, approximately 2.05 million panoramic radiographs were taken in the general dental service in England and Wales.[9] Researchers have developed a number of panoramic based mandibular indices, image processing and analyzing techniques for quantification of mandibular bone mass and trabecular architecture to discriminate osteoporotic patients from non-osteoporotic ones. The thickness of the mandibular cortical bone is decreased in osteoporoic patients[10] and inferior border of the mandible is more porous than controls.[11-13] Mandibular cortical index (MCI) has been developed to assess osteoporosis in the cortical area of the mandible using panoramic radiographs.[12] In this technique, the inferior cortex on both sides of the mandible, distal to the mental foramen is classified into three groups according to the following criteria:

1. Cl 1: The endosteal margin of the cortex is even and sharp on both sides of the mandible.

2. Cl 2: The endosteal margin has resorptive cavities with cortical residues one to three layers thick on one or both sides.

3. Cl 3: The endosteal margin consists of thick cortical residues and is clearly porous.

Mandibular cortical index is found to be useful in evaluating the patients for the risk of osteoporosis in various studies. In a study, Horner and Devlin evaluated whether a relationship exists between mandibular cortical index and bone mineral density of the body of the mandible as measured by dual energy X-ray dual absorptiometry. They reported that MCI was significantly related to bone mineral density of the body of the mandible but there were limitations in its repeatability.[14] Taguchi et al evaluated MCI and mandibular cortical width on panoramic radiographs and compared them with bone mineral density of either the lumbar spine or the femoral neck. They concluded that the odds ratio of having osteoporosis was 5.90 in women identified by cortical width and 8.66 in women identified by cortical shape of the mandible.[15] Again, in another study, Taguchi et al evaluated the effectiveness of MCI in discriminating osteoporotic patients with 60 observers from 16 countries of the world and reported that the overall mean sensitivity, specificity, positive predictive value, and negative predictive value of the 60 observers in identifying women with osteoporosis by cortical erosion panoramic radiographs were 82.5, 46.2, 46.7, and 84% respectively.[16] The repeatability of this index is also evaluated and while some studies were reporting satisfactory levels of agreement,[11-13,17] others were reporting lower levels of agreement, especially between different observers even among expert observers.[14,18] As a consequence of this finding, the authors reported that this limits the technique's applicability clinically.[18]

Fractal analysis is a mathematical technique which is helpful in the quantification of complex structures.[19] The fractal dimension describes how an object occupies space and is related to the complexity of its structure: it gives a numerical measure of the degree of boundary irregularity or surface roughness.[20,21] Lacunarity was initially introduced by Mandelbrot as a means of further classifying fractals and textures which had the same FD and a very different visual appearance.[21] Lacunarity is a measure of how the fractal fills space, if the fractal is dense the lacunarity is small, the lacunarity increases with coarseness. Higher lacunarity values indicate wider range of sizes of structures within an image.[22] An advantage of lacunarity is that it is not predicated on fractalness or self similarity, and is therefore useful for natural images and also medical images that may show at most only a limited fractalness.[22] These techniques are quantitative techniques and have no observer dependency.

Evaluating the mandibular cortical shape with these techniques would eliminate the observer dependency and might improve the usefulness of mandibular cortical shape in screening osteoporotic patients.

The aim of this study was to evaluate whether Fractal Dimension and Lacunarity can discriminate patients having different MCI classifications.

MATERIALS AND METHODS

Randomly selected panoramic radiographs of 52 patients which were taken during routine dental examination were included to the study (2002 CC Proline PlanMeca Helsinki Finland). None of the patients had systemic disease which effects bone metabolism and their ages were between 40-64. In the first part of the study, the panoramic radiographs were evaluated for MCI classification by the same observer three times with four weeks intervals. The agreement between the observations was calculated with weighted Kappa statistics.

Among these panoramic radiographs, 22 of them which were evaluated as Class 1 in at least two observations were accepted as Class 1; accordingly 20 panoramic radiographs were accepted as Class 2 and 10 panoramic radiographs were accepted as Class 3. These radiographs were scanned in 300 dots per inch resolution with a scanner having transparency adaptor. Image processing and analyzing was performed with ImageJ program.[23] On these radiographs region of interests (ROI), where best represents the mandibular cortical morphology were created both in left and right side. FD in box-counting method and Lacunarity were calculated from these ROIs and the mean values of them were used in the study.

The radiographs were arbitrarily rotated until the basal cortical bone where the ROI will be created becomes parallel to the horizontal plane (Figure 1). The ROIs extended in the medio-lateral direction and when creating ROIs, great care was shown to include only the inferior cortical bone of the mandible (Figure 2). Digital images were segmented to binary image as described by White and Rudolph.[24] The ROIs were duplicated and blurred by a Gaussian filter with a diameter of 35 pixels. The resulting heavily blurred image was then subtracted from the original, and 128 was added to the result at each pixel location. The image was then made binary, thresholding on a brightness value of 128 and inverted. With this method, the regions which represent trabecular bone were set to white and porosities of the cortical bone were set to black (Figure 3). The aim of this operation was to reflect individual variations in the image such as cortical bone and porosities.

Fractal Dimension and Lacunarity were calculated with ImageJ plugin named FracLacCirc (First Version). FracLacCirc calculates the box counting Fractal Dimension using a shifting grid algorithm that does multiple scans on each image, and it is suitable for analyzing images of biological cells and textures. It works on only

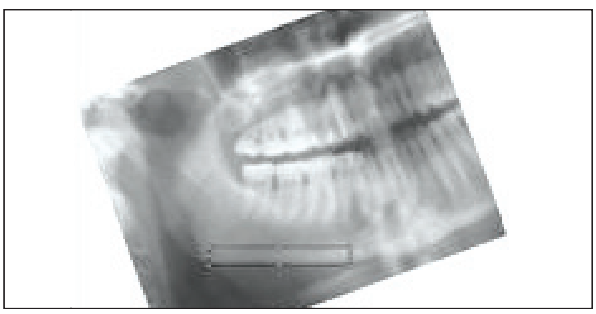

Figure 1. Rotated cropped panoramic radiograph.

Figure 2. ROI extending from distal to the mental foramen distally.

Figure 3. Binary form of the ROI.

Figure 1. Rotated cropped panoramic radiograph.

binarized images, so images must be thresholded prior to analysis.[23]

Weighted Kappa index, which was calculated with a program named ComKappa,[25] was used as a measure of intra-observer agreement for cortical index evaluation. Kolmogorov-Smirnov and Levene's tests were used to check for the normality and homogeneity of the data. ANOVA was used to evaluate whether Fractal Dimension differs significantly between the patients having Class 1, Class 2 and Class 3 MCI morphology using P value as 0.05 with 95% confidence interval. As multiple comparisons were made, Bonferroni was used as post-hoc test. The data of Lacunarity (P:0.012) did not have normal distribution in mandibular cortices which were classified as Cl 2, so Kruskal Wallis test was used to evaluate whether Lacunarity differs significantly between the patients having Class 1, Class 2 and Class 3 and Mann Whitney U test with Bonferroni correction was used for paired comparisons. SPSS 10.0 for Windows (SPSS, Inc., Chicago, IL) was used for the statistical analysis.

RESULTS

The agreements between the observations are given in Table 1. Interpretation of the Kappa statistics was quoted from the guidelines of Landis and Koch: Less than 0.00 poor agreement, 0.00-0.20 slight agreement, 0.21-0.40 fair agreement, 0.41-0.60 moderate agreement, 0.61-0.80 substantial agreement, 0.81-1 almost perfect agreement.[26] There was substantial agreement among the observations in this study. Table 2 shows the descriptive statistics of the variables. The data of Fractal Dimension was showing normal distribution (P:0.200 for Cl 1, P:0.112 for Cl 2, and P:0.200 for Cl 3); and it was homogeneous (FD P:0.744). However, the data of Lacunarity did not show normal distribution in radiographs which were classified as having CL 2 mandibular cortical shape (P:0.200 for Cl 1; P:0.012 for Cl 2; and P:0.200 for Cl 3).

ANOVA test results showed that there were statistically significant difference between Fractal Dimension (P=0.000) values in patients having different MCI morphology (Table 3). As multiple comparisons were made, Bonferroni was used as post-hoc test (Table 4). It was found that there were statistically significant difference between the Fractal Dimension of radiographs which were classified as having Cl 1 and Cl 2 (P=0.000); and

Table 1. Weighted Kappa statistic results.

Observations	Measure of Agreement (Kappa)		
	Value	SE	Approx. Sig.
First Observation - Second Observation	0.718	0.103	0.000
Second Observation - Third Observation	0.780	0.101	0.000
First Observation - Third Observation	0.805	0.100	0.000

Table 2. Characteristics of the studied parameters.

	MCI	N	Mean	SD	SE	Interval for Mean		Min.	Max.
						Lower Bound	Upper Bound		
Fractal Dimension	Cl 1	22	1.660	0.049	0.010	1.639	1.682	1.576	1.755
	Cl 2	20	1.724	0.042	0.010	1.704	1.744	1.611	1.781
	Cl 3	10	1.715	0.043	0.014	1.684	1.746	1.650	1.783
	Total	52	1.695	0.054	0.008	1.680	1.710	1.576	1.783
Lacunarity Analysis	Cl 1	22	0.715	0.169	0.036	0.640	0.790	0.426	1.025
	Cl 2	20	0.559	0.158	0.035	0.485	0.633	0.379	1.028
	Cl 3	10	0.516	0.106	0.034	0.439	0.592	0.360	0.642
	Total	52	0.617	0.175	0.024	0.568	0.665	0.360	1.028

Cl 1 and Cl 3 cortical morphology (P=0.008); but there was no statistically significant difference between Fractal Dimension of radiographs which were classified as having Cl 2 and Cl 3 cortical morphology (P=1.000). For Lacunarity, Kruskal Wallis test was used and it was found that there was also statistically significant difference between different MCI groups for Lacunarity (P=0.001). The mean differences were significant at the 0.05 level (P=0.05) (Table 5). For paired comparisons between the groups, Mann Whitney U statistics with Bonferroni correction was used. It was found that there was statistically significant difference between Cl 1 and Cl 2 (P=0.003) and Cl 1 and Cl 3 (P=0.001) but there weren't statistically significant difference between Cl 2 and Cl 3 (P=0.758) as in FD (Table 5).

According to the results of this study, the mandibular cortex having Cl 1 cortical morphology is less complex and more heterogeneous than Cl 2 and Cl 3. That means, there is wider range of sizes of structures within the cortices which are classified as Cl 1 and contrary to this, the cortices which are classified as having Cl 3 cortical morphology are more complex and homogeneous, that is the sizes of the porosities within the cortices are similar to each other.

DISCUSSION

Panoramic mandibular index (PMI),[27] mandibular cortical width (CW),[28] antegonial AGI),[29] gonial index (GI)[30] and mandibular cortical index (MCI)[12] are panoramic based indices which are developed to discriminate osteoporotic patients from non-osteoporotic ones. Some of the researchers reported that, these indices were effective in discriminating osteoporotic patients[10,29,30] but there are other studies in which some of these indices were reported to be not useful in identifying osteoporotic patients.[13,17,31] Some measurements and calculations are necessary in PMI, CW, AGI and GI. Among these indices, MCI is relatively simple because no measurements or calculations are required but it depends on visual assessments. Its repeatability has been evaluated and especially inter-observer agreement is reported to be poor in some of the studies.[19] However, Bollen et al,[11] Klemetti et al,[12] Taguchi et al,[13] have reported satisfactory levels of inter and intra-observer agreement.

Table 3. Analysis of variance for fractal dimension.

	Sum Of Squares	df	Mean Square	F	Sig
Between Groups	0.048	2	0.024		
Within Groups	0.101	49	0.002	11.583	0.000
Total	0.148	51			

* The mean difference is significant at the 0.05 level.

Table 4. Paired comparisons with Bonferroni correction.

MCI	Observations	Mean Difference	SE	Sig.*	95% Confidence Interval	
					Lower Bound	Upper Bound
Fractal Dimension	Cl1-Cl2	-0.0639	0.0140	0.000	-0.0985	-0.0292
	Cl1-Cl3	-0.0548	0.0173	0.008	-0.0976	-0.0120
	Cl2-Cl3	0.0090	0.0175	1.000	-0.0345	0.0525

Table 5. Kruskal Wallis test for Lacunarity and paired comparisons for Lacunarity with Mann Whitney U Test with Bonferroni correction.

Kruskal Wallis Test		Lacunarity Analysis	Cl1 - Cl2	Cl1 - Cl3	Cl2 - Cl3
Chi-Square	14.236	Mann Whitney U	103.000	26.000	93.000
df	2	Wilcoxon W	313.000	81.000	148.000
Asymp. Sig.	0.001	Z	-2.947	-3.415	-0.348
		Asymp. Sig. (2-tailed)	0.003	0.001	0.758

*: The mean difference is significant at the 0.05 level. Grouping Variable: MCI

Visual perception of human eye and brain has an inevitable role in all kinds of evaluations performed on radiographs.[32] This limits the repeatability and as a consequence of this, clinical application of these measurements or evaluations.

As in other fields of medicine,[33] Fractal Dimension has also found applications in dental studies.[34,35] It is found to be efficacious in discriminating osteoporotic patients from non-osteoporotic ones[36] and both Fractal Dimension and Lacunarity could discriminate dentate from edentulous regions in mandibular posterior region.[37] In MCI evaluations, the porosity of mandibular cortical bone is evaluated visually and a limitation in its repeatability, especially between different observers, is reported to be a serious problem for the method to be used clinically.[18] Contrary to the subjective nature of MCI evaluations, Fractal Dimension and Lacunarity are quantitative measurement methods and have no dependency on observers. According to the results of this study, it can be concluded that both Fractal Dimension and Lacunarity can discriminate patients having Cl 1 from Cl 2 and Cl 1 from Cl 3 mandibular cortical morphology but they cannot differentiate Cl 2 from Cl 3. The mandibular cortex has more complex structure in patients having Cl 2 MCI classification than Cl 1. So the finding of this study is concordant with the description of Fractal Dimension because more complex objects have a higher Fractal Dimension. Lacunarity is related to the distribution of gap sizes: the objects having low lacunarity are homogeneous because all gap sizes are the same, whereas high lacunarity objects are heterogeneous.[22] Lacunarity is low in objects having higher Fractal Dimension.[22] According to the results of this study, the structure of the cortical bone which is classified as Cl 1 has less porous structure than Cl 2 and Cl 3 cortices, and the sizes of the gaps are less similar to each other in Cl 1 than Cl 2 and Cl 3 radiographically.

As reported in a study performed by Taguchi et al, mandibular cortical shape which is defined as Cl 2 has a greater range of appearances radiographically than Cl 1 and Cl 3 because early cases can sometimes be defined as Cl 1 by some observers and also some late cases of Cl 2 can be defined as Cl 3 by other observers.[38] In this study there was no case which was classified as Cl 1 in one observation and Cl 3 in the other observation. However, there were some cases which were classified as Cl 1 in one of the observations and Cl 2 in the other or Cl 2 in one of the observations and Cl 3 in the other. This means that, probably some early cases of Cl 2 may be classified as Cl 1 and similarly, some late cases of Cl 2 may be classified as Cl 3 in some observations. Fractal Dimension and Lacunarity can differentiate Cl 1 from both Cl 2 and Cl 3 but they cannot differentiate Cl 2 from Cl 3. The appearance of Cl 1 and Cl 3 are widely different from each other but the appearance of Cl 3 and late Cl 2 cases may resemble each other so Fractal Dimension and Lacunarity cannot discriminate them. In this study, the number of radiographs which were classified as Cl 3 was relatively less than the radiographs which were classified as Cl 1 and Cl 2 and this might also have a role on not discriminating Cl 2 from Cl 3.

Halling et al compared mean bone mineral density measurement by heel DEXA in the osteopenic (MCI 3 group) and normal groups (MCI 1 and MCI 2 groups were combined) and they reported that a negative finding is highly predictive of the absence of osteopenia/osteoporosis as defined by the DEXA measurements.[39] Combining this finding with the results of this study, a threshold value for Fractal Dimension and Lacunarity can be generated by studying with large sample sizes and patients having higher Fractal Dimension and lower Lacunarity values from these thresholds can be conveyed to bone densitometry clinics for further evaluation to rule out the possibility of osteoporosis especially when the patient has other risk factors in addition. Calculating Fractal Dimension and Lacunarity may somewhat be time consuming and prevent the method to be a real time method because the radiographs should be scanned first. However, digital panoramic machines are replacing the conventional machines in many of the countries and this would increase the applicability of the procedure. Fractal Dimension and Lacunarity are quantitative measurements and they don't have observer dependency as radiomorphometric indices based on panoramic radiographs. The only part that depends on the observer is to choose the place of the ROI.

CONCLUSIONS

In conclusion, contrary to other radiomorphometric indices, such as PMI, MCW, AGI and GI; in MCI no measurements and calculations are needed but visual assessment plays a significant role and this creates a major limitation in the application of the technique clinically, especially in inter-observer agreement. It is possible to differentiate mandibular cortices having Cl 1 cortices from Cl 2 and Cl 3 cortices by evaluating MCI quantitatively with Fractal Dimension and Lacunarity however Fractal Dimension and Lacunarity could not differentiate Cl 2 cases from Cl 3. The reason of this might be the relatively small number of cases having Cl 3 cortices and it can be advised that Fractal Dimension and Lacunarity can be used as supportive diagnostic techniques to MCI in cases where inter-observer agreement is important and desired because these techniques are independent from observers and they can overcome the limitation of disagreement among observers in MCI classification. The Kappa values of this study were varying between 0.718-0.805 and this may be seen as visual evaluation of MCI is superior to Fractal Dimension and Lacunarity because these techniques could not differentiate Cl 2 cases from Cl 3, but the real limitation of visual evaluation of MCI is reported to be in inter-observer agreement in various studies and these techniques would overcome this limitation of MCI evaluation by eliminating observer dependency. As it was aimed to evaluate whether Fractal Dimension and Lacunarity could differentiate different shapes of mandibular cortical bone in this preliminary study, the bone mineral density status of the patients were not known. Further study is needed with osteoporotic and non-osteoporotic patients and greater sample size especially for Cl 3 cases. In that case it would be possible to evaluate whether Fractal Dimension and Lacunarity can discriminate osteoporotic patients from non-osteoporotic ones.

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