RESEARCH ARTICLE

Feasibility of cone beam computed tomography radiomorphometric analysis and fractal dimension in assessment of postmenopausal osteoporosis in correlation with dual X-ray absorptiometry

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Objectives: The aim of the present study was to assess the feasibility of using mandibular CBCT radiomorphometric indices and box-counting fractal dimension (FD) to detect osteoporosis in post-menopausal females, compare them with the healthy control group and to correlate the findings with the bone mineral density measured by dual X-ray absorptiometry (DXA).

Methods: This study consisted of 50 post-menopausal females, with age ranging from 55 to 70 years. Based on their DXA results, they were classified into osteoporotic and control groups. Mandibular CBCT radiomorphometric indices and FD analysis were measured.

Results: Significant differences were found for the CT cortical index scores (CTCI), CT mental index (CTMI) and CT mandibular index (CTI) between the control and osteoporotic groups. The control group showed higher mean values than the osteoporotic group. For FD values, no significant differences were found between the two groups.

Conclusions: CBCT radiomorphometric indices could be used as an adjuvant tool to refer patients at risk of osteoporosis for further assessment.

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Introduction

Reduced bone mass and high risk of fragility fractures are the major symptoms of osteoporosis and are considered to be the major challenges to public health worldwide.¹ The problem with osteoporosis is that no signs of the disease are manifested until a fragility fracture occurs. For this reason, intense interest exists within the medical community in developing accurate early diagnostic techniques.²

Osteoporosis is characterized by decreased bone strength that reflects the integration of both bone mineral density (BMD) and bone quality, which refers to the trabecular bone architecture and geometry.³ Bone quality is considered as a major parameter for anticipating bone strength; this may be attributed to the fact that traumatic fractures caused by osteoporosis occur in patients with reduced bone density as well as bone microstructure changes. Moreover, these fractures could occur in patients with normal BMD.⁴

To assess trabecular microarchitecture, three-dimensional imaging modalities such as CT and MRI

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Figure 1 Demonstration of the way the slice was selected: (a) on the axial image, line x (dotted line) represents an anteroposterior tangent to the buccal cortical plate of the bone. Line y (solid line) was situated to be perpendicular to line x through the centre of the mental foramen. (b) Line x was moved to line x' , which represents the bisecting position of the buccolingual dimension of the body of the mandible. (c) On the sagittal image, the sagittal plane is aligned so that line z (dashed line) becomes parallel to the mandibular inferior border of the mandible and perpendicular to line y at the same time. A, anterior; L, left; P, posterior; R, right.

must be used. Although they are not able to illustrate single trabeculae because of their spatial resolution, some studies demonstrated high correlations in comparison with micro-CT images, which are considered to be a gold standard.⁵ CBCT has been introduced as a modality for analyzing trabecular microstructure at implant sites.⁶

As the radiographic appearance of the jaws change in patients with osteoporosis, the relationship between the mandibular morphology and the rate of osteoporosis can be quantified by the determination of the thickness and completeness of the mandibular inferior cortex.⁷

Various quantitative and qualitative indices had been utilized on panoramic radiographs to evaluate the bone in cases of osteoporosis. The efficiency of these indices had shown a debate: while some investigations consider them effective in diagnosing osteoporosis,^{8,9} others reported that some of these indices are not.^{10–12}

Fractal dimension (FD) analysis is a statistical texture analysis that is based on fractal mathematics for describing complex shapes and structural patterns. It is used to express the texture roughness and indicate figure complexity by characterizing self-similarity of the texture grey-level variations over different scales.¹³

FD can be used to discriminate individuals with osteoporosis, measure bone fragility and show the increased risks for fracture. Some findings support that FD increases in the diseased, osteoporotic state. Others support that the diseased state reduces trabecular complexity and decreases FD.¹⁴

To our knowledge, no study in the dental literature could be found that investigated FD in post-menopausal females with osteoporosis using CBCT images. Moreover, only one study could be found that investigated the use of CBCT radiomorphometric indices to detect osteoporotic-related changes in the mandible.¹⁵

Figure 2 Different types of CT cortical index (CTCI) on the sagittal image: (a) Type 1, (b) Type 2 and (c) Type 3.

Figure 3 Non-orthogonal coronal image showing lines drawn to measure the CT mental index (CTMI) and CT mandibular index (CTI). R, right.

Therefore, the aim of this study was to assess the feasibility of CBCT mandibular radiomorphometric analysis and box-counting FD to detect osteoporosis in post-menopausal females, compare them with the healthy control group and correlate the findings with the BMD measured by dual X-ray absorptiometry (DXA).

Methods and materials

This study involved 50 post-menopausal females with ages ranging from 55 to 70 years. Based on their lumbar spine BMD measured by DXA, they were classified into 25 females with osteoporosis (t -score of < -2.5) and 25 control group (t -score > -1.0). Only natural menopausal females who had been post-menopausal for at least 10 years and were non-smokers and non-alcoholic were selected.

Ethical consideration: this study received approval from the Faculty of Dentistry Ain Shams University Research Ethics Committee. All subjects received explanation regarding the objectives of the study and signed a statement of informed consent. Confidentiality of data was ensured by the commitment of the principal investigator—by using codes for all study subjects included in this study. It worth mentioning that CBCT images were performed for the patients for research purposes only and this is not a normal practice.

CBCT imaging

CBCT scanning (Planmeca ProMax[®] 3D Classic, Helsinki, Finland) was performed not more than 2 weeks

after the DXA scan. The scan was set at: 88 kVp, 12 mA, a voxel size of 0.2 mm and a field of view of 80×80 mm. Images were viewed using a Planmeca Romexis[®] (Helsinki, Finland) viewer on personal computer running Windows XP software with a 17-inch LCD screen with a resolution of 1366×768 pixels.

Slice selection

Using the multiplanar reformation screen, axial images with a slice thickness of 0.1 mm were selected and the mental foramen was identified by scrolling through sequential slices. The slice which clearly identified and represented the widest mesiodistal dimension of the mental foramen was selected (Figure 1).

Three radiomorphometric indices were assessed on the CBCT images. As CBCT was utilized in this study, the terms of the indices used were obtained as a result of a modification of Ledgerton's classification for panoramic images.^{15,16} The indices were:

- (1) *CT cortical index (CTCI)* denoted the mandibular cortical index (MCI); this index represents the type of the mandibular inferior cortex of the mandible. It was evaluated from the non-orthogonal sagittal image obtained after slice preparation. The morphology of the mandibular inferior cortex was visually examined distal to the mental foramen bilaterally and classified using Klemetti's classification as follows:^{15,17}
 - CTCI Type 1: the endosteal margin of the inferior cortex is smooth on both ends (Figure 2a).
 - CTCI Type 2: the endosteal margin shows semi-lunar defects or appears to form endosteal cortical residues (Figure 2b).
 - CTCI Type 3: the cortex is obviously porous with dense endosteal residues (Figure 2c).
- (2) *CT mental index (CTMI)* symbolized the mental index (MI), which is the mandibular cortical width at the mental foramen region as described by Ledgerton et al.¹⁶ On the non-orthogonal coronal image obtained after slice preparation, the CTMI was measured by measuring the thickness of the mandibular cortex at a line that is perpendicular to a line tangent to the inferior border of the mandible at the mental foramen region (Figure 3).
- (3) *CT mandibular index (CTI)* symbolized the panoramic mandibular index (PMI), which represented the ratio of the thickness of the mandibular cortex to the distance between the middle of the mental foramen and the inferior mandibular cortex.¹¹ This was measured on the non-orthogonal coronal image obtained after slice preparation (Figure 3). The measurement was made on both sides and the mean value was used in statistical analysis.

Fractal dimension analysis

FD was assessed from the non-orthogonal coronal image which was used to measure the CTMI and CTI.

Figure 4 Steps used in image processing to calculate the fractal dimension: (a) the original image with a 20×20 pixel-sized circular region of interest (ROI) was selected; (b) the ROI was blurred with a Gaussian filter. (c) The blurred image [(b) in Figure 2] was subtracted from the original image [(a) in Figure 2]; (d) 128 was added to the resulting image; and (e) the image was converted into binary.

Each image was imported into Image J software (Image J; US National Institutes of Health, Bethesda, MD). A circular region of interest (ROI) with a diameter of 20 pixels was selected, which was located below the roots of the premolar and the mental foramen and just above the inferior border of the mandible.¹⁸

Great care was considered not to include the lamina dura, periodontal ligament space or root structure in the selected ROI.¹⁹ Pre-processing steps were performed on the images and then FD was calculated using the box-counting method²⁰ (Figure 4).

All measurements were made bilaterally for each patient and the mean values were used for further statistical analysis.

Statistical analysis

Statistical analysis was performed using SPSS® v. 16.0 for Windows (IBM Corp., New York, NY; formerly SPSS Inc., Chicago, IL) and Microsoft Excel® (Microsoft, Redmond, WA). The data were expressed as mean and standard deviation. To compare the osteoporotic and normal groups, Mann–Whitney *U*-test was used to

Table 1 Demographic data of the study sample

Characteristics	Osteoporotic	Control
	Mean $\pm$ SD	Mean $\pm$ SD
Number	25	25
Age (years)	61.1 $\pm$ 4.9	60.1 $\pm$ 3.7
Height	156 $\pm$ 5.7735	158.96 $\pm$ 6.26
Weight	77.36 $\pm$ 14	85.96 $\pm$ 11.62
<i>t</i> -score	−3.28 $\pm$ 0.58	0.51 $\pm$ 0.9

SD, standard deviation.

Table 2 Comparison between osteoporotic and control groups regarding CT cortical index (CTCI) scores

Scores CTCTI	Osteoporotic group	Control group	Total
CTCI Type 1	4	18	22
CTCI Type 2	14	7	21
CTCI Type 3	7	0	7
Total	25	25	50
<i>p</i> -value	<0.001		

Table 3 Means, standard deviations (SDs) and two-tailed *t*-test results for osteoporotic and control groups

Groups	Indices	Mean	SD	t	p-value
CTMI	Osteoporotic (<i>n</i> = 25)	3.7520	0.67907	-3.803	0.000
	Control (<i>n</i> = 25)	4.4376	0.59274		
CTI	Osteoporotic (<i>n</i> = 25)	0.2743	0.05692	-3.104	0.003
	Control (<i>n</i> = 25)	0.3202	0.04708		
FD	Osteoporotic (<i>n</i> = 25)	1.1996	0.04255	1.995	0.052
	Control (<i>n</i> = 25)	1.1739	0.04828		

CTI, CT mandibular index; CTMI, CT mental index; FD, fractal dimension.

evaluate CTCI scores while two-tailed student's *t*-test was used for other variables (CTMI, CTI and FD). Spearman's correlation coefficient test was used to assess the levels of association of each of the variables (CTCI, CTMI, CTI and FD) with the lumbar spine BMD measured by DXA (*t*-scores).

Results

The characteristics of the study subjects are represented in Table 1. Significant differences were found for CTCI scores between the control and osteoporotic groups. In the osteoporotic group, 14 cases showed CTCI Type 2 followed by CTCI Type 3, which was 7 cases. On the other hand, the control group showed higher number of cases belonging to CTCI Type 1 (18 cases) (Table 2).

There was a high significant negative correlation between CTCI and lumbar spine BMD measured by DXA (*t*-score) ($r = 0.613$). As the *t*-score increased, the likelihood of the subjects belonging to CTCI Type 1 increased.

Significant differences were found for the CTMI and CTI between the control and osteoporotic groups ($p < 0.001$). The control group showed higher mean values than the osteoporotic group Table 3.

A high significant positive correlation was found between CTMI and CTI with lumbar spine BMD measured by DXA (*t*-score) [$(p < 0.001)$, ($r = 0.463$); ($p < 0.05$), ($r = 0.340$), respectively] (Figure 5).

For FD values, no significant difference was found between the two groups; however, the control group showed lower values than the osteoporotic group (1.173 ± 0.048 vs 1.199 ± 0.0425), respectively (Table 3).

A negative significant correlation was found between FD and lumbar spine BMD measured by DXA (*t*-score) ($p < 0.05$; $r = 0.359$) (Figure 6).

Intraobserver agreement showed moderate agreement regarding CTCI (0.576). Strong agreement was found regarding CTMI and CTI, while FD showed good intraobserver agreement (0.701).

Discussion

Panoramic mandibular radiomorphometric indices has been proofed to be one of the preliminary osteoporotic

Figure 5 Scatter diagrams showing a positive correlation between the CT mental index (CTMI) and the CT mandibular index (CTI) with *t*-score.

Figure 6 Scatter diagram showing a negative correlation between fractal dimension (FD) and *t*-score.

diagnostic tools.⁹ Moreover, FD is considered to be a distinguishing parameter between osteoporosis and normal bone density.²¹ Therefore, the aim of this study was to assess the feasibility of using mandibular CBCT radiomorphometric indices and FD analysis in post-menopausal females to detect osteoporosis.

We decided to use CBCT as an evaluation tool because it has several uses in dentistry and in the field of maxillofacial imaging. It provides three-dimensional images of high resolution. It also allows the qualitative and quantitative evaluation of osseous structures.²²

Our results showed a significant difference between the two study groups for CTCI scores. Moreover, the mean values of CTMI and CTI results showed higher values in the control group than in the osteoporotic group and the differences were highly significant between the two study groups.

Our results were in agreement with the only study that could be found in the dental literature that investigated these indices using CBCT. In that study, the authors used CBCT indices to evaluate BMD among post-menopausal females. Their results showed that there was a significant difference between the normal and osteoporotic groups regarding CTCI. Moreover, CTI and CTMI showed higher mean values in the healthy group than in the osteoporotic group.¹⁵

As a result of limited studies using CBCT for the assessment of radiomorphometric indices, our study results were compared with the results of similar studies that used panoramic images. Dagistan and Bilge²³ conducted a study to compare the mandibular values of MI, PMI and MCI between normal and osteoporotic groups. The results showed that MI and PMI values within the osteoporosis group were significantly lower than control group.

Our results were also in accordance with a study by Mahl *et al*,²⁴ who studied PMI, MI and MCI on 49 patients who were classified into: 19 normal patients and 30 patients with bone mass loss (24 patients with osteopenia and 6 patients with osteoporosis). The results demonstrated that there were significant differences present among the three groups for the PMI and MI. However, MCI did not show a significant difference between the groups.

Also supporting our results is a cross-sectional study by Khojastehpour *et al*²⁵ which evaluated PMI in 140 female patients who were categorized as either normal, osteopenic or osteoporotic according to the World Health Organization classification in relation to their spinal and femoral BMD determined by DXA. The results demonstrated a statistically significant difference between the three groups regarding mean PMI values. A statistically significant difference was also found in the mean of the PMI of menopausal females with osteoporosis in comparison with those without osteoporosis.

Our results were in partial agreement with the results of a study performed by Khojastehpour *et al*²⁶ on 119 post-menopausal females using digital panoramic radiography to evaluate MI of the mandibular inferior cortex. The results showed a statistically significant difference between the MIs of normal and osteopenic/osteoporotic groups.

Regarding the correlation between the radiomorphometric indices and the BMD of the lumbar spine measured by DXA (*t*-score), our results showed a significant negative correlation between CTCI scores and BMD of the lumbar spine. In addition, a significant positive correlation was found in CTMI and CTI with the BMD of the lumbar spine. As the *t*-score increases, both CMI and CTI increase.

Our results were in agreement with those of Khojastehpour *et al*,²⁶ who demonstrated that the lumbar vertebrae BMD in post-menopausal females were significantly correlated with the MCI assessed using panoramic radiograph. Also in support to our results is the study by Miliuniene *et al*²⁷ on 130 females with age ranging from 30 to 80 years, which showed a significant correlation between the MI on panoramic images and the BMD of the lumbar spine.

In regard to the comparison of FDs between the osteoporotic and control groups, many controversies were found in the literature concerning the relation between FD and trabecular bone complexity. Some studies showed that there was an inverse correlation between FD and osteoporotic state, while others found that the reduction in trabecular complexity was associated with decreased FD.¹⁴ In the present study, the control group showed lower FD values than the osteoporotic group.

In support to our results, Yaşer and Akgunlu²⁸ found that the FD was higher in the osteoporotic group than in the non-osteoporotic group and these differences were not statistically significant. They also concluded that FD can be used as an indicator of post-menopausal osteoporosis.

Our results were also in agreement with the findings of Tosoni et al,²⁹ who assessed FD efficiency in detecting osteoporotic-associated bone density changes. They stated that although there were no significant differences in FD between osteoporotic and normal populations, the FD of the osteoporotic group was higher than that of the normal group.

In contrast to our results, an *in vitro* study investigated the FD of the simulated osteoporotic human maxillary alveolar bone process. After demineralization, a decrease in FD was observed. The authors stated that their results were supported by graphical analysis that showed obvious smoothing of the rough bone surface after demineralization. Also, similar results were found when using the osteoporotic rabbit model: upon increasing the cumulative steroid dose, there was a decrease in the FD of the mandible.³⁰

Moreover, an *in vivo* evaluation of the microarchitecture of human vertebrae on multidetector CT demonstrated statistically significant differences in FD between females with and without history of osteoporotic fractures.³¹

With regard to the correlation between FD and lumbar spine BMD measured by DXA (*t*-score), it was

observed that there was a negative significant correlation between FD and BMD of the lumbar spine. In support to our results, Hua et al³² evaluated decalcified bone samples in relation to DXA using CBCT and found a negative correlation between FD and bone density.

Our results were not in agreement with those of a study carried out by Southard et al,³⁰ who demonstrated that the FD of the alveolar process was not significantly related to the spine, hip or radius density. However, it should be taken into consideration that this study used a different imaging modality and study samples.

Conclusions

We suggest that radiomorphometric indices that are assessed using CBCT could be used as a useful adjuvant tool to refer patients at risk of osteoporosis for further densitometric analysis. Regarding FD, further research must be conducted to evaluate the usefulness of using this tool in CBCT images to diagnose osteoporosis.

Further research should contain a larger sample size of female populations of different age groups and menstruation conditions. Also, further research should include patients with osteopenia, as this may give further information about the mandibular osseous changes at the initial stages of the disease.

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