Journal of Oral Science, Vol. 58, No. 2, 185-194, 2016

Original

Evaluation of osteoporosis in jaw bones using cone beam CT and dual-energy X-ray absorptiometry

Enes Güngör[1], Derya Yildirim[2], and Remzi Çevik[3]

[1]Department of Dentomaxillofacial Radiology, Faculty of Dentistry, Zirve University, Gaziantep, Turkey
[2]Department of Dentomaxillofacial Radiology, Faculty of Dentistry, Süleyman Demirel University, Isparta, Turkey
[3]Department of Physical Therapy and Rehabilitation, Faculty of Medicine, Dicle University, Diyarbakır, Turkey

(Received November 4, 2015; Accepted January 22, 2016)

Abstract: The aim of this study was to evaluate changes in jaw bones due to osteoporosis using cone beam computed tomography (CBCT) images. Subjects that had undergone CBCT for various oral conditions and demonstrating clinical findings of osteoporosis were invited to participate in the study. Dual X-ray absorptiometry (DXA) was performed on 90 patients aged over 30 years who underwent CBCT. The study groups were based on DXA results, and included 26 osteoporosis patients (mean age ± standard deviation; 58.52 ± 5.91), 33 osteopenia patients (52.67 ± 8.61) and 31 healthy controls (49.81 ± 10.47). CBCT images of jaw bones were evaluated using radiomorphometric indexes, CT values, histogram analysis (HA) and fractal dimension (FD) analysis. Right and left mandibular radiomorphometric indexes, CT values and HA measurements in osteoporosis patients were significantly lower than measurements in osteopenia patients and control subjects ($P \leq 0.05$). Positive correlations were observed between measurements of spine bone mineral density (BMD) and right and left mandibular CT values ($P \leq 0.01$) and HA ($P \leq 0.01$) measurements. Left maxilla FD measurements in osteoporosis patients were significantly lower than in the control ($P \leq 0.05$) and osteopenia ($P \leq 0.05$) groups. Osteoporosis caused significant changes in radiomorphometric indexes, CT values, and HA and FD measurements in the jaw bones.
(J Oral Sci 58, 185-194, 2016)

Keywords: cone beam computed tomography; fractal dimension analysis; histogram analysis; Hounsfield unit; osteoporosis.

Introduction

Osteoporosis refers to both decreased bone mass and micro-architectural deterioration of the bone scaffold, leading to bone fragility and enhanced susceptibility to fractures. (1) Osteoporosis is one of the most common diseases of modern society, affecting primarily elderly and middle-aged women. In Europe, osteoporotic fractures account for 2.7 million fractures in both men and women (2). Dual X-ray absorptiometry (DXA) is now widely used to estimate axial, proximal appendicular and total body bone mass. Further, DXA is currently considered the gold standard for quantification of bone mineral density, and has been shown to correlate with fracture risk and treatment efficacy (3). Nonetheless, there are different methods that can be used to predict low bone mineral density (BMD) when evaluating alveolar and cortical bone (4,5).

In previous *in vitro* and *in vivo* studies, bone density obtained using CT values was evaluated on cone beam computed tomography (CBCT) images (6-10). While several studies (11-14) have evaluated mandibular radiomorphometric indices on panoramic radiography images

Correspondence to Dr. Enes Güngör, Department of Dentomaxillofacial Radiology, Faculty of Dentistry, Zirve University, Gaziantep, Turkey
Fax: +90-544-9434304 E-mail: dt.enes1453@hotmail.com

doi.org/10.2334/josnusd.15-0609
DN/JST.JSTAGE/josnusd/15-0609

as potential indicators of osteoporosis, including mental foramen index (MI), mandibular cortical index (MCI) and panoramic mandibular index (PMI), only Koh and Kim have reported the use of CBCT image computed tomography indices (CTI) to evaluate mandibular bone quality (15).

Digital images comprise numerous square elements called pixels, which contain their own brightness and color information. Using histogram analysis (HA), the brightness and color information for each region on a digital image can be transformed into a numerical expression, and this can be used for different purposes in medicine and dentistry, including the determination of BMD.

Fractal dimension (FD) analysis is a statistical texture analysis based on fractal mathematics, and is used for describing complex shapes and structural patterns. In a previous osteoporosis study, FD was used to examine the micro architecture of the trabecular bone (16). Consequently FD may prove to be a non-invasive means of detecting and quantifying changes in the bone mineral content of the alveolar process (17).

There have been studies evaluating the effects of osteoporosis on jaw bones using these four methods individually. These studies were performed on different populations and CT value measurements, HA, FD and radiomorphometric index values of different part of jaws were measured (4-17). However, there have been no studies using these four methods on the same population and same standard areas of the jaw. The purpose of this *in vivo* study was to determine whether statistically significant differences are present in jaw bone tissues on CBCT images from osteoporosis and osteopenia patients, and from non-osteoporotic individuals. For this purpose, different methods, including radiomorphometric indices, CT value measurements, HA and FD were used, and the results obtained were compared with DXA values.

Materials and Methods

This research was conducted at the Dicle University Department of Dentomaxillofacial Radiology Faculty of Dentistry. Patients that had undergone CBCT for the purpose of diagnosing various oral conditions (cysts, tumors, etc.), as well as for implant treatment, were included prospectively. Those randomly selected subjects clinically suspected of having osteoporosis were invited to participate in the present study. They were asked for some clinical findings of osteoporosis, such as ankle pain, limited joint movement and vertebral fracture, and then DXA was performed. Based on DXA results, the study involved 90 patients divided into three experimental groups. Twenty-six individuals ranging in age from 48 to 71 years were enrolled as the osteoporotic patient group, 33 individuals ranging in age from 35 to 66 years were enrolled as the osteopenia group, and 31 individuals ranging in age from 24 to 63 years were enrolled as the healthy group. After CBCT images were acquired, DXA was performed on patients who consented to participate in the study. Selection criteria included a diagnosis of osteoporosis by DXA. According to the World Health Organization (WHO) criteria, individuals with DXA measurements of the hip or the lumbar spine that yielded T-scores of less than −2.5 were diagnosed with osteoporosis, individuals with T-scores between −1.0 and −2.5 were diagnosed with osteopenia, and participants with T-scores of −1 or greater were considered to have normal bone density. Individuals with metabolic diseases such as hyper- or hypo-parathyroidism, diabetes, osteomalacia, thyrotoxicosis and renal disease were excluded from the study. Patients were also excluded from the study if pathology was detected in the area to be examined, if measurements were evaluated incorrectly because of negative values obtained in the CT value measurements of the bone structure, or if measurements could not be obtained.

The study was approved by the Dicle University Medicine Faculty Ethics Committee for Non-interventional Studies (362-2012), and conformed to the principles of the Helsinki-Tokyo declaration. All subjects were informed by clinicians of all of the study procedures, and provided consent for participation.

CBCT images and DXA

CBCT images were obtained with i-CAT (vision; Imaging Sciences International Inc., Hatfield, PA, USA), using a 130 × 100 mm field of view (FOV). The nominal beam was 120 kV and 18.59 mA, with an 8.9 s rotation time, and a voxel size of 0.3 mm. Each participant's head was aligned with a chin rest and laser lines, with the Frankfurt plane parallel to the floor, and the median sagittal plane perpendicular to the floor. Images were analyzed with the i-CAT Vision (Imaging Sciences International Inc.) software, using 0.21 mm slices. The BMD (T-score) of the lumbar vertebra (L1-L3) and the femur were calculated by DXA using a DXA scanner (HologicDiscovery QDR; Hologic Inc., Bedford, MA). Sectional CBCT images to be examined were defined by noting those containing anatomic structures such as the foramen, nasal cavity, maxillary sinus, canal and tooth root. Measurements were then made of the radiomorphometric indices of the right and left sides of the mandible that the instrument was able to define for CT value, fractal dimension analysis,

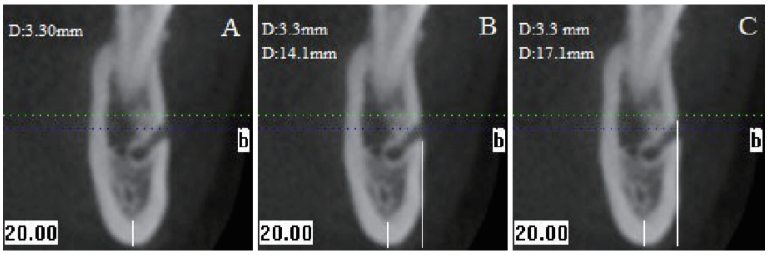

Fig. 1 Radiomorphometric index measurements. (A) CTMI measurement of the mandibular inferior cortical width; (B) CTI(I) ratio measurement of the length between the lower margin of the mental foramen and the lower border of the mandible; (C) CTI(S) ratio measurement of the length between the upper margin of the mental foramen and the lower border of the mandible.

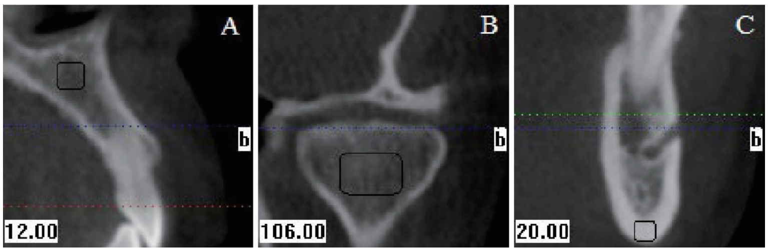

Fig. 2 CT values and HA measurements were obtained in the same area on cross-sections of the CBCT images. (A) The spongeous area of the maxillary bone showing 3 × 3 mm area. (B) Condyle head with the widest spongeous bone field showing 8.4 × 6.6 mm area. (C) Cortical bone with the best view of the mental foramen showing 2.4 × 2.4 mm area.

and histogram analysis measurements.

Measurements

Radiomorphometric index measurements including computed tomography index (inferior) (CTI) (I), computed tomography index (superior) (CTI) (S) and computed tomography mandibular index (CTMI) were obtained, as defined by Koh et al. (15). To obtain the radiomorphometric index measurements, a cross-sectional image that clearly indicated the mental foramen on the right and left sides of the mandible was selected from the CBCT images. To obtain the CTMI, a horizontal line contacting the lower border of the mandible was placed on the cross-sectional image. The line was extended vertically from the upper border of the inferior cortical width, and the length of the perpendicular line was measured. To obtain CTI (I) ratio, a horizontal line contacting the lower border of the mandible was also placed on the cross-sectional image. CTMI (inferior) is the ratio of the inferior cortical width to the distance from the inferior margin of the mental foramen to the inferior border of the mandible. To obtain CTI (S) ratio, a horizontal line contacting the lower border of the mandible was placed on the cross-sectional image. CTMI (superior) is the ratio of the inferior cortical width to the distance from the superior margin of the mental foramen to the inferior border of the mandible (Fig. 1). The maxilla CT value, and HA and FD analysis measurements were obtained by first selecting a single 3 × 3 mm field that included spongeous bone in the area of the incisor and canine teeth on both the right and left side cross-sections of the CBCT images (Fig. 2A). The condyle head CT value, and HA and FD analysis measurements were obtained by first selecting a single 8.4 × 6.6 mm field that included spongeous bone, with the widest view of both the right and left side condyle heads on CBCT images (Fig. 2B). Evaluation of the mandibular cortical area was performed by first selecting a single 2.4 × 2.4 mm field that did not extend into the spongeous area, where the right and left side mental foramen were clearly visible in the cortical area on CBCT images (Fig. 2C).

The CBCT cross-sectional images used for the CT value measurements were recorded in JPEG format and transferred to the ImageJ program. For HA in ImageJ software, 14 × 14 pixel areas were selected for the maxilla, 40 × 30 pixel areas were selected for the condyle head and 12 × 12 pixel areas were selected for the mandible. Images were saved in TIFF format, and HA was performed.

ImageJ (1.41) image processing and analysis software

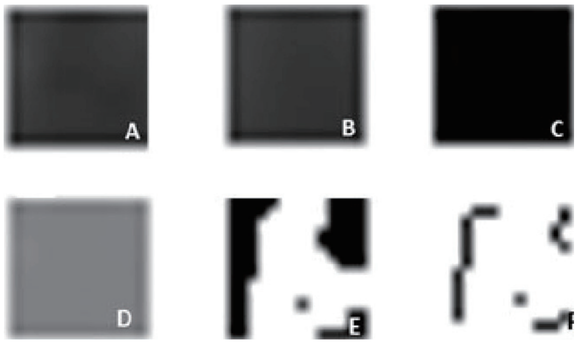

Fig. 3 (A) ROIs were cropped and transferred to Image J. (B) Cropped ROIs were duplicated; (C) Duplicated images were blurred with a Gaussian filter (kernel size = 35); (D) Blurred images were then subtracted from the original image; (E) Resultant image was converted to binary by thresholding at a gray value of 128, and regions that represented trabecular bone were set to black and marrow spaces were set to white; (F) Finally, the image was skeletonized and used for fractal analysis.

was obtained online (http://rsb.info.nih.gov). The box counting method reported by Mandelbrot was used for maxilla and condyle head FD analysis (Mandelbrot 1977) (Fig. 3).

Statistical analysis

For normally distributed variables, comparisons of the three groups were conducted using one-way analysis of variance (ANOVA), and Tukey's and Tamhane's post-hoc analyses were used to conduct multiple comparison tests.

For variables that were not normally distributed, Kruskal-Wallis test was used to compare the three groups, and Mann-Whitney *U* test with Bonferroni correction was used for multiple comparison tests. To determine whether there was a relationship between the variables obtained by different methods and variables obtained by DXA, Pearson's correlation (r) test was used. Data were evaluated using SPSS software (ver. 18; SPSS Inc., Chicago, IL, USA).

Results

Mandibular radiomorphometric index measurements

Mandibular radiomorphometric index measurements were obtained from the right and left sides of the mandible. Following the application of exclusion criteria, 80 patients were included for CTMI measurements, 83 patients remained for CTI (I) measurements, and 83 patients were included for CTM (S) measurements. The mean CTMI (P = 0.001), CTI (I) (P = 0.001) and CTI (S) (P = 0.002) measurements from osteoporosis patients were significantly lower than the mean measurements of the osteopenia and control groups. Evaluation of CTMI measurements revealed that the CTMI values of osteoporosis group were significantly lower than the CTMI values of osteopenia group (P = 0.007) and the control group (P = 0.001). Evaluation of CTI (I) measurements revealed that the osteoporosis group CTI (I) values were significantly lower than the osteopenia group (P = 0.004) and the control group (P = 0.001). Finally, evaluation of CTI (S) measurements revealed that the CTI (S) values of osteoporosis group were significantly lower than the osteopenia group (P = 0.038) and the control group (P = 0.002; Table 1).

The correlations between vertebral and femoral head BMD values and radiomorphometric indices were evaluated based on DXA results. The results revealed a positive correlation between vertebral BMD and CTMI (r = 0.48, $P \leq 0.01$), CTI (I) (r = 0.40, $P \leq 0.01$), and CTI (S) (r = 0.32, $P \leq 0.01$). A positive correlation was also detected between the femoral head BMD and CTMI (r = 0.32, $P \leq 0.01$).

CT Values

Evaluation of CT values taken from six separate areas of the jaw bone, including the right and left maxilla, right and left mandible, and the right and left condyle, was performed. Measurements of the right maxilla, the left maxilla, the right mandible, the left mandible, the right condyle, and the left condyle were obtained from 71, 74, 75, 78, 32, and 69 patients, respectively. The mean CT values of the left maxilla (P = 0.018), left mandible (P = 0.001) and right mandible (P = 0.001) from the osteoporosis patients were significantly lower than measurements obtained from the osteopenia and the control groups.

Evaluation of the left maxilla measurements revealed that the CT values in the osteoporosis group were significantly lower than measurements obtained in the

Table 1 Radiomorphometric index measurements obtained from the jaw, and results of Tukey's and Tamhane analyses

		Osteoporosis		Osteopenia		Normal	O:o	O:N	o:N
	n	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*P*	*P*	*P*
CTMI (mm)	26	2.76 ± 0.50	29	3.42 ± 0.58	26	3.62 ± 0.59	0.007**	0.001***	0.491
CTI(I)	26	0.20 ± 0.06	30	0.25 ± 0.05	28	0.27 ± 0.04	0.004**	0.001***	0.479
CTI(S)	26	0.16 ± 0.05	30	0.19 ± 0.04	28	0.20 ± 0.03	0.038*	0.002**	0.521

N, group with normal BMD; O, group with osteoporosis; o, group with osteopenia; SD, standard deviation; BMD, bone mineral density; *n*, number of patients or normal; *$P \le 0.05$; **$P \le 0.01$; ***$P \le 0.001$.

Table 2 CT values obtained from the jaw, and results of Tukey's and Mann-Whitney *U* analyses

		Osteoporosis		Osteopenia		Normal	O:o	O:N	o:N
	n	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*P*	*P*	*P*
Right maxilla	15	294.07 ± 190.02	28	252.57 ± 163.42	28	258.96 ± 180.23	0.826	0.779	0.935
Left maxilla	20	200.80 ± 187.81	27	265.89 ± 156.61	26	300.27 ± 146.02	0.043*	0.006**	0.383
Right mandible	23	1,309.86 ± 124.23	27	1,390.63 ± 106.23	26	1,479.27 ± 112.91	0.042*	0.001***	0.016*
Left mandible	26	1,334.8 ± 21.05	28	1,409.14 ± 85.12	25	1,500.76 ± 82.31	0.034*	0.001***	0.003**
Right condyle	9	100.33 ± 58.51	9	77.56 ± 45.42	14	95.79 ± 57.41	0.546	0.877	0.284
Left condyle	21	121.43 ± 71.13	22	125.91 ± 59.63	26	167.19 ± 61.42	0.971	0.046*	0.074

N, group with normal BMD; O, group with osteoporosis; o, group with osteopenia; SD, standard deviation; BMD, bone mineral density; *n*, number of patients or normal; *$P \le 0.05$; **$P \le 0.01$; ***$P \le 0.001$.

osteopenia ($P = 0.043$) and control groups ($P = 0.006$). Furthermore, evaluation of the left mandibular measurements revealed that the CT values in the osteoporosis group were significantly lower than values in the osteopenia ($P = 0.034$) and control groups ($P = 0.001$). A comparison of the osteopenia and control group measurements revealed that the osteopenia group CT values were significantly lower ($P = 0.003$). Lastly, evaluation of the right mandible measurements revealed that the CT values in the osteoporosis group were significantly lower than those in the osteopenia ($P = 0.042$) and control groups ($P = 0.001$), and that the CT values in the osteopenia group were significantly lower than those in the control group ($P = 0.016$; Table 2).

According to the DXA results obtained, an evaluation of potential correlations between the vertebral and femoral head BMD and CT value measurements obtained from the six defined areas revealed significant positive correlations between vertebral BMD and the left maxilla (r = 0.28, $P \le 0.05$), the right mandible (r = 0.58, $P \le 0.01$) and the left mandible (r = 0.63, $P \le 0.01$) CT values. A positive correlation was also detected between the femoral head BMD and both the left mandible (r = 0.25, $P \le 0.05$) and the left condyle CT values (r = 0.27, $P \le 0.05$).

Histogram analysis

Measurements from the right maxilla, left maxilla, right mandible, left mandible, right condyle and left condyle were obtained from 85, 84, 76, 80, 77, and 82 patients, respectively. Mean HA measurements from the left maxilla ($P = 0.002$), left mandible ($P = 0.001$) and right mandible ($P = 0.001$) of osteoporosis patients were significantly lower than the osteopenia and control group values.

Evaluation of the left maxilla HA values from the osteoporosis group revealed significantly lower values than those from the osteopenia ($P = 0.008$) and control groups ($P = 0.002$). Furthermore, the right mandible HA values from the osteoporosis group were significantly lower than those from the osteopenia ($P = 0.004$) and control groups ($P = 0.001$). A comparison of the osteopenia group and the control group revealed that the osteopenia group HA values were significantly lower ($P = 0.009$). Finally, evaluation of the left mandible HA values from the osteoporosis group revealed significantly lower values than those from the control group ($P = 0.001$; Table 3).

According to the DXA results obtained, evaluation of potential correlations between the vertebral and femoral head BMD and HA measurements obtained from the six defined areas revealed a positive correlation between the vertebral BMD and the right maxilla (r = 0.24, $P \le 0.01$), left maxilla (r = 0.38, $P \le 0.01$) right mandible (r = 0.61, $P \le 0.01$) and left mandible HA measurements (r = 0.54, $P \le 0.01$).

Table 3 HA measurements obtained from the jaw, and results of Tukey's and Mann-Whitney *U* analyses

		Osteoporosis		Osteopenia		Normal	O:o	O:N	o:N
	n	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*P*	*P*	*P*
Right maxilla	25	59.76 ± 17.01	30	62.43 ± 12.87	30	66.17 ± 14.23	0.272	0.080	0.318
Left maxilla	25	55.82 ± 15.91	29	63.79 ± 12.72	30	67.87 ± 11.84	0.008**	0.002**	0.205
Right mandible	23	139.55 ± 8.74	27	147.56 ± 8.15	26	153.54 ± 8.57	0.004**	0.001***	0.009**
Left mandible	26	142.52 ± 10.62	28	147.93 ± 7.27	26	154.04 ± 7.21	0.077	0.001***	0.026*
Right condyle	24	44.46 ± 8.41	26	43.35 ± 6.55	27	46.37 ± 6.71	0.840	0.612	0.282
Left condyle	25	52.72 ± 6.23	28	51.00 ± 6.25	29	54.79 ± 7.37	0.783	0.345	0.093

N, group with normal BMD; O, group with osteoporosis; o, group with osteopenia; SD, standard deviation; BMD, bone mineral density; *n*, number of patients or normal; *$P \leq 0.05$; **$P \leq 0.01$; ***$P \leq 0.001$.

Table 4 FD analysis measurements obtained from the jaw, and results of the Mann-Whitney *U* analysis

		Osteoporosis		Osteopenia		Normal	O:o	O:N	o:N
	n	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*P*	*P*	*P*
Right maxilla	25	0.94 ± 0.08	29	0.96 ± 0.05	29	0.91 ± 0.17	0.380	0.926	0.293
Left maxilla	25	0.93 ± 0.05	29	0.95 ± 0.05	30	0.96 ± 0.04	0.039*	0.011*	0.909
Right condyle	25	1.37 ± 0.07	24	1.39 ± 0.03	27	1.40 ± 0.02	0.838	0.237	0.104
Left condyle	25	1.39 ± 0.04	28	1.40 ± 0.02	28	1.39 ± 0.07	0.464	0.657	0.176

N, group with normal BMD; O, group with osteoporosis; o, group with osteopenia; SD, standard deviation; BMD, bone mineral density; *n*, number of patients or normal; *$P \leq 0.05$.

Fractal Dimension Analysis

Evaluation of FD analysis measurements taken from four separate areas of the jawbone, including the right and left maxilla and the right and left condyles, was conducted. Measurements were obtained from the right maxilla, left maxilla, right condyle and left condyle from 83, 84, 76, and 81 patients, respectively. The mean FD analysis measurements from the left maxilla of osteoporosis patients were significantly lower than those in the osteopenia ($P = 0.039$) and control groups ($P = 0.011$; Table 4).

According to the DXA results obtained, the correlations between vertebral and femoral head BMD and FD Analysis measurements taken from the four defined areas revealed a positive correlation between vertebral BMD and right condyle FD analysis measurements (r = 0.23, $P \leq 0.05$).

Discussion

Previous reports have indicated that as with other osteoporotic bones, there are negative effects on implant treatment in the socket of an extracted tooth, including a decrease in the rate of bone formation, alveolar bone interdental bone thickness, and in the density and thickness of the mandibular inferior cortex (18-20).

In this study, osteoporosis was evaluated using the DXA method, which is considered to be the gold standard for diagnosing osteoporosis. Based on DXA results, three experimental groups comprising the osteoporosis group, the osteopenia group and the healthy control group were defined. The inclusion of the osteopenia group, which showed symptoms occurring before osteoporosis onset, was aimed at determining changes that can be identified in the bone prior to the development of osteoporosis.

Several studies have involved the application of different methods to examine bone structure using panoramic radiography (13,14,21-24). However, only a limited number of studies have evaluated bone structure using CT (25,26). Nonetheless, the superior radiographic imaging properties of CBCT have led to an increase in application of the technology among dental practitioners (27). Furthermore, research on the evaluation of jaw bones using CBCT CT value measurements (6,10,9,28), radiomorphometric indices (15) and computer software is ongoing (29-32).

In the present study, radiomorphometric index measurements, CT value, and the HA and FD methods were used to evaluate jaw bones on CBCT images. CT and HA measurements were made in the maxilla, the spongeous bone of the condyle head, and in the mandibular cortical bone. FD measurements, which are trabecular bone measurements, were obtained from the maxilla and condyle head.

Koh has reported the use of CBCT images (CTI(I),CTI(S),CTMI) to evaluate mandibular bone quality (15). This study has an additional osteopenia group and larger study group than Koh's study, which focused on mandibular radiomorphometric index measurements.

Several studies have involved the application of different methods to examine bone structure using panoramic radiography (13,14,21-24). However, only a limited number of studies have evaluated bone structure using CT (25,26). Anatomic landmarks such as fossa fovea cannot be seen on panoramic radiographs due to its two-dimensional properties. Moreover, these landmarks (foramen, nasal cavity, maxillary sinus, tooth roots, mandibular canal) were considered to prevent superposition in the measurement of CT, HA and FD values (5,16,17).

There have been numerous *in vitro* studies (6,8,9,28) and some *in vivo* studies (10) evaluating the utility of CT values in density measurement. Cross-sectional CBCT images show a thickness of 2-3 mm, and this demonstrates the significant advantage of CT for panoramic images. Therefore anatomic landmarks do not affect the measurement of CT values, HA and FD. In addition, there have been numerous osteoporosis studies that have used panoramic radiography with the HA method (4,5). CT values and HA are not classified according to spongeous and cortical bone for osteoporosis in these studies. In the present study, the effects of osteoporosis on the jaw bone were separately evaluated in cortical and spongeous bone. To the best of our knowledge, no previous studies have involved the simultaneous application of different methods in the same bone regions.

In the present study, the use of CTI(I), CTI(S) and CTMI measurements indicated a significant difference between osteoporosis patients, and the osteopenia and control groups ($P \leq 0.01$). The paired comparison of the osteoporosis and osteopenia groups and of the osteoporosis and control groups indicated that significant differences were apparent in all of the index measurements. However, the paired comparison of the osteopenia and control group revealed no significant differences in the index measurements between the two groups. The results indicate that in the presence of osteopenia, no changes in the jaw indices were apparent, whereas in the presence of osteoporosis, significant differences were detected in the index measurements. Furthermore, while significant positive correlations between CTMI, CTI(I) and CTI(S) measurements and vertebral BMD were determined by DXA, when the femoral head BMD measurements were analyzed, a positive correlation was only noted between femoral head BMD and CTMI index.

When studies that compared radiomorphometric indices with BMD or T-scores defined by DXA were examined, the results of a single index study conducted using CBCT (15) and several studies that included panoramic radiography (12,33,34) supported the present findings. However, the results of other panoramic radiographic studies did not support the present findings (14,35). Possible explanations for the apparent differences in radiomorphometric index measurements include incorrect positioning of the patient, non-standardization of positions during imaging, and variations in anatomic structures (36). Nonetheless, measurements obtained from CBCT cross-sectional imaging may yield more accurate evaluations.

CT value measurement on CBCT images is somewhat controversial. While various studies have found that bone density could be measured by CT values (6,10), others have reported that it is not possible because of metallic artefacts, and noted differences in CT values in bone densities of the same bone regions caused by positioning (7-9). In the present study, a significant difference in the left and right mandible CT value measurements in the cortical bone was detected between the osteoporosis, osteopenia and control groups ($P \leq 0.001$). In addition, a correlation was observed between the vertebral BMD value and left-right CT value of the mandible ($P \leq 0.01$), and between the femoral BMD and left mandible CT value ($P \leq 0.05$). When the correlations between the vertebral and femoral head BMD measurements and CT values were compared, a more significant positive correlation was detected between the vertebral BMD and CT values. While vertebral fractures are detected more often in post-menopausal women, the frequency of femoral fractures is greater in individuals over the age of 70 years. Therefore, in osteoporosis evaluations, the measurement of vertebral BMD is preferred in post-menopausal females, while measurement of the femoral head BMD is favored in individuals over 70 years (37). Most of the current study participants were female (62%) with a mean age of 52.11 ± 13.72 years; thus, the majority of females in the present study might have been post-menopausal. Therefore, the correlation between vertebral BMD and CT values was considered to be a more significant finding than the correlation between femoral BMD and CT values. The strong correlation noted between vertebral BMD and both the right and left mandibular CT value measurements indicated that the CT values from both sides of the mandible were similar.

The correlation found between the lumbar vertebra BMD and the CT value of the right side of the mandible agreed with the findings of a study by Klemetti et al., which was conducted using CBT (22). In a study by Marquezan et al., although no relationship was detected between BMD and cortical bone CT value, a correlation was noted between BMD value and the total bone CT values (38).

There should be no data loss in studies focusing on image analysis. TIFF format is the best method for performing HA and FD analyses, and when data is converted from JPEG to TIFF format, data loss can occur. Unfortunately, it was not possible for the CBCT cross-sectional images to be recorded in TIFF format with the software used in this study. Total file size of TIFF images is reduced when these images are compressed to JPEG images (39,40).

In the present study, the mean HA values of the osteoporosis patients in the right and left mandible and in the maxilla were lower than the values in the osteopenia and control groups. In addition, the results of the paired comparisons revealed that the HA values in the osteoporosis patients were lower, which agreed with the results of previous studies that involved panoramic radiography (5). Furthermore, significant positive correlations were found between vertebra BMD measurements and HA measurements in the right and left mandible and the left maxilla demonstrated that changes reflected in BMD measurements of the jaw are similarly reflected by HA measurements.

Fractal analysis uses statistical texture analysis in order to examine the spongeous bone microarchitecture with a numerical expression of the FD as a measure of image complexity. Alman et al. and Demirbaş et al. have reported that FD analysis was performed on spongeous bone of the first molar and second premolar (41,42). In this study, FD analysis was performed on spongeous bone, as mentioned above.

Some studies have reported that osteoporosis patients have higher FD values than controls (43,44). This was thought to be related to increased microfractures in trabecular bone in osteoporosis patients (44). In the present study, it was found that the left maxilla FD measurements in osteoporosis patients were significantly lower than the osteopenia ($P \leq 0.05$) and control group measurements ($P \leq 0.05$). In addition, we found a positive correlation between vertebral BMD and the right condyle FD analysis measurements ($P \leq 0.05$), which agreed with the results of previous studies (41,42,45,46).

As a result of the present study, CTMI, CTI(I), CT and HA values may be used to compare osteoporosis, osteopenia and control groups (P = 0.001) on CBCT images of the mandible. HA values on CBCT images of right mandible may also be used in paired comparisons. HA values in the left maxilla may be used to compare osteoporosis, osteopenia and control groups (P = 0.002) on the CBCT images of maxilla and condyle, while HA values on CBCT images of the left maxilla may be used in paired comparisons.

The results of the present study supported the notion that changes in the jaw bone associated with osteoporosis can be defined by radiomorphometric index measurements, CT values, and HA and FD analysis on CBCT images. Similarly, the findings indicated that the evaluation of CT values, and HA and FD measurements may provide an advantage in the determination of jaw bone status, particularly prior to implant treatment. Furthermore, the importance of the mandibular cortical bone CT values and HA measurements are apparent when considering unsuccessful implant treatment, and the bone resorption that occurs in the cortical bone in the cervical section of an implant. CT values generated by CBCT instruments should be standardized, and further studies should be conducted on individuals from different socio-demographic backgrounds at centers with available CBCT instruments.

Acknowledgments

This study was presented as a PhD thesis on Dentomaxillofacial Radiology within the Süleyman Demirel University Faculty of Dentistry in 2013.

Conflicts of interest

The authors declare that they have no conflicts of interest.

References

1. White SC (2002) Oral radiographic predictors of osteoporosis. Dentomaxillofac Radiol 31, 84-92.
2. Kanis JA, Borgstrom F, De Laet C, Johansson H, Johnell O, Jonsson B et al. (2005) Assessment of fracture risk. Osteoporos Int 16, 581-589.
3. Marshall D, Johnell O, Wedel H (1996) Meta-analysis of how well measures of bone mineral density predict occurrence of osteoporotic fractures. BMJ 312, 1254-1259.
4. Law AN, Bollen AM, Chen SK (1996) Detecting osteoporosis using dental radiographs: a comparison of four methods. J Am Dent Assoc 127, 1734-1742.
5. Bozic M, Ihan Hren N (2006) Osteoporosis and mandibles. Dentomaxillofac Radiol 35, 178-184.
6. Aranyarachkul P, Caruso J, Gantes B, Schulz E, Riggs M, Dus I et al. (2005) Bone density assessments of dental implant sites: 2. Quantitative cone-beam computerized tomography. Int J Oral Maxillofac Implants 20, 416-424.
7. Swennen GRJ, Schutyser F (2006) Three-dimensional cephalometry: spiralmulti-slice vs cone-beam computed tomography. Am J Orthod Dentofacial Orthop 130, 410-421.
8. Katsumata A, Hirukawa A, Noujeim M, Okumura S, Naitoh M, Fujishita M et al. (2006) Image artifact in dental cone-

beam CT. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 101, 652-657.

9. Katsumata A, Hirukawa A, Okumura S, Naitoh M, Fujishita M, Ariji E et al. (2007) Effects of image artifacts on gray-value density in limited-volume cone-beam computerized tomography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 104, 829-836.
10. Kaya S, Yavuz I, Uysal I, Akkuş Z (2012) Measuring bone density in healing periapical lesions by using cone beam computed tomography: a clinical investigation. J Endod 38, 28-31.
11. Yüzügüllü B, Gulsahi A, Imirzalioglu P (2009) Radiomorphometric indices and their relation to alveolar bone loss in completely edentulous Turkish patients: a retrospective study. J Prosthet Dent 101, 160-165.
12. Dagistan S, Bilge OM (2010) Comparison of antegonial index, mental index, panoramic mandibular index and mandibular cortical index values in the panoramic radiographs of normal males and male patients with osteoporosis. Dentomaxillofac Radiol 39, 290-294.
13. Hastar E, Yilmaz HH, Orhan H (2011) Evaluation of mental index, mandibular cortical index and panoramic mandibular index on dental panoramic radiographs in the elderly. Eur J Dent 5, 60-67.
14. Ferreira Leite A, de Souza Figueiredo PT, Ramos Barra F, Santos de Melo N, de Paula AP (2011) Relationships between mandibular cortical indexes, bone mineral density, and osteoporotic fractures in Brazilian men over 60 years old. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 112, 648-656.
15. Koh KJ, Kim KA (2011) Utility of the computed tomography indices on cone beam computed tomography images in the diagnosis of osteoporosis in women. Imaging Sci Dent 41, 101-106.
16. Bollen AM, Taguchi A, Hujoel PP, Hollender LG (2001) Fractal dimension on dental radiographs. Dentomaxillofac Radiol 30, 270-275.
17. Southard TE, Southard KA (1996) Detection of simulated osteoporosis in maxillae using radiographic texture analysis. IEEE Trans Biomed Eng 43, 123-132.
18. Shimizu M, Furuya R, Kawawa T, Sasaki T (2000) Bone wound healing after maxillary molar extraction in ovariectomized aged rats: quantitative backscattered electron image analysis. Anat Rec 259, 76-85.
19. Jonasson G, Bankvall G, Kiliaridis S (2001) Estimation of skeletal bone mineral density by means of the trabecular pattern of the alveolar bone, its interdental thickness, and the bone mass of the mandible. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 92, 346-352.
20. Tadinada A, Ortiz D, Taxel P, Shafer D, Rengasamy K, Pendrys D et al. (2015) CBCT evaluation of buccal bone regeneration in postmenopausal women with and without osteopenia or osteoporosis undergoing dental implant therapy. J Prosthet Dent 114, 498-505.
21. Benson BW, Prihoda TJ, Glass BJ (1991) Variations in adult cortical bone mass as measured by a panoramic mandibular index. Oral Surg Oral Med Oral Pathol 71, 349-356.
22. Klemetti E, Vainio P, Lassila V, Alhava E (1993) Cortical bone mineral density in the mandible and osteoporosis status in postmenopausal women. Scand J Dent Res 101, 219-223.
23. Ledgerton D, Horner K, Devlin H, Worthington H (1999) Radiomorphometric indices of the mandible in a British female population. Dentomaxillofac Radiol 28, 173-181.
24. Dutra V, Devlin H, Susin C, Yang J, Horner K, Fernandes AR (2006) Mandibular morphological changes in low bone mass edentulous females: evaluation of panoramic radiographs. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 102, 663-668.
25. Turkyilmaz I, McGlumphy EA (2008) Influence of bone density on implant stability parameters and implant success: a retrospective clinical study. BMC Oral Health 8, 32.
26. Schreiber JJ, Anderson PA, Rosas HG, Buchholz AL, Au AG (2011) Hounsfield units for assessing bone mineral density and strength: a tool for osteoporosis management. J Bone Joint Surg Am 93, 1057-1063.
27. De Vos W, Casselman J, Swennen GR (2009) Cone-beam computerized tomography (CBCT) imaging of the oral and maxillofacial region: a systematic review of the literature. Int J Oral Maxillofac Surg 38, 609-625.
28. Lee S, Gantes B, Riggs M, Crigger M (2007) Bone density assessments of dental implant sites: 3. Bone quality evaluation during osteotomy and implant placement. Int J Oral Maxillofac Implants 22, 208-212.
29. Hua Y, Nackaerts O, Duyck J, Maes F, Jacobs R (2009) Bone quality assessment based on cone beam computed tomography imaging. Clin Oral Implants Res 20, 767-771.
30. Torres SR, Chen CS, Leroux BG, Lee PP, Hollender LG, Schubert MM (2011) Fractal dimension evaluation of cone beam computed tomography in patients with bisphosphonate-associated osteonecrosis. Dentomaxillofac Radiol 40, 501-505.
31. González-Martín O, Lee EA, Veltri M (2012) CBCT fractal dimension changes at the apex of immediate implants placed using undersized drilling. Clin Oral Implants Res 23, 954-957.
32. Huang Y, Van Dessel J, Liang X, Depypere M, Zhong W, Ma G et al. (2014) Effects of immediate and delayed loading on peri-implant trabecular structures: a cone beam CT evaluation. Clin Implant Dent Relat Res 16, 873-883.
33. Vlasiadis KZ, Skouteris CA, Velegrakis GA, Fragouli I, Neratzoulakis JM, Damilakis J et al. (2007) Mandibular radiomorphometric measurements as indicators of possible osteoporosis in postmenopausal women. Maturitas 58, 226-235.
34. Marandi S, Bagherpour A, Imanimoghaddam M, Hatef M, Haghighi A (2010) Panoramic based mandibular indices and bone mineral density of femoral neck and lumbar vertebrae in women. J Dent (Tehran) 7, 98-106.
35. Gulsahi A, Paksoy CS, Ozden S, Kucuk NO, Cebeci AR, Genc Y (2010) Assessment of bone mineral density in the jaws and its relationship to radiomorphometric indices. Dentomaxillofac Radiol 39, 284-289.

36. Akesson L, Håkansson J, Rohlin M, Zöger B (1993) An evaluation of image quality for the assessment of the marginal bone level in panoramic radiography. a comparison of radiographs from different dental clinics. Swed Dent J 17, 9-21.
37. Nordin BEC, Chatterton BE, Need AG, Horowitz M (1995) The definition, diagnosis and classification of osteoporosis. Physic Med Rehabili Clin North Am 6, 395-414.
38. Marquezan M, Lau TC, Mattos CT, Cunha AC, Nojima LI, Sant'Anna EF et al. (2012) Bone mineral density. Angle Orthod 82, 62-66.
39. Gürdal P, Hildebolt CF, Akdeniz BG (2001) The effects of different image file formats and image-analysis software programs on dental radiometric digital evaluations. Dentomaxillofac Radiol 30, 50-55.
40. Yasar F, Apaydin B, Yilmaz HH (2012) The effects of image compression on quantitative measurements of digital panoramic radiographs. Med Oral Patol Oral Cir Bucal 17, e1074-1081.
41. Demirbaş AK, Ergün S, Güneri P, Aktener BO, Boyacioğlu H (2008) Mandibular bone changes in sickle cell anemia: fractal analysis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 106, e41-48.
42. Alman AC, Johnson LR, Calverley DC, Grunwald GK, Lezotte DC, Hokanson JE (2012) Diagnostic capabilities of fractal dimension and mandibular cortical width to identify men and women with decreased bone mineral density. Osteoporos Int 23, 1631-1636.
43. Ruttiman UE, Webber RL, Hazelrig JB (1992) Fractal dimension from radiographs of periodental alveolar bone: a possible diagnostic indicator of osteoporosis. Oral surg Oral Med Oral Pathol 74, 98-110.
44. Yaşar F, Akgünlü F (2006) The differences in panoramic mandibular indices and fractal dimension between patients with and without spinal osteoporosis. Dentomaxillofac Radiol 35, 1-9.
45. Geraets WG, Verheij JG, van der Stelt PF, Horner K, Lindh C, Nicopoulou-Karayianni K et al. (2007) Prediction of bone mineral density with dental radiographs. Bone 40, 1217-1221.
46. Topoliński T, Mazurkiewicz A, Jung S, Cichański A, Nowicki K (2012) Microarchitecture parameters describe bone structure and its strength better than BMD. ScientificWorldJournal 2012:502781. doi: 10.1100/2012/502781.