Relationship of gray values in cone beam computed tomography and bone mineral density obtained by dual energy X-ray absorptiometry

Abbas Shokri, MSc,[a] Mahsa Ghanbari, DDS,[b] Fatemeh Hafez Maleki, MSc,[c] Leila Ramezani, MSc,[c] Payam Amini, PhD,[d] and Leili Tapak, PhD[e]

Objectives. The aim of this study was to assess the correlation between bone mineral density (BMD) determined with cone beam computed tomography (CBCT) gray values and BMD determined by dual energy X-ray absorptiometry (DEXA).

Study Design. Women age greater than 50 years requiring CBCT for implant treatment were included in the study. BMD was determined by calculating the mean gray value of CBCT cross-sectional images of anterior, premolar, retromolar, and tuberosity areas of the mandible and maxilla. Patients were then subjected to DEXA of the femoral neck and lumbar spine. Independent *t* tests, analysis of variance (ANOVA), Pearson's correlation tests, and receiver operating characteristic (ROC) evaluation were used for data analysis.

Results. Of 61 asymptomatic patients (mean age 64 years), 47.5% and 55.7% had abnormal BMD, based on the T-scores of the femoral neck and lumbar spine, respectively. Significant correlations were noted between the T-scores of the femoral neck and lumbar spine and the gray values of the maxillary incisor and tuberosity areas.

Conclusions. A strong correlation exists between the CBCT gray values at different sites in the maxilla and the results of DEXA. A gray value less than 298 at the maxillary tuberosity can help distinguish patients with osteoporosis from normal individuals, with 66% to 67% accuracy and suggests the need for DEXA analysis. (Oral Surg Oral Med Oral Pathol Oral Radiol 2019;128:319–331)

According to the World Health Organization, osteoporosis is defined as "bone mineral density (BMD) that lies 2.5 standard deviations or more below the average value for young healthy Individuals." Osteoporosis often occurs in older adults and is characterized by a reduction in bone strength, which increases susceptibility to bone fracture.[1,2] Osteoporosis has a high prevalence in both developed and developing countries; in the United States, approximately 1.5 million fractures caused by osteoporosis have been reported.[3] About half these fractures occur in the spine and the remaining in the radius, hip, and other bones.[4] The prevalence of bone fractures in females is higher than that in males. Postmenopausal women are particularly prone to bone fracture as a result of a significant reduction in serum levels of estrogen.[5,6]

[a]Associate Professor, Dental Implant Research Center, Department of Oral and Maxillofacial Radiology, Dental School, Hamadan University of Medical Sciences, Hamadan, Iran.
[b]General Dentist, Hamadan, Iran.
[c]Assistant Professor, Department of Oral and Maxillofacial Radiology, Dental School, Hamadan University of Medical Sciences, Hamadan, Iran.
[d]Department of Epidemiology and Reproductive Health, Reproductive Epidemiology Research Center, Royan Institute for Reproductive Biomedicine, ACECR, Tehran, Iran.
[e]Assistant Professor, Department of Biostatistics, School of Public Health, Hamadan University of Medical Sciences, Hamadan, Iran.
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Dual energy X-ray absorptiometry (DEXA) is commonly performed to measure BMD.[7,8] Although DEXA has been considered the gold standard for this purpose, it has some disadvantages, such as high cost, large equipment size, and difficulty in interpreting results, which limit its utility.[9,10] In DEXA, BMD and T-scores are reported. *BMD* refers to the bone mineral mass per volume of bone, and *T-score* refers to the standard deviations higher or lower than the mean value in adults age greater than 30 years who are of the same sex and race/ethnicity. The T-score is −2.5 or less in patients with osteoporosis.[11]

Cone beam computed tomography (CBCT) provides 3-dimensional (3-D) scans of the maxillofacial structures, enabling accurate dimensional analysis. Clinical applications of CBCT are increasing because of the relatively low cost of equipment, low patient radiation dose in comparison with multislice computed tomography (CT),[12] short scanning time, and high image resolution.[12-15]

The term *gray value* indicates the level of brightness of a pixel.[16] In CBCT, hard tissues, such as bone and

Statement of Clinical Relevance

If significant correlation exists between the cone beam computed tomography gray value and the results of dual energy X-ray absorptiometry, this index can be used for primary assessment of bone mineral density and early detection of osteoporosis in patients presenting to a radiologist for primary assessment of bone mineral density.

teeth, absorb greater amounts of X-ray energy compared with soft tissues, such as skin, tongue, and gingiva, creating different shades of gray on 3-D images. Thus, CBCT uses different gray values to define morphology and to measure the density of objects.[17] The efficacy of this index for the assessment of BMD has been well documented in recent years.[17-19]

On CBCT images, BMD can be determined on the basis of the difference in the gray scale.[17] Considering the importance of early detection of osteoporosis and the common use of CBCT for dental imaging, BMD may be primarily assessed on CBCT scans to enhance early detection of osteoporosis by referral to appropriate specialists.

Although the radiation dose is low in CBCT, it is not recommended for screening for osteoporosis in older patients. However, the capability of CBCT software could be utilized in the skeletal evaluation of older patients who undergo CBCT for other diagnostic and therapeutic purposes, such as dental implantation and periodontal surgery.

Given that a significant correlation exists between CBCT gray values and the results of DEXA,[17,20] this index can be used for primary assessment of BMD and early detection of osteoporosis. Moreover, early detection of osteoporosis in patients presenting to a radiologist for primary assessment of BMD can have a significant impact on treatment planning and prognosis. Early diagnosis of osteopenia (defined as a T score less than −1 and greater than −2.5) may help prevent progression of disease to osteoporosis by indicating the need for preventive measures. This study aimed to compare the gray values in CBCT scans and the data from DEXA examinations in the determination of BMD. The null hypothesis stated that there were no significant correlations between CBCT gray values and DEXA T-scores.

MATERIALS AND METHODS

This study was conducted on female patients who had undergone CBCT, as requested by their dentists, for implant treatment.

Ethics

This study was performed on postmenopausal women who were older than 50 years of age and had been informed about the need for bone densitometry with DEXA because of their risk for osteoporosis. Written informed consent was obtained from patients before the study. Furthermore, the study was approved by the Ethics Committee of Hamadan University of Medical Sciences (No. IR.UMSHA.REC.1396.426).

The inclusion criteria were female sex; age greater than 50 years; presence of central incisors, premolars, and one or both of the maxillary and mandibular right and left molar teeth; and no history of tobacco or alcohol use or surgical procedures at the aforementioned sites. Exclusion criteria were presence of systemic diseases affecting bone metabolism, such as cancer, osteomalacia, endocrine disorders (hyperthyroidism, hyperparathyroidism), severe renal insufficiency, and liver failure; presence of rheumatoid arthritis; history of nontraumatic bone fracture; history of ovariectomy; and use of medications interfering with bone turnover and those under corticosteroid therapy or hormone therapy.[21,22] Furthermore, patients whose radiographs exhibited exophytic bone lesions or noisy images with abundant scatter radiation were excluded from the study.

Six regions in the jaws were chosen for assessment of BMD to identify the region of the jaw that had the highest correlation with the results of DEXA. Because pulpal and periapical diseases and tooth extraction affect alveolar bone density, we performed BMD assessment in the tooth-bearing areas (where teeth were sound and had no pulpal or periapical diseases) and in the non−tooth-bearing areas.

CBCT images were acquired by using the Scanora 3-D CBCT system (Soredex, Tuusula, Finland) with 90 kVp, 10 mA, 12.4-second exposure time, and 13 × 14 cm^2 field of view (FOV). The images were analyzed by using OnDemand 3-D Dental software (CyberMed, Seoul, Korea).

Regions of interest (ROIs) on cross-sectional images were chosen to determine BMD according to the mean gray value in the following locations:

1. Between the mandibular incisor roots
2. Between the left mandibular premolar roots
3. In the retromolar area of the left mandible
4. Between the maxillary incisor roots
5. Between the left maxillary premolar roots
6. In the left maxillary tuberosity

In all sites, the mean gray values of cancellous and cancellous plus cortical bone segments were measured (Figures 1 and 2). A 15-inch liquid crystal display monitor (Toshiba Satellite L40, Tokyo, Japan) with a 768 × 1367 pixel matrix was used for observation and interpretation of images in a dimly lit room with no time restriction. The 2 observers were allowed to adjust the brightness, contrast, and magnification of images to obtain the best visual results. (The calculated mean gray values are not altered by changing the settings, such as brightness, contrast, and gamma). All cross-sectional slices had 1-mm intervals and 0.5-mm thickness. After selection of the ROIs in the software, the observers traced a polyline in the aforementioned regions that included cortical and cancellous bones,

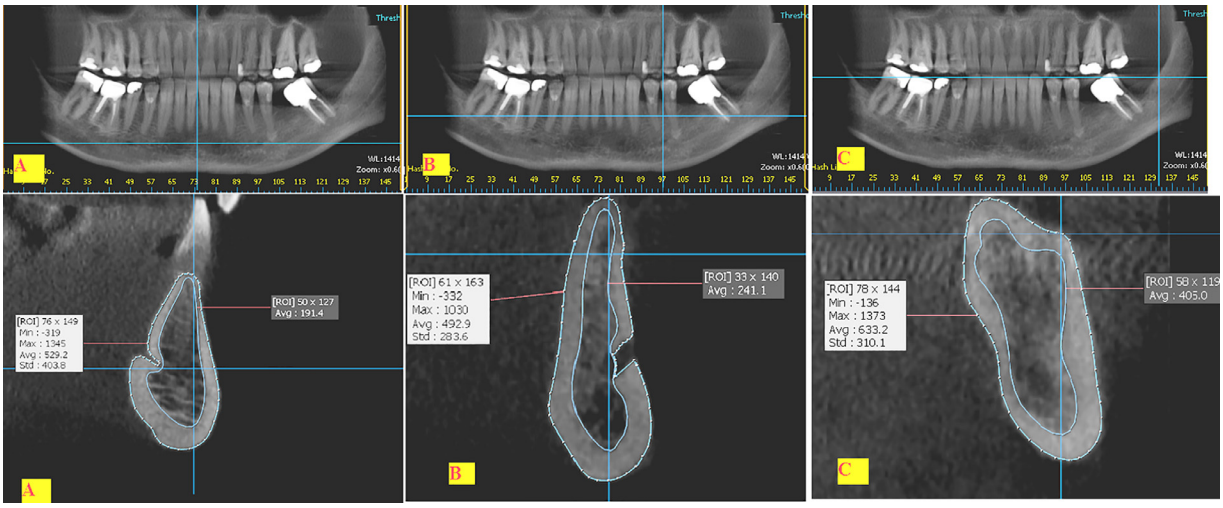

Fig. 1. Cone beam computed tomography (CBCT) image, **A,** Gray values of cancellous and cancellous plus cortical bones at the site of the mandibular incisors, **B,** Gray values of cancellous and cancellous plus cortical bones at the site of the mandibular premolar, **C,** Gray values of cancellous and cancellous plus cortical bones at the mandibular retromolar area.

and then the software automatically calculated the mean gray values for the selected ROIs.

To standardize the mean gray value measurements and calculations for different specimens, the size of the ROI was selected such that the desired region of bone included only cancellous bone at first, and then both cortical and cancellous bones. Sections were selected perpendicular to the ROI, avoiding any inclination. As a result, no dental structures, such as tooth roots, were included in the desired section. This was done to avoid any inaccuracies in density measurement. In dental sites, sections were selected from the interradicular areas. The tuberosity region was delineated on cross-sections as the prominence distal to the second molar. The retromolar region of the mandible was demarcated posterior to the distal root of the second molar along the external oblique ridge anteriorly.

All measurements were made by an experienced oral and maxillofacial radiologist and a senior dental student, who were experienced in the use of OnDemand 3-D Dental software. Interobserver agreement was calculated to ensure that both observers selected the same regions and subsequently measured the same gray values. To assess intraobserver agreement, both observers reanalyzed all CBCT images after 2 weeks and calculated the BMD of the aforementioned regions.

After the study was explained and the patients provided their written informed consent, they were referred for bone densitometry with DEXA of the femoral neck and lumbar spine with use of the Osteocore

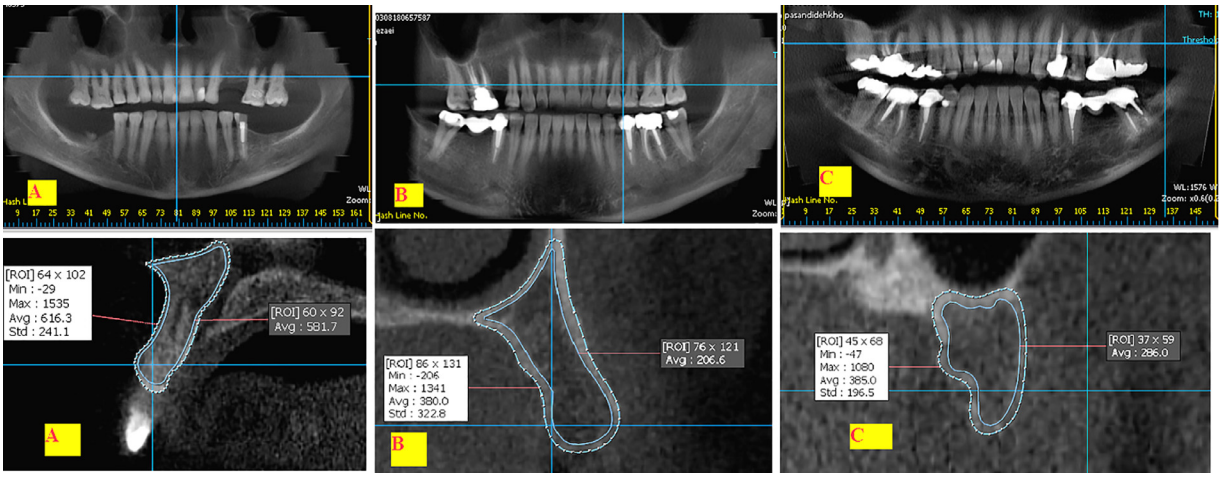

Fig. 2. Cone beam computed tomography (CBCT) image, **A,** Gray values of cancellous and cancellous plus cortical bones at the site of the maxillary incisors, **B,** Gray values of cancellous and cancellous plus cortical bones at the site of the maxillary premolar, **C,** Gray values of cancellous and cancellous plus cortical bones at the site of the maxillary tuberosity.

bone densitometer (Medilink, Paris, France) operating at a maximum voltage of 86 kVp, 9 mA, and 1 μG/scan/hr patient radiation dose. All X-ray parameters were chosen by the software, and BMD was calculated on the basis of the patient's age, sex, height, and weight.

BMD values determined by CBCT gray values were compared with the DEXA results for each patient to assess the reliability of the gray value in the detection of osteoporosis. Patients who were diagnosed with osteoporosis on the basis of the DEXA results were referred to a specialist for treatment.

The mean, standard deviation, and maximum and minimum values were reported for quantitative variables. Independent *t* tests were used for pairwise comparison of quantitative variables. One-way analysis of variance (ANOVA) was applied for multiple comparisons of quantitative variables. Pearson's correlation test was used to analyze the correlations between continuous quantitative variables. The receiver operating characteristic (ROC) analysis was performed to find the cutoff point for quantitative variables. Cronbach's alpha was calculated to assess intraobserver and interobserver agreements.

In the present study, the random forest method[23] was used to select the most important variables for correct prediction of the T-scores of the femoral neck and lumbar spine. To implement this method, the number of *ntree* (= 1000 bootstrap samples) was drawn from the original data set, and for each of them, an unpruned tree was grown (at each node, a randomly sampled *mtry* [= 5 of the predictors] was selected, and the best split from those variables was chosen). Then, prediction of the status of a participant was obtained by averaging the predictions of *ntree*. The significance of a variable was calculated on the basis of the extent of increase in prediction error when out-of-bag data for that variable were permuted, considering that the other variables remain unchanged.[23]

RESULTS

In this study, 61 females (mean age 64 years; range 48−80 years) were included after application of the inclusion and exclusion criteria. To assess intraobserver and interobserver reliabilities, Cronbach's alpha was calculated; it showed 90% intraobserver agreement and 88% interobserver agreement. Because there was a strong agreement between the 2 observers, the measurements made by each observer were averaged for statistical analysis.

Table I shows the minimum, maximum, mean, and standard deviation of the CBCT gray values in different parts of the jaws. In the 61 patients included in the study, the results of bone densitometry and the T-scores of the femoral neck showed that 32 were normal, 28 had osteopenia, and 1 had osteoporosis. T-scores of the lumbar spine indicated that 27 were normal, 24 had osteopenia, and 10 had osteoporosis. In another classification, patients were divided into 2 groups in terms of BMD: (1) normal and (2) abnormal (with osteopenia and osteoporosis). According to the T-scores of the femoral neck, of the 61 patients, 32 were assigned to the normal group and 29 (47.5%) to the abnormal group (28 with osteopenia and 1 with osteoporosis). According to the T-scores of the lumbar spine, 27 were assigned to the normal group and 34 (55.7%) to the abnormal group (24 with osteopenia and 10 with osteoporosis) (Table II).

According to the results, the number of study participants with abnormal BMD according to the lumbar spine T-scores was higher compared with those with abnormal BMD according to the femoral neck T-scores. Thus, this index can be used with higher certainty for identification of patients with or at risk of osteoporosis. To compare the mean gray values of cancellous bone and cancellous plus cortical bone segments, paired *t* tests were used where the difference in gray values was shown as the mean difference. Table III shows the results for each region. The

Table I. Descriptive statistics of the gray values in different sites of the jaws

Area	*Minimum*	*Maximum*	*Mean*	*Standard deviation*
Cancellous bone at the site of mandibular incisors	85.50	1110.20	458.29	206.26
Cancellous plus cortical bone at the site of mandibular incisors	391.00	1367.80	734.42	173.57
Cancellous bone at the site of mandibular premolars	87.40	560.60	309.21	126.21
Cancellous plus cortical bone at the site of mandibular premolars	303.00	906.70	586.57	125.54
Cancellous bone at the site of mandibular retromolar area	81.00	514.20	298.18	100.41
Cancellous plus cortical bone at the site of mandibular retromolar area	317.00	857.70	604.71	109.11
Cancellous bone at the site of maxillary incisors	265.50	936.20	550.74	133.35
Cancellous plus cortical bone at the site of maxillary incisors	328.10	953.30	602.89	130.10
Cancellous bone at the site of maxillary premolars	147.10	673.80	361.20	123.88
Cancellous plus cortical bone at the site of maxillary premolars	266.50	816.60	468.62	123.24
Cancellous bone at the site of maxillary tuberosity	146.00	661.00	326.02	86.77
Cancellous plus cortical bone at the site of maxillary tuberosity	234.00	766.10	400.51	91.04

Table II. Classification of patients into 3 groups of normal participants, those with osteopenia, and those with osteoporosis and also into normal and abnormal groups in terms of the results of T-score of the femoral neck and lumbar spine

	T-score of femoral neck		*T-score of lumbar spine*	
	Frequency	*Percentage*	*Frequency*	*Percentage*
Osteoporosis	1	1.6	10	16.4
Osteopenia	28	45.9	24	39.3
Normal	32	52.5	27	44.3
Abnormal	29	47.5	34	55.7
Normal	32	52.5	27	44.3
Total	**61**	**100**	**61**	**100**

Table III. Comparison of mean difference of gray values at each region (subtraction of cancellous bone gray value from cancellous plus cortical bone gray value)

Area	*Pairwise comparisons*				*P value*
	Mean	*Standard deviation*	*95% confidence interval*		
			Upper	*Lower*	
Cancellous bone at the site of mandibular incisors Cancellous plus cortical bone at the site of mandibular incisors	−276.13	93.40	−300.26	−252.00	<.001
Cancellous bone at the site of mandibular premolars Cancellous plus cortical bone at the site of mandibular premolars	−277.36	81.94	−298.52	−256.19	<.001
Cancellous bone at the mandibular retromolar area Cancellous plus cortical bone at the mandibular retromolar area	−306.52	66.92	−323.81	−289.23	<.001
Cancellous bone at the site of maxillary incisors Cancellous plus cortical bone at the site of maxillary incisors	−52.14	34.19	−60.89	−43.38	<.001
Cancellous bone at the site of maxillary premolars Cancellous plus cortical bone at the site of maxillary premolars	−107.41	31.47	−115.48	−99.35	<.001
Cancellous bone at the site of maxillary tuberosity Cancellous plus cortical bone at the site of maxillary tuberosity	−74.48	25.79	−81.09	−67.88	<.001

numbers represent the subtraction of the gray values for cancellous bone from the gray values for cancellous and cortical bones. In all 6 comparisons, a significant difference was noted between the gray value of cancellous bone alone and those of cancellous and cortical bone segments. The maximum difference was observed at the retromolar area of the mandible, and the minimum difference was noted at the maxillary incisor region.

Table IV shows the correlation of gray values of different parts of the jaws and the T-score values determined by DEXA of the femoral neck and lumbar spine. Significant correlations were found between the T-scores of the femoral neck and the gray values of cancellous bone ($P = .042$) and those of cancellous and cortical bones ($P = .045$) segments at the site of the maxillary incisors; the cancellous and cortical bone segments at the site of the maxillary premolars ($P = .043$); and the cancellous bone segment ($P = .003$) and the cancellous and cortical bone segments ($P = 0.001$) at the maxillary tuberosity.

Significant correlations were noted between the T-scores of the lumbar spine and the gray values of the cancellous bone segment at the site of the maxillary incisors ($P = .046$) and the cancellous bone segment ($P = .008$) and the cancellous and cortical bone segments ($P = .003$) at the site of the maxillary tuberosity (see Table IV).

The random forest analysis was then performed to determine which variable was most important for correct prediction of the T-scores of the femoral neck and lumbar spine. This algorithm analyzes nonlinear effects and the correlation between variables. The results showed that the cancellous bone segment and the cancellous and cortical bone segments at the site of the maxillary tuberosity were the 2 most important variables for correct prediction of the T-scores of the femoral neck (Figure 3A) and lumbar spine (Figure 3B). For the T-scores of the femoral neck, the cancellous and cortical bone segments were the most important variable, whereas for the T-scores of the lumbar spine, the cancellous bone segment was the most important variable. The determination coefficients (R^2) for prediction of the T-scores of the femoral neck and lumbar spine were 0.90 and 0.94, respectively, indicating excellent predictive value of the variables.

Table IV. Pearson's correlation test for assessment of the correlation of BMD of different parts of the jaws and T-scores of the femoral neck and lumbar spine

Area	*T-score of femoral neck*		*T-score of lumbar spine*	
	P value	*Pearson's correlation coefficient*	*P value*	*Pearson's correlation coefficient*
Cancellous bone at the site of mandibular incisors	.605	0.068	.792	0.035
Cancellous plus cortical bone at the site of mandibular incisors	.886	0.019	.994	−0.001
Cancellous bone at the site of mandibular premolars	.471	0.095	.165	0.182
Cancellous plus cortical bone at the site of mandibular premolars	.860	−0.023	.725	0.046
Cancellous bone at the mandibular retromolar region	.352	0.122	.171	0.179
Cancellous plus cortical bone at the mandibular retromolar region	.585	0.072	.307	0.134
Cancellous bone at the site of maxillary incisors	.042*	0.262	.046*	0.256
Cancellous plus cortical bone at the site of maxillary incisors	.045*	0.257	.069	0.234
Cancellous bone at the site of maxillary premolars	.053	0.249	.091	0.219
Cancellous plus cortical bone at the site of maxillary premolars	.043*	0.260	.055	0.247
Cancellous bone at the site of maxillary tuberosity	.003†	0.369	.008†	0.336
Cancellous plus cortical bone at the site of maxillary tuberosity	.001‡	0.411	.003†	0.369

*Significant at $P < .05$.
†Significant at $P < .01$.
‡Significant at $P < .001$.

The mean gray values at each site of the jaw among the 3 groups (osteoporosis, osteopenia, and normal) according to the T-scores of the femoral neck (Table V) and lumbar spine (Table VI) were compared by using ANOVA. The results indicated that there was no significant difference in the gray values of the osteoporosis, osteopenia, and normal groups, according to the T-scores of the femoral neck ($P \geq .162$). However, comparison of the gray values of the 3 groups according to the T-scores of the lumbar spine showed that the differences approached significance in the cancellous bone segments ($P = .052$) and were significant in the cancellous and cortical bone segments ($P = .038$) at the site of the maxillary tuberosity.

Because identification of patients with osteopenia is as important as that of patients with osteoporosis, and because prevention and treatment strategies for both conditions are the same, we assigned these patients to the abnormal group, and data were subjected to independent *t* test analysis.

Comparison of the mean gray values of different parts of the jaws by using independent *t* tests in the 2 groups—normal and abnormal (with osteoporosis and osteopenia)—according to the T-scores of the femoral neck and lumbar spine yielded results similar to those of ANOVA. Because we classified the results of DEXA or T-score values as qualitative data (i.e., osteoporosis, osteopenia, and normal) in the ANOVA and

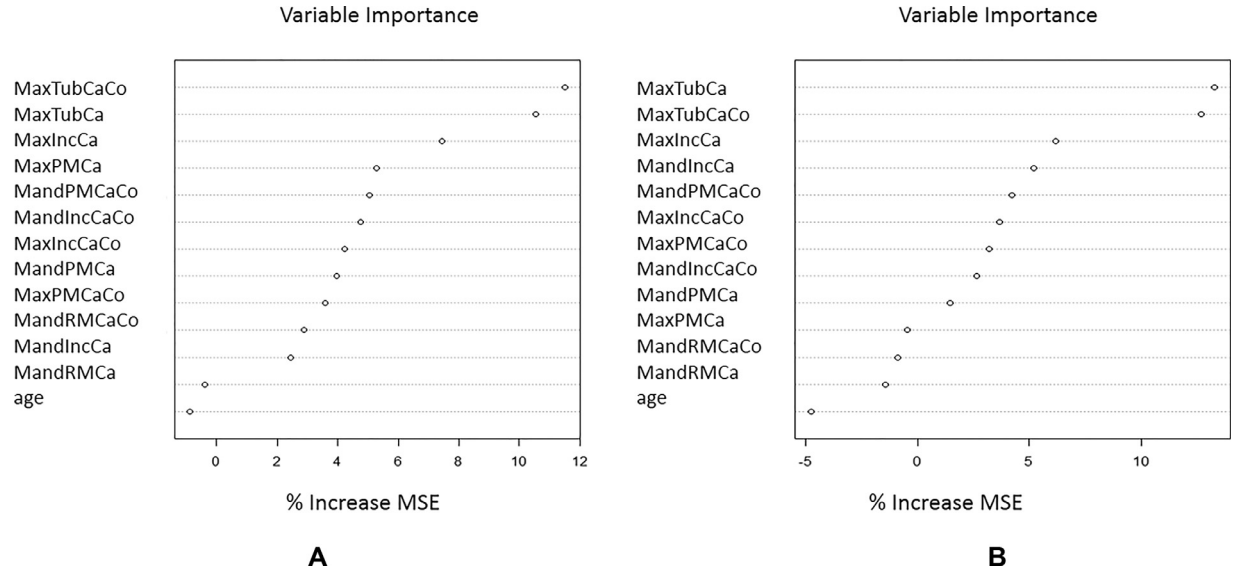

Fig. 3. Importance of the variables in predicting **A,** the T-score of the femoral neck and **B,** the T-score of the lumbar spine using the random forest analysis. The X-axis shows the mean reduction in accuracy represented as percentage increase in mean squared error (MSE).

Table V. Analysis of variance (ANOVA) for assessment of the gray values in different parts of the jaws in the 3 groups of patients with osteoporosis, patients with osteopenia, and normal participants, according to the T-score of the femoral neck

		N	*Mean*	*Standard deviation*	*Minimum*	*Maximum*	*P value*
Cancellous bone at the site of mandibular incisors	Osteoporosis	1	428.50	–	428.50	428.50	.987
	Osteopenia	28	456.54	194.96	85.50	858.80	
	Normal	31	460.83	222.32	146.30	1110.20	
	Total	60	458.29	206.26	85.50	1110.20	
Cancellous plus cortical bone at the site of mandibular incisors	Osteoporosis	1	641.10	–	641.10	641.10	.851
	Osteopenia	28	740.70	149.55	391.00	999.90	
	Normal	31	731.77	196.93	468.00	1367.80	
	Total	60	734.42	173.57	391.00	1367.80	
Cancellous bone at the site of mandibular premolars	Osteoporosis	1	323.00	–	323.00	323.00	.970
	Osteopenia	28	305.08	145.03	91.60	560.60	
	Normal	31	312.50	111.19	87.40	539.90	
	Total	60	309.21	126.21	87.40	560.60	
Cancellous plus cortical bone at the site of mandibular premolars	Osteoporosis	1	576.10	–	576.10	576.10	.915
	Osteopenia	28	593.96	135.10	303.00	850.60	
	Normal	31	580.24	120.31	333.10	906.70	
	Total	60	586.57	125.54	303.00	906.70	
Cancellous bone at the mandibular retromolar region	Osteoporosis	1	394.60	–	394.60	394.60	.565
	Osteopenia	28	303.18	115.15	81.00	514.20	
	Normal	31	290.56	86.61	96.20	465.40	
	Total	60	298.18	100.41	81.00	514.20	
Cancellous plus cortical bone at the mandibular retromolar region	Osteoporosis	1	810.80	–	810.80	810.80	.162
	Osteopenia	28	599.11	128.5	317.00	857.70	
	Normal	31	603.12	84.62	445.10	782.60	
	Total	60	604.71	109.11	317.00	857.70	
Cancellous bone at the site of maxillary incisors	Osteoporosis	1	581.70	–	581.70	581.70	.290
	Osteopenia	28	521.40	152.12	265.50	936.20	
	Normal	32	575.45	113.24	418.20	896.30	
	Total	61	550.74	133.35	265.50	936.20	
Cancellous plus cortical bone at the site of maxillary incisors	Osteoporosis	1	616.30	–	616.30	616.30	.203
	Osteopenia	28	570.53	143.63	328.10	953.30	
	Normal	32	630.77	114.18	457.00	940.30	
	Total	61	602.89	130.10	328.10	953.30	
Cancellous bone at the site of maxillary premolars	Osteoporosis	1	444.80	–	444.80	444.80	.293
	Osteopenia	28	335.47	103.22	147.10	576.40	
	Normal	32	381.10	138.53	156.70	673.80	
	Total	61	361.20	123.88	147.10	673.80	
Cancellous plus cortical bone at the site of maxillary premolars	Osteoporosis	1	576.50	–	576.50	576.50	.168
	Osteopenia	28	438.34	97.18	266.50	627.70	
	Normal	32	491.74	139.34	268.00	816.60	
	Total	61	468.62	123.24	266.50	816.60	
Cancellous bone at the site of maxillary tuberosity	Osteoporosis	1	252.80	–	252.80	252.80	.625
	Osteopenia	28	321.37	59.11	216.00	422.90	
	Normal	32	332.39	106.28	146.00	661.00	
	Total	61	326.02	86.77	146.00	661.00	
Cancellous plus cortical bone at the site of maxillary tuberosity	Osteoporosis	1	360.80	–	360.80	360.80	.538
	Osteopenia	28	388.14	61.83	284.50	515.20	
	Normal	32	412.58	111.23	234.00	766.10	
	Total	61	400.51	91.04	234.00	766.10	

the independent *t* tests, some data were randomly lost during performance of these statistical procedures. Therefore, Pearson's correlation test was applied for more accurate assessment of the correlation of gray values and T-scores.

To find the cutoff point for the gray value quantitative variables, the ROC area under the curve (AUC) analysis was conducted for all 12 sites, according to the T-scores of the lumbar spine. The AUCs were calculated; these values are presented in Table VII, along with the sensitivity and specificity values calculated on the basis of the cutoff point. AUCs greater than 0.5 indicate the prediction power of the variable with use of the determined cutoff point. The greater the area, the higher was the predictive power of the variable. Gray values in the maxillary tuberosity yielded 66% to

Table VI. Analysis of variance (ANOVA) for assessment of gray values at different parts of the jaws in the 3 groups of osteoporosis, osteopenia, and normal according to the T-score of the lumbar spine

		N	*Mean*	*Standard deviation*	*Minimum*	*Maximum*	*P value*
Cancellous bone at the site of mandibular incisors	Osteoporosis	10	521.60	180.63	197.10	801.40	.326
	Osteopenia	24	413.17	165.11	152.10	796.00	
	Normal	26	475.59	244.36	85.50	1110.20	
	Total	60	458.29	206.26	85.50	1110.20	
Cancellous plus cortical bone at the site of mandibular incisors	Osteoporosis	10	749.84	118.95	593.90	917.00	.848
	Osteopenia	24	718.69	134.71	468.40	999.90	
	Normal	26	743.02	221.13	391.00	1367.80	
	Total	60	734.42	173.57	391.00	1367.80	
Cancellous bone at the site of mandibular premolars	Osteoporosis	10	291.41	148.87	119.00	556.60	.799
	Osteopenia	24	303.97	115.97	87.40	505.90	
	Normal	26	320.91	130.18	91.60	560.60	
	Total	60	309.21	126.21	87.40	560.60	
Cancellous plus cortical bone at the site of mandibular premolars	Osteoporosis	10	581.92	110.60	415.50	727.70	.987
	Osteopenia	24	585.57	107.38	431.20	840.30	
	Normal	26	589.29	148.89	303.00	906.70	
	Total	60	586.57	125.54	303.00	906.70	
Cancellous bone at the mandibular retromolar region	Osteoporosis	10	290.70	83.48	172.60	460.90	.968
	Osteopenia	24	299.32	115.22	81.00	514.20	
	Normal	26	300.00	95.09	104.00	470.70	
	Total	60	298.18	100.41	81.00	514.20	
Cancellous plus cortical bone at the mandibular retromolar region	Osteoporosis	10	605.58	92.79	432.30	696.60	.971
	Osteopenia	24	600.60	112.41	427.30	857.70	
	Normal	26	608.17	115.50	317.00	813.10	
	Total	60	604.71	109.11	317.00	857.70	
Cancellous bone at the site of maxillary incisors	Osteoporosis	10	466.97	122.52	265.50	646.60	.093
	Osteopenia	24	568.23	133.44	277.00	936.20	
	Normal	27	566.22	129.83	285.00	896.30	
	Total	61	550.74	133.35	265.50	936.20	
Cancellous plus cortical bone at the site of maxillary incisors	Osteoporosis	10	522.68	126.46	328.10	734.70	.101
	Osteopenia	24	620.50	129.20	368.00	953.30	
	Normal	27	616.94	125.66	355.80	940.30	
	Total	61	602.89	130.10	328.10	953.30	
Cancellous bone at the site of maxillary premolars	Osteoporosis	10	333.39	112.47	204.70	576.40	.531
	Osteopenia	24	351.35	107.85	156.70	550.70	
	Normal	27	380.26	141.35	147.10	673.80	
	Total	61	361.20	123.88	147.10	673.80	
Cancellous plus cortical bone at the site of maxillary premolars	Osteoporosis	10	439.79	98.89	323.50	627.70	.362
	Osteopenia	24	452.53	112.05	268.00	663.00	
	Normal	27	493.60	139.11	266.50	816.60	
	Total	61	468.62	123.24	266.50	816.60	
Cancellous bone at the site of maxillary tuberosity	Osteoporosis	10	319.75	56.15	228.80	422.90	.052
	Osteopenia	24	296.37	73.94	146.00	413.70	
	Normal	27	354.71	98.82	231.40	661.00	
	Total	61	326.02	86.77	146.00	661.00	
Cancellous plus cortical bone at the site of maxillary tuberosity	Osteoporosis	10	379.07	55.38	284.50	486.90	.038
	Osteopenia	24	372.35	66.79	234.00	515.20	
	Normal	27	433.48	109.92	297.10	766.10	
	Total	61	400.51	91.04	234.00	766.10	

67% accuracy, as measured by AUCs. Figures 4 and 5 show the AUCs of different sites in the mandible and the maxilla.

DISCUSSION

Osteoporosis is a major health problem affecting most women age greater than 50 years. Early diagnosis of osteoporosis is important in the prevention of serious complications, such as hip, spinal, and other bone fractures. Currently, determination of BMD values of the femoral neck and spine by using DEXA is the gold standard for the diagnosis of osteoporosis. However, although commonly used as the screening test for osteoporosis, this method can be costly.[24,25] Analysis of the data obtained from dental radiographs requested for dental examination can serve as a low-cost screening method for this purpose. This method has no extra cost for patients. Several studies have assessed the correlation between bone trabeculae and BMD of the jaws by using radiographs. However, the utility of the data

Table VII. Cutoff points of the gray values based on the T-score of the lumbar spine

Variable	*Area under the curve*	*Cutoff point of gray value*	*Sensitivity*	*Specificity*
Cancellous bone at the site of mandibular incisors	0.52	476.7	0.52	0.64
Cancellous plus cortical bone at the site of mandibular incisors	0.50	657.8	0.63	0.44
Cancellous bone at the site of mandibular premolars	0.55	286.2	0.63	0.53
Cancellous plus cortical bone at the site of mandibular premolars	0.51	560.2	0.56	0.44
Cancellous bone at the mandibular retromolar region	0.52	286.4	0.60	0.53
Cancellous plus cortical bone at the mandibular retromolar region	0.53	588.3	0.63	0.53
Cancellous bone at the site of maxillary incisors	0.55	582.2	0.48	0.62
Cancellous plus cortical bone at the site of maxillary incisors	0.54	617.2	0.48	0.50
Cancellous bone at the site of maxillary premolars	0.56	341.7	0.56	0.50
Cancellous plus cortical bone at the site of maxillary premolars	0.60	441.8	0.52	0.47
Cancellous bone at the site of maxillary tuberosity	0.66	297.9	0.63	0.56
Cancellous plus cortical bone at the site of maxillary tuberosity	0.67	382.5	0.60	0.59

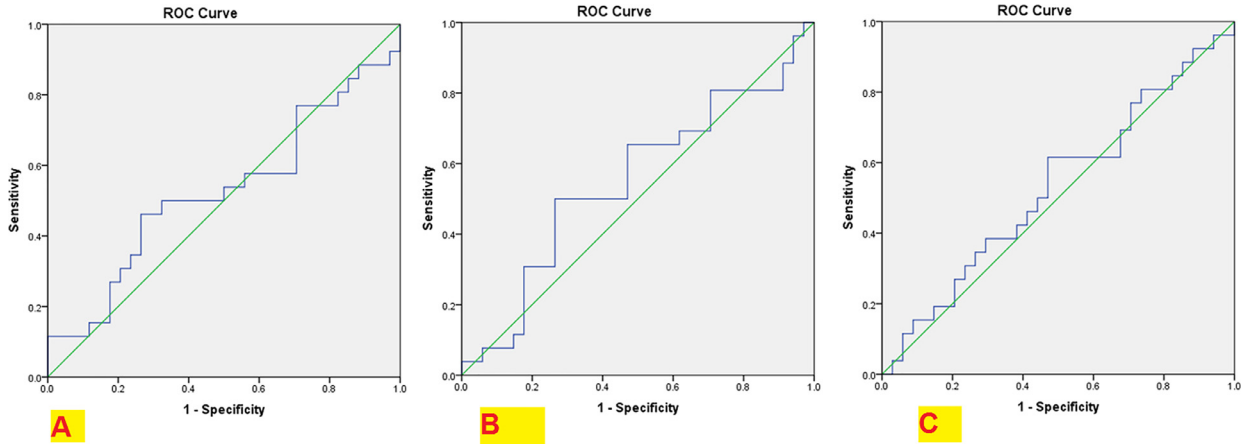

Fig. 4. Receiver operating characteristic (ROC) area under the curve (AUC) of different sites of the mandible. **A,** Incisor area. **B,** Premolar area. **C,** Retromolar area.

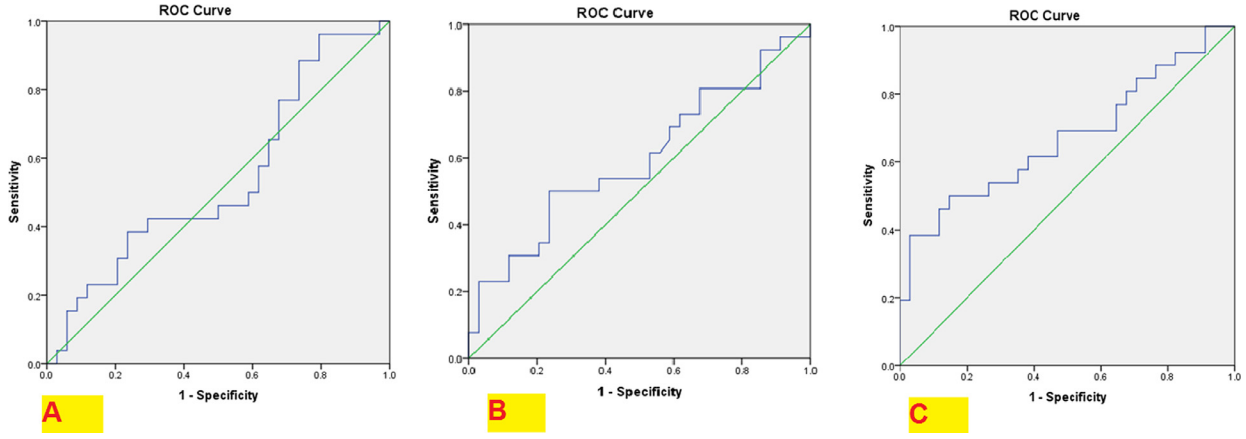

Fig. 5. Receiver operating characteristic (ROC) area under the curve (AUC) of different sites of the maxilla. **A,** Incisor area. **B,** Premolar area. **C,** Tuberosity area.

obtained from dental radiographs for the purpose of screening for osteoporosis is still a matter of debate.[20,26]

The present study assessed the correlation between BMD in different parts of the maxilla and mandible, reported as mean gray values, and DEXA results as the gold standard method for early detection of osteoporosis. Of the 61 asymptomatic patients in the study, 47.5% and 55.7% were assigned to the abnormal group on the basis of the T-scores of the femoral neck and lumbar spine, respectively. The abnormal group in our study comprised patients with osteopenia and

osteoporosis. Although osteopenia and osteoporosis have different numerical ranges of T-scores (osteoporosis defined as T-scores ≤ -2.5 indicated, and osteopenia defined as T-scores < -1 to < -2.5), we assigned these patients to the same group in our study because the treatment for both types of patients is the same in the clinical setting.

In recent studies, in variable percentages of asymptomatic patients screened with bone densitometry tests, osteoporosis and osteopenia were detected. For instance, Drage et al.[27] showed that of 18 patients who underwent DEXA of the lumbar spine, the BMD of 17% of the patients was abnormal; however, DEXA of the hip showed abnormal BMD in only 11% of the patients.[24] Similar to the present study, Drage et al.'s study showed that the T-score of the lumbar spine was able to detect abnormal BMD in a higher number of individuals. In a report by Barngkgei et al. of 38 patients, 74% were abnormal according to the BMD of the lumbar spine, whereas this rate was 55% according to the BMD of the femoral neck; these results confirm our findings.[20] In studies by Güngör et al.,[28] Gulsahi et al.,[29] Naitoh et al.,[30] and Mostafa et al.,[31] of the total number of study patients, 66%, 43%, 66%, and 50%, respectively, had osteoporosis, according to the BMD of the lumbar spine and femoral neck.

Considering that a high percentage of women older than 50 years of age have low BMD, the use of proper screening methods for early detection is imperative.

The presence of cortical bone significantly increases bone density, and this is more significant in the mandible. Only a few studies have assessed and compared the densities of cancellous bone alone and cancellous bone and cortical bone as one unit. Lindh et al.[32] used quantitative computed tomography for maxillary bone densitometry. They assessed the density of cancellous bone alone as well as cancellous and cortical bones in each region. They pointed to the significance of the difference between trabecular and compact bones in the determination of BMD and in implant placement.[32] They also believed that CT was suitable for site-specific assessment of different parts of the jaw.[32] Naitoh et al. separately assessed and compared the densities of the cortical and cancellous bones of the mandible with those of other bones.[30] A significant finding of their study was that the BMD of cancellous bone alone is different from that of cancellous bone and the surrounding cortical bone.

In dental implant treatment, the presence of an adequate amount of cortical bone plays a critical role in primary stability of implants. Moreover, the presence of an adequate amount of cancellous bone enhances the blood supply to the area and subsequently increases the success rate of dental implant treatment. Thus, for assessment of BMD in different parts of the jaws, it is imperative to assess the gray values of cancellous and cortical bones together and of cancellous bone alone.[33]

In the present study, the gray values of different parts of the jaws and the T-scores of the femoral neck and lumbar spine determined by bone densitometry revealed a significant correlation between the T-score of the femoral neck and the gray values of different parts of the maxilla. Furthermore, a significant correlation was noted between the T-score of the lumbar spine and the gray values of the anterior maxilla and maxillary tuberosity. Lindh et al. reported similar results, demonstrating that maxillary bone density was significantly correlated with the bone density of the lumbar spine.[32] The only difference was that only the anterior maxilla had a significant correlation with BMD of the lumbar spine in their investigation, whereas in the present study, not only the anterior maxilla and the premolar site but also the maxillary tuberosity had strong correlations with BMD of the lumbar spine. This small difference may have resulted from the different imaging techniques used because Lindh et al. used CT and Hounsfield units, whereas we used CBCT and gray values for assessment of BMD.[32] In a study by Esfahanizadeh et al., the BMD of the anterior maxilla was correlated with the BMD of the femoral neck and lumbar spine, although they used DEXA for the assessment of bone density in the jaws.[34]

The stronger correlation between maxillary BMD and the density of other bones may result from the greater blood supply to the maxilla. The maxilla has a greater volume of cancellous bone and a smaller amount of cortical bone compared with the mandible. Therefore, it has a richer blood supply and is more commonly affected by hormonal changes, which are among the risk factors for osteoporosis.

Horner et al., Drage et al., Pluskiewicz et al., and Esfahanizadeh et al. compared the BMD of the mandible and other bones by using DEXA and found a significant correlation between the BMD of the anterior, body, and ramus of the mandible and the BMD of the femoral bone, lumbar spine, and forearms.[27,34-36] Klemetti et al. found a significant association between the BMD obtained with quantitative computed tomography of the mandible and the BMD obtained with DEXA of the femoral bone and lumbar spine.[37] The results of the aforementioned studies differed from ours, which may be explained by the use of different densitometry techniques of the jaws. Cakur et al. assessed the density of the mandibular angle (antegonial notch) by using DEXA and found no association between the BMD of the mandible and that of other bones, which was in agreement with the results of the current study.[38]

In the present study, the densities of different parts of the mandible were not correlated with the results of

DEXA of the femoral neck and lumbar spine. This finding was in line with that of Naitoh et al., who used CT for the assessment of the width of the buccal and lingual cortical plates at the site of the mental foramen. Their results indicated that the width of the buccal and lingual cortical plates and the density of cancellous bone in the mandible at the site of the mental foramen had a weak correlation with BMD, as determined by DEXA of the lumbar spine.[30] Such a weak correlation may result from the lower blood supply and the smaller effect of hormonal changes on the mandible. In fact, mandibular bone quality is affected by a number of factors, such as occlusion, attached muscles, and cigarette smoking.[30]

There was significant difference in the BMD of patients in the normal and abnormal groups according to their T-scores of the lumbar spine at the site of the maxillary tuberosity. As shown in Table VII, the maxillary tuberosity can be considered the most reliable site for the assessment of changes in BMD, with AUC values of 0.66 to 0.67.

Nackaerts et al. assessed the BMD of the mandible and maxilla using intraoral radiography and found a relatively good correlation between the density of the premolar region and the BMD of other bones determined by using DEXA.[39] Although no significant correlation was found at the premolar site in the present study, the BMD of the premolar site of the maxilla was correlated with the BMD of the femoral neck.

Brasileiro et al., evaluated the efficacy of CBCT for detection of osteoporosis in postmenopausal women and concluded that cortical indices at the site of the mental foramen were smaller in patients with osteoporosis than in normal participants. They stated that these indices had high efficacy for differentiating normal individuals and patients with osteoporosis.[40] This finding was in contrast to our results. In our study, bone density at the premolar region was not significantly different between the patients in the normal and abnormal groups. This difference may be explained by the fact that Brasileiro et al., only assessed cortical bone thickness, whereas we used the gray values of cortical and cancellous bones at the premolar region for the assessment of BMD.

In their study, Koh and Kim used the thickness of cortical bone as an index for the detection of normal and abnormal BMD. They found the CT mandibular index (inferior) and the CT mandibular index (superior) at the site of mental foramen were significantly different between healthy participants and those with osteoporosis and that the difference in the CT mental index was not significant.[41] These different findings from the studies by Brasileiro et al. and Koh and Kim indicate the low efficacy of some cortical indices for the identification of patients with osteoporosis.[40,41]

Our results were different from those of Barngkgei et al.,[42] who assessed the trabecular bone structure in and healthy women and those with osteoporosis by using CBCT and concluded that the trabecular bones of the maxilla and mandible are not affected by osteoporosis.[42] However, in the present study, the mean gray value of different sites was evaluated, whereas Barngkgei et al. performed histomorphometric analysis of trabecular bone by using Image J software. The type of analysis is the main reason for the difference between our study and theirs. Other parameters of the 2 studies, including the FOV (13×15 cm^2), voltage (105 kVp), amperage (9 mA), and voxel size (250 μ) were similar. Quantification of trabecular bone on CBCT scans is significantly influenced by the FOV of the imaging systems. Differences in the results of studies on the association between bone density of the jaws and bone density obtained with DEXA may be attributed to the use of different exposure parameters, such as FOV, because with small FOVs, image resolution increases significantly, and the trabecular bone pattern is more clearly visualized.[42]

Furthermore, the type of CBCT system, the image acquisition settings, the position of the object in the FOV, the size of the FOV, artifacts, different exposure settings, and different CBCT machines can all affect gray values when measured with CBCT.[43] In the present study, none of the aforementioned items could have biased the results because all of the study patients were scanned with the same CBCT system and identical exposure settings. Artifacts in the region may affect the gray values on CBCT.[44] In the present study, images with artifacts from root filling materials, which can compromise the surrounding bone quality, were excluded. This confounding factor was eliminated or minimized by selecting sections unaffected by artifacts in images with insignificant artifacts.

One strength of our study was the clear definition of the cutoff points of the gray values for different parts of the jaws; these cutoff points have not been defined in any other study. Considering the difference in the densities of different parts of the maxilla and mandible, it seems that cutoff points can vary in different parts of the jaws. In the present study, the most accurate cutoff points belonged to the maxillary tuberosity with 66% to 67% accuracy (as measured by the AUC of 0.66 and 0.67) with the gray value threshold of less than 298. This means that if the mean gray value of the tuberosity on CBCT images is less than 298, the patient has abnormal BMD, determined with 66% accuracy.

Considering the differing natures of CT and CBCT, the Hounsfield unit of CT differs from the gray value of CBCT. Because most of the previous studies used CT and reported BMD values in Hounsfield units, and considering the fact that CBCT is commonly used for

most dental procedures, it is imperative that the indices and thresholds of the gray values be assessed for classification of different bone types, especially for dental implant treatment. This calls for further studies in this respect.

CONCLUSIONS

A strong correlation exists between the CBCT gray values of different parts of the maxilla and BMD values determined with DEXA. The maxillary tuberosity had the highest diagnostic value for the detection of osteoporosis, and a gray value less than 298 in this region can differentiate patients with osteoporosis from normal participants with 66% accuracy. These findings in the maxillary tuberosity can serve as a screening tool; therefore, we suggest that the patient be referred for DEXA examination to confirm any suspicion of low bone density. In the present study, mandibular bone density had no correlation with BMD of the femoral neck and lumbar spine. Signs of osteoporosis can be detected earlier by measuring the T-score of the lumbar spine.

DISCLOSURE

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Reprint requests:

Mahsa Ghanbari
Department of Oral and Maxillofacial Radiology
Dental School, Hamadan University of Medical Sciences
Shahid Fahmideh Blvd. Hamadan
Iran
Zip code: 6516647447.
MahsaGhanbari.DDS@gmail.com