THE QUALITY OF TRABECULAR BONE ASSESSED USING CONE-BEAM COMPUTED TOMOGRAPHY

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Abstract. Dental implant stability depends on the quality of bone in the target site. Although subjective bone quality assessments are still important, objective measurements of bone density by X-ray imaging is increasingly appreciated in implant planning. Using conventional computed tomography (CT), an objective bone density scale was established in terms of mean CT numbers of various bone types, which characterize their ability to attenuate X-ray beams. Cone-beam computed tomography (CBCT) is preferred for three-dimensional dental imaging because it is cheaper than CT and exposes the patient to lower doses of X-rays. The results of bone density measurements by CBCT, however, are less consistent than CT results: they depend on the type of CBCT device and on image acquisition parameters. Here we analyzed CBCT images of 46 patients, recorded in identical conditions by the same type of CBCT unit. We computed the CT numbers of cancellous bone from 400 potential implant sites. Moreover, for each site, we recorded the standard deviation of the CT numbers of constituent voxels, which is a measure of bone heterogeneity. We classified the sites in eight groups, according to gender and location (anterior and posterior regions of the mandible and the maxilla). Based on the one-way ANOVA test and on the Kruskal-Wallis test, we found that significant differences exist between the mean values of CT numbers and the standard deviations of CT numbers. Our study suggests that, under identical conditions, CBCT is able to detect differences in bone density and microstructure. The CBCT scale established here for trabecular bone density and heterogeneity might be useful for pre-operative evaluation of bone quality.

Key words: CT number, radiodensity, Hounsfield unit (HU), dental implant.

INTRODUCTION

To withstand masticatory forces, a dental implant needs to transmit loads via the bone-to-implant interface. Therefore, the success of oral implantology hinges on a correct assessment of bone quality in the receiving site. The bone density scale proposed by Misch [14], although subjective, proved useful in this respect, allowing for pre-operative assessment of the load bearing capacity of the bone from the target site. Misch classified bones of the dental arches in five bone density

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classes, ranging from D1 to D5: D1 bone is dense cortical bone, D2 bone is thick dense-to-porous cortical bone that wraps a coarse trabecular bone, D3 bone is thin porous cortical bone that wraps a fine trabecular bone, D4 is fine trabecular bone within the ridge and minimal or no cortical bone on the crest, whereas D5 is immature, non-mineralized bone [14, 15].

The quality of bone depends on the anatomical location. The most dense bone type is found in the anterior mandible, being followed by the posterior mandible, the anterior maxilla, and the posterior maxilla. The anterior mandible is mainly composed of D2 bone, but also contains D1 bone in about 6% of the population; the posterior mandible is made of D2 bone and D3 bone, and rarely contains D1 bone and D4 bone; the anterior maxilla is mainly made of D3 bone, but also of D2 bone (25% occurrence) and D4 bone (10% occurrence); the posterior maxilla is made of D3 bone and D4 bone, and, occasionally, of D2 bone (10% occurrence) [15].

An important leap in bone quality estimation was made using computed tomography (CT), by characterizing bone density in terms of the CT number (or radiodensity), expressed in Hounsfield units (HU) [18]. The CT number describes the ability of a substance to attenuate an X-ray beam, ranging from –1000 HU for air to about 3000 HU for enamel [9]. A significant correlation was found between the observed radiodensities of the implant sites and their subjective bone density scores [18]. Further studies [12, 20, 23, 24] have established the ranges of HU values corresponding to each bone density class: D1 bone > 1250 HU, D2 bone 850–1250 HU, D3 bone 350–850 HU, D4 bone 150–350 HU and D5 bone < 150 HU [15].

Nevertheless, for the three-dimensional (3D) visualization of hard tissues from the oral environment CT is not the imaging technique of choice; it exposes the patient to relatively high doses of ionizing radiation and requires expensive equipment. Instead, cone beam computed tomography (CBCT) is preferred because it involves less radiation exposure (by about one order of magnitude) and requires a device that is about five times cheaper than a full-body CT scanner [7, 22]. While in a conventional CT scanner the body part of interest is traversed by a fan-shaped beam of X-rays that falls on a linear arrangement of detectors, in a CBCT device the investigated body part is traversed by a cone-shaped beam of X-rays that falls on a flat panel detector (such as a screen of scintillator crystals placed on a matrix of photodiodes embedded in solid-state amorphous silicon; the scintillator crystals convert X-rays into visible light, which is detected by the photodiodes) [13].

CBCT is routinely used to visualize the bony structures of the head and neck with typical voxel sizes as small as 0.2×0.2×0.2 mm. The image reconstruction software associates to each voxel a HU value, also called CT number in the literature, although it is recorded using a CBCT device. Commercially available

CBCT systems, however, have a contrast resolution of approximately 10 HU, whereas state-of-the-art multi-detector helical CT scanners have contrast resolutions of the order of 1 HU. This discrepancy originates from the different beam geometry (the cone beam favors X-ray scattering) and from differences in detector performance [13]. A CBCT device is calibrated by the manufacturer to give –1000 HU for air and 0 HU for a water phantom, but daily calibrations of the detector and the X-ray tube, as usual for CT scanners, are not carried out for CBCT units. Therefore, CT numbers in CBCT are not absolute values [17].

When CBCT was used to assess bone density, the results were found to depend on the type of device, on the image acquisition parameters, and on the position of the evaluated tissue with respect to the field of view [16, 19]. Therefore, the use of CBCT for bone density evaluation is a subject of intense research [1, 2, 3, 4, 10, 21].

In this work we focus on CBCT assessment of the quality of trabecular bone from the mandible and the maxilla. We concentrate on the trabecular bone because it is the most homogeneous part of the hard tissue from an implant site, and it has been carefully characterized in terms of HU values measured using conventional CT [6]. Thus, our results can be compared with a reliable set of reference values.

For consistency, we analyze data recorded with a single type of CBCT device, using the same image acquisition parameters (tube voltage, current intensity, voxel size and field of view). In this way we minimize the number of factors that are known to affect the bone density estimation by CBCT [16].

Besides the mean CT numbers of the bone samples, we also analyze the standard deviations of the CT numbers of the constituent voxels. Each voxel is characterized by a CT number (voxel value), and the CBCT image analysis software reports both the mean value and the standard deviation of CT numbers of the voxels that belong to the selected volume. The latter is a measure of bone heterogeneity. Coarse trabecular bone is more heterogeneous than fine trabecular bone, so we hypothesize that the standard deviations of HU values obtained by CBCT might reveal differences between different types of cancellous bone.

Our study also deals with the gender dependence of the trabecular bone density. To this end, we analyze the same number of sites for men and women.

Nevertheless, in this work we do not take into account certain factors that might impact bone density, such as age, medication, nutritional status, and lifestyle.

The main question we address here is whether there are significant differences between the mean CT numbers and the standard deviations of CT numbers of trabecular bones from different regions of the dental arches. If so, it would prove that, under similar settings, CBCT is capable to distinguish differences in bone quality, allowing one to establish quantitative criteria for bone density assessment by CBCT.

MATERIALS AND METHODS

PATIENTS

For this retrospective study 46 edentulous patients were selected from the Mall Dental Clinic Timisoara, Romania, who had undergone a CBCT investigation, between 2011 and 2013, for reasons that had nothing to do with the present study. No patient was subject to ionizing radiations for the sake of this work.

To enroll patients, we relied on the following inclusion criteria: (i) CBCT images were recorded using a tube voltage of 84 kV and a current intensity of 14 mA, (ii) the CBCT images were recorded with a cylindrical field of view (FOV) of 80 mm both in diameter and height (Figure 1), (iii) the voxel size was 0.2×0.2×0.2 mm, (iv) the dental arches were positioned similarly in the FOV, as depicted in Figure 1.

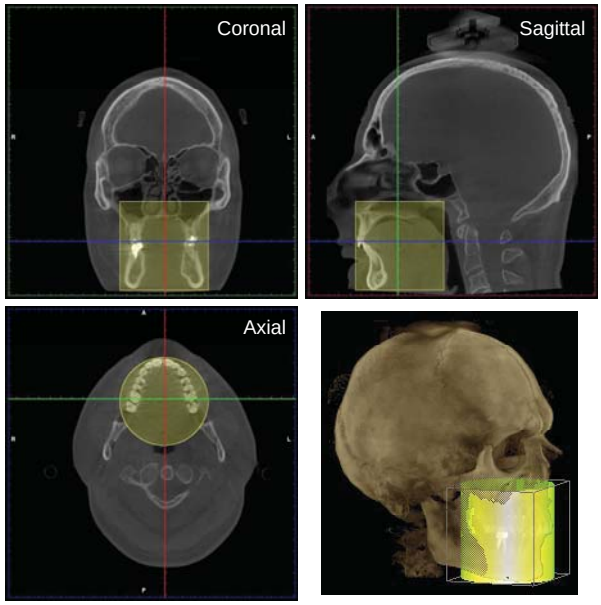

Fig. 1. The field of view (FOV) was a cylinder of 80 mm in diameter and height. The lower right panel is a 3D rendering of a full-scull CBCT image, whereas the other panels represent cross-sections of the same image, taken in the axial, coronal and sagittal plane.

We excluded from the study patients who had pathologic and/or traumatic lesions of the jaws.

To assure gender balance, an equal number of men and women were enrolled in the study. Moreover, the number of investigated implant sites was the same for each gender.

Once we identified eligible patients, we contacted them, explained the details of this retrospective study in what concerns the handling of their data, and asked them to sign a form of informed consent.

IMAGE ACQUISITION AND BONE DENSITY ASSESSMENT

For image acquisition, we used a ProMax 3D CBCT unit (Planmeca, Finland), with settings specified in the previous section. Images were saved in DICOM format. To locate implant target sites and to record the mean CT number of the trabecular bone from these sites, we used the Romexis 3.0.1.R software (Planmeca, Finland). In each site, our region of interest was a rectangular volume of trabecular bone located within the alveolar ridge (Figure 2).

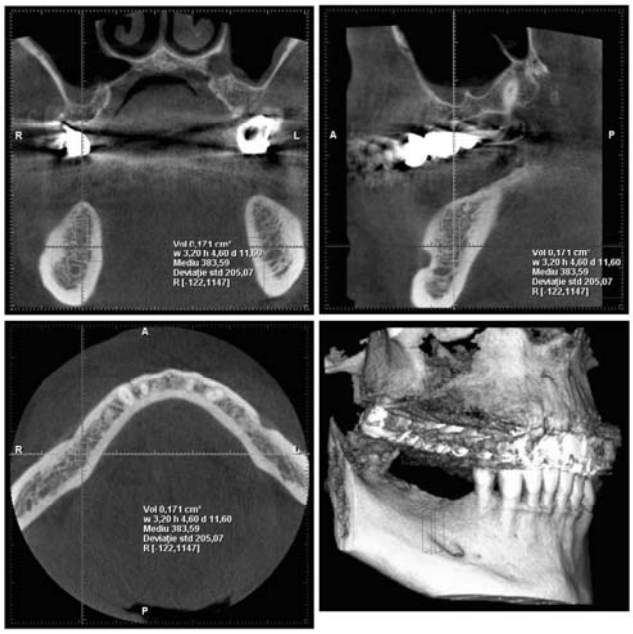

Fig. 2. A typical CBCT recording included in this study, taken with the cylindrical field of view highlighted in Figure 1. The region of interest is a rectangular slab of trabecular bone located in edentulous regions of the alveolar ridge. The Romexis software characterizes the selected volume (white text in frame), listing its size, the mean value of the CT numbers associated to the voxels that compose it (labeled as "Mediu"), the standard deviation of the CT numbers of the constituent voxels (labeled as "Deviație std"), and the range of CT numbers of the voxels from the volume (listed in the format R [smallest CT number, largest CT number]).

Each voxel of this volume is characterized by a CT number, expressed in HU. The software displays the mean value of the CT numbers of the constituent voxels, the standard deviation of these CT numbers, as well as the range of HU values (the smallest and the largest HU values encountered in the volume) (Figure 2).

STATISTICAL ANALYSIS

We divided the trabecular bone samples into eight groups according to gender and anatomical location: 1 – women anterior maxilla, 2 – women posterior maxilla, 3 – women anterior mandible, 4 – women posterior mandible, 5 – men anterior maxilla, 6 – men posterior maxilla, 7 – men anterior mandible, 8 – men posterior mandible. In each dental arch, anterior and posterior regions were delimited by the mesial surface of the first premolar.

To test whether there are significant differences between the mean values obtained for the 8 groups, we performed a one-way analysis of variance (one-way ANOVA) and a Kruskal-Wallis test [5] using the Statistics Toolbox from MATLAB 7.13 (MathWorks, Natick, MA, USA). These tests reveal whether the mean values of all groups are equal or not, but they do not tell which pairs of means differ significantly from each other. To address this problem, we used the honestly significant difference (Tukey-Kramer) criterion to perform multiple comparisons between means.

Since ANOVA relies on the assumption that the data are normally distributed [5], we applied the Jarque-Bera test to accept or reject the null hypothesis that the data from each group come from a normal distribution.

RESULTS

According to the inclusion criteria, our study was conducted on CBCT recordings of 23 men and 23 women. A total of 400 volumes (sites) of trabecular bone were sampled from edentulous regions of the alveolar bone; these sites were divided into eight groups, as described in the previous section. Table 1 presents the descriptive statistics of the mean CT numbers of the trabecular bones from each group.

To test whether the data are normally distributed, we performed a Jarque-Bera test, which is a two-sided goodness-of-fit test suitable to decide whether the null hypothesis (H_0: the data are normally distributed with unspecified mean and standard deviation) or the alternative hypothesis (H_a: the data are not normally distributed) is valid. The last column of Table 1 lists the corresponding P-values for a significance level of 5%. Small values of P cast doubt on the validity of H_0.

Table 1

Descriptive statistics of the CT numbers of the investigated trabecular bone volumes. The last column lists the *P*-values of the normality test

Gender	Anatomical location	Number of sites	Mean CT number (HU)	Standard error (HU)	Skewness	Kurtosis	*P*
Women	Anterior maxilla	34	354	30.0	0.3235	3.401	> 0.5
	Posterior maxilla	66	193	17.4	0.6999	2.828	0.046
	Anterior mandible	27	514	30.5	0.4455	2.086	0.185
	Posterior mandible	73	234	17.5	0.9581	3.369	0.012
Men	Anterior maxilla	40	473	33.5	–0.1010	3.289	> 0.5
	Posterior maxilla	60	250	18.7	0.8194	3.277	0.031
	Anterior mandible	28	521	22.0	0.7559	3.806	0.071
	Posterior mandible	72	389	28.0	0.6159	2.689	0.057

We also analyzed the standard deviations of the CT numbers of the voxels that compose the 3D image of the regions of interest; the results of their descriptive statistics are listed in Table 2, along with the *P*-values of the Jarque-Bera test of normality (last column).

Table 2

Descriptive statistics of the standard deviations (SD) of CT numbers of voxels that compose the image of the trabecular bone of interest. The last column lists the *P*-values of the normality test

Gender	Anatomical location	Number of sites	Mean SD of CT numbers (HU)	Standard error (HU)	Skewness	Kurtosis	*P*
Women	Anterior maxilla	34	206	7.57	–0.165	2.544	> 0.5
	Posterior maxilla	66	176	5.08	0.4987	2.765	0.133
	Anterior mandible	27	243	10.1	0.0904	2.539	> 0.5
	Posterior mandible	73	212	5.13	0.2695	2.282	0.184
Men	Anterior maxilla	40	208	5.67	–0.1041	2.159	0.389
	Posterior maxilla	60	193	4.66	0.2782	2.224	0.193
	Anterior mandible	28	247	11.3	0.07911	2.495	> 0.5
	Posterior mandible	72	220	5.44	0.4889	3.284	0.120

To test whether there are significant differences between the mean CT numbers obtained for the eight groups of trabecular bone volumes, we performed a one-way ANOVA test, which tells whether to accept the null hypothesis (H_0: the mean values of CT numbers are equal) or the alternative hypothesis (H_a: not all the means are equal).

Using the *anova1* function from MATLAB's Statistics Toolbox, we generated box plots (Figure 3), which characterize the eight groups of trabecular bone slabs. In the left panel, on each box, the central line is the median of the CT numbers obtained for the bone regions that belong to the respective group. The edges of the box mark the first and the third quartile (that is, half of the data points lie within the

box), whereas the whiskers span the interval between extreme data points not classified as outliers. Individual markers (+ signs) represent outliers. The right panel represents similar box plots of the standard deviations of CT numbers of the constituent voxels.

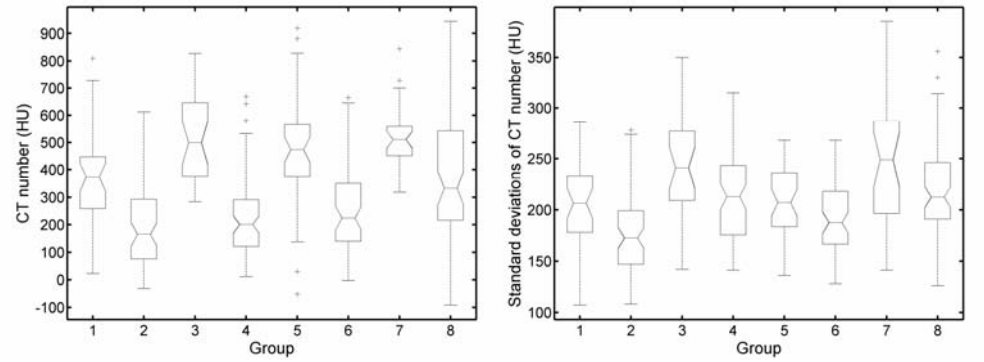

Fig. 3. Box plots of the medians of the CT numbers (left) and the medians of the standard deviations of CT numbers (right) obtained for eight groups of trabecular bone volumes: 1 – women anterior maxilla, 2 – women posterior maxilla, 3 – women anterior mandible, 4 – women posterior mandible, 5 – men anterior maxilla, 6 – men posterior maxilla, 7 – men anterior mandible, 8 – men posterior mandible.

Table 3 presents the results of this test as a standard one-way ANOVA table [5]. In the terminology of ANOVA distinct groups are called treatments. The first row of Table 3 refers to treatments: 7 is the number of degrees of freedom (equal to the number of treatments minus 1), the number listed in the next column (*SS*) is the treatment sum of squares, it is followed by the treatment mean square (in column *MS*), by the *F*-statistic given by the ratio of the variation among sample means to the variation within the samples (column *F*), and the corresponding *P*-value. The second row of Table 2 refers to errors: the number of degrees of freedom is the number of observations minus the number of treatments (column *df*); it is followed by the error sum of squares (column *SS*), and the error mean square (column *MS*, given by the ratio of the error sum of squares to the number of degrees of freedom for errors).

Table 3

The results of the one-way ANOVA test for the mean CT numbers of the voxels that compose the trabecular bone volumes under study

Source	***df***	***SS***	***MS***	***F***	***P***
Groups	7	5.3284×10^{6}	7.6120×10^{5}	25.03	3.2168×10^{-28}
Error	392	1.1922×10^{7}	3.0413×10^{4}	–	–
Total	399	1.7250×10^{7}	–	–	–

The large value of *F* suggests that the discrepancies between sample means might not stem from discrepancies between the values that belong to individual

samples. Can we conclude that there are significant differences between the means? In a hypothesis test, the decision is based on the *P*-value, which is the probability of obtaining the observed results when H_0 is true. The small value of *P*, (more precisely, $P < 0.05$ at a 5% significance level) indicates that H_0 can be rejected in favor of H_a; that is there are significant differences between certain mean values.

One-way ANOVA was also used to test whether there are significant differences between the mean values of the standard deviations of CT numbers of the voxels that compose the 3D images of the bone slabs under study. Table 4 lists the results of this test, indicating that not all means are equal.

Table 4

The results of the one-way ANOVA test for the mean values of the standard deviations of CT numbers of the voxels that compose the investigated trabecular bone volumes

Source	***df***	***SS***	***MS***	***F***	***P***
Groups	7	1.6811×10^{5}	2.4016×10^{4}	12.41	2.2605×10^{-14}
Error	392	7.5872×10^{5}	1.9355×10^{3}	–	–
Total	399	9.2683×10^{5}	–	–	–

The one-way ANOVA tests presented in Tables 3 and 4 reveal significant differences between means.

Table 5

The results of the Kruskal-Wallis test for the mean CT numbers of the voxels from trabecular bone samples

Source	***df***	***SS***	***MS***	***Chi-sq***	***P***
Groups	7	1.7695×10^{6}	2.5279×10^{5}	132.39	1.9938×10^{-25}
Error	392	3.5637×10^{6}	9.0910×10^{3}	–	–
Total	399	5.3332×10^{6}	–	–	–

Table 6

The results of the Kruskal-Wallis test for the mean values of the standard deviations of CT numbers of the voxels from trabecular bone samples

Source	***df***	***SS***	***MS***	***Chi-sq***	***P***
Groups	7	8.6215×10^{5}	1.2316×10^{5}	64.51	1.8902×10^{-11}
Error	392	4.4706×10^{6}	1.1405×10^{4}	–	–
Total	399	5.3328×10^{6}	–	–	–

Since the ANOVA test is based on the assumption that the data are normally distributed [5], and the normality test gave a borderline result for groups 2, 4, 6 and 8 (see last column of Table 1, values corresponding to posterior regions of the dental arches), we also performed a Kruskal-Wallis test for the same null hypothesis (H_0) and alternative hypothesis (H_a). Tables 5 and 6 show the results of

the Kruskal-Wallis test for the mean CT numbers and the mean values of the standard deviations of CT numbers, respectively.

Hence, both the one-way ANOVA test and the Kruskal-Wallis test indicate that not all means are equal. These tests, however, do not give any hint on which pairs of means differ from each other. To address this question, we performed multiple comparisons using the *multcompare* function from the Statistics Toolbox of MATLAB. The results of multiple comparisons are shown on Figure 4.

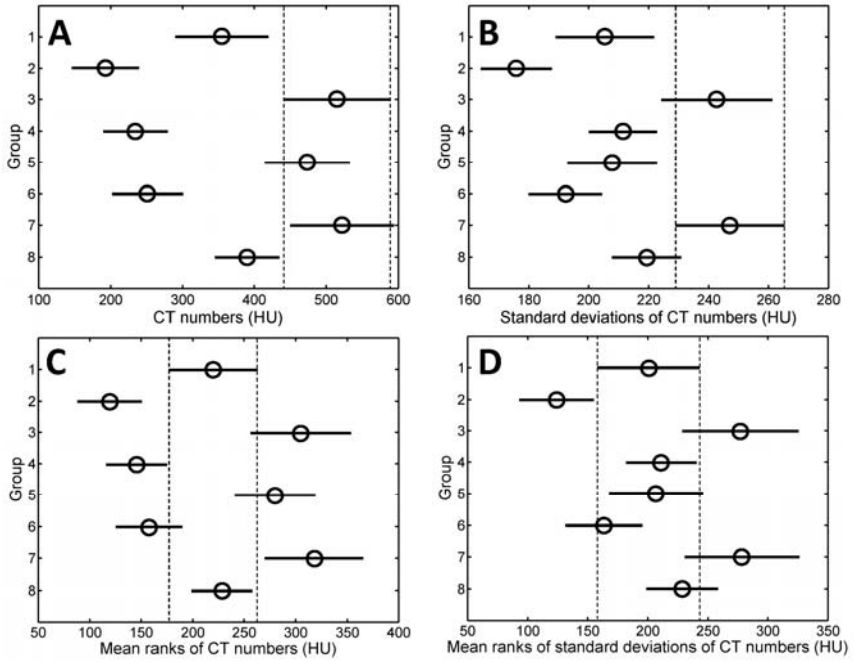

Fig. 4. Multiple comparisons of the mean values of CT numbers (A) and standard deviations of CT numbers (B) based on the one-way ANOVA test; multiple comparisons of the mean ranks of CT numbers (C) and mean ranks of standard deviations of CT numbers (D) based on the Kruskal-Wallis test. The groups of trabecular bone regions under study are: 1 – women anterior maxilla, 2 – women posterior maxilla, 3 – women anterior mandible, 4 – women posterior mandible, 5 – men anterior maxilla, 6 – men posterior maxilla, 7 – men anterior mandible, 8 – men posterior mandible.

Figure 4A refers to the mean CT numbers of the eight populations (groups of trabecular bone slabs) under study. Circular markers represent the mean values and horizontal lines span their intervals of confidence, calculated at the 95% level of confidence. Two means differ significantly if their intervals of confidence do not overlap. For example, to identify the groups whose mean CT numbers differ from the mean CT number of group 3, it is useful to draw two vertical lines at the

extremities of the corresponding confidence interval (dotted lines on Figure 4A); the means that differ from the mean of group 3 are the ones whose confidence interval plots do not extend in the area delimited by the vertical lines. Thus, we conclude that the mean CT numbers of groups 1, 2, 4, 6, and 8 differ significantly from the mean CT number of group 3. The Kruskal-Wallis result shown on Figure 4C can be analyzed in a similar fashion.

The analysis of Figures 4B and 4D allows one to identify groups for which the mean values of standard deviations of CT numbers differ significantly from the mean of a selected group. For example, the dotted vertical lines drawn on the multiple comparison plot of Figure 4B show that, regarding the standard deviations of CT numbers, the mean of group 7 differs significantly from the means of groups 1, 2, 4, 5, and 6.

DISCUSSION

An important problem in dental implant planning is the evaluation of bone quality in prospective implant sites. CT numbers recorded with fan-beam CT devices represent an objective scale for bone density, which strongly correlates with subjective bone quality scores. Moreover, mean CT numbers of implant sites strongly correlate also with their anatomical location [18]. Recording the mean CT numbers of 139 implant sites, Norton and Gamble reported that the average values of CT numbers were 970 HU for the anterior mandible, 696 HU for the anterior maxilla, 669 HU for the posterior mandible, and 417 HU for the posterior maxilla [18]. This hierarchy of the mean bone densities of the four jaw regions, seen also in the present work, has been observed in several studies [6, 11, 23, 24].

To characterize trabecular bone density in terms of HU, de Oliveira *et al*. have examined CT recordings of 75 potential implant sites, obtaining mean voxel values of 383 HU for the anterior mandible, 370 HU for the anterior maxilla, 306 HU for the posterior mandible and 256 HU for the posterior maxilla [6]. Typical ranges of HU values were established as follows: poor quality, fine trabecular bone (the cancellous component of D4 or D5 bone) had CT numbers lower than 200, whereas high quality, coarse trabecular bone had CT numbers higher than 400; the interval between these limits corresponds to intermediate quality trabecular bone [6]. Although measured using a CBCT device, our results fall within these ranges, with standard errors of less than 10% of the mean (Table 1). One notable exception is the mean radiodensity of cancellous bone from the posterior maxilla of men (about 250 HU). Nevertheless, this value lies within the HU range for D4 bone, which mainly consists of fine trabecular bone [15].

The mean values of CT numbers obtained in our study (Table 1) are also comparable with the ones inferred by Fuh *et al*. from CT scans of 35 women and 27 men, with a total of 154 potential implant sites analyzed: the trabecular bone

density was found to be the highest in the anterior mandible (530 HU), followed by the anterior maxilla (516 HU), the posterior mandible (359 HU) and the posterior maxilla (332 HU) [8]. In what concerns the anterior mandible our results are closer to the ones of ref. [8], whereas for the posterior maxilla our results are closer to the ones of ref. [6].

In their study of trabecular bone from the mandible by CBCT and multislice helical CT [17], Naitoh *et al*. found a strong correlation between voxel values (HU values) measured via CBCT and bone mineral density obtained by helical CT. Nevertheless, their CBCT-derived voxel values, of 655 HU to 747 HU for the anterior mandible, and 519 HU for the posterior mandible, are higher than ours, although their study group consisted mainly of women (4 men and 12 women). This discrepancy might stem from using a different type of CBCT unit, Alphard VEGA (Asahi Roentgen Ind. Co., Japan), and different settings [17].

Bone density measurements in HU units were performed on 236 potential implant sites identified in CBCT scans of 74 men and 54 women, recorded by the same type of unit as ours, at slightly different settings (90 kV, 14 mA, and voxel size of 0.2×0.2×0.2 mm) [10]. Although it does not focus on trabecular bone, but on bone located in the vicinity of a cylindrical implant simulated using the Simplant software, a comparison with our results is justified for D4 bone, which is basically cancellous. Moreover, it is reasonable to assume that the simulated implants, 4.1 mm in diameter and 10 mm in length, placed in edentulous spans of the posterior jaws are mainly surrounded by trabecular bone. Indeed, the mean CT numbers of the posterior mandible (394 HU) and the posterior maxilla (220 HU) are comparable with our results. The slightly higher HU value observed by Hao *et al*. in the posterior mandible and the significantly higher HU values observed in the anterior jaws might stem from cortical bone contributions [10].

Significant differences between means can be identified from Figure 4 keeping in mind that the Kruskal-Wallis test is less efficient than the one-way ANOVA test when the assumptions for applying the latter hold [5]. Thus, for analyzing HU values, for which the normality test gave borderline results, the Kruskal-Wallis test is more reliable. This was the statistical test of choice also in reference [8] for the analysis of CT numbers of trabecular bone acquired by conventional CT. In our study, according to the last column of Table 1, HU values of samples from the anterior portion of the dental arches are normally distributed, while the HU values of samples from the posterior regions are not (excepting the posterior mandible of men, whose *P*-value, however, barely exceeds 0.05). Therefore, to identify mean HU values that differ significantly from each other, it is preferable to rely on the confidence intervals of mean ranks shown in Figure 4C, derived from multiple comparisons based on the Kruskal-Wallis test (instead of Figure 4A, which stem from the one-way ANOVA test). For instance, looking at the region delimited by the dotted lines from Figure 4C, we infer that the mean CT number of group 1 (anterior maxilla of women) differs significantly from the mean

CT numbers of groups 2, 4 and 7. The same figure shows that the mean CT number of trabecular bone from the anterior mandible of men (521 HU) is significantly higher than the mean CT numbers of other groups, except for the anterior mandible of women (514 HU) and anterior maxilla of men (473 HU). Moreover, we remark that, for each anatomical region, the mean CT number is larger for men than for women, but their difference is not significant from the statistical point of view.

For analyzing standard deviations of HU values (which are normally distributed according to Table 2) multiple comparisons based on the one-way ANOVA test (Figure 4B) are more powerful than those based on the Kruskal-Wallis test (Figure 4D) [5]. From the dotted lines of Figure 4B we infer that, regarding standard deviations of CT numbers of the constituent voxels, the mean of group 7 (anterior mandible of men) is significantly larger than the means of other groups, except for groups 3 (anterior mandible of women) and 8 (posterior mandible of men). Thus, standard deviations of CT numbers of the constituent voxels discriminate between coarse and fine trabecular bone. Just as in the case of mean voxel values, for each anatomical region, the standard deviation of CT numbers is larger for men than for women, but not significantly so from the statistical point of view.

CONCLUSIONS

In this article we have analyzed voxel values of trabecular bone samples, as a function of gender and anatomical location, measured by one type of CBCT unit, ProMax 3D (Planmeca, Finland), under identical conditions.

The Kruskal-Wallis test applied for the mean values of CT numbers revealed that not all means are equal, and multiple comparisons have identified the groups whose means differ significantly from each other.

Due to the normal distribution of the data, the one-way ANOVA test was suitable for pointing out significant differences between mean values of the standard deviations of CT numbers of voxels that compose the investigated bone slabs. These standard deviations are a measure of structural heterogeneity, and their analysis suggests that CBCT detects significant differences between fine and coarse trabecular bone. Since the software provided by manufacturers of CBCT units routinely report these standard deviations, the methodology presented here is within the reach of implant specialists for pre-operative assessment of the coarseness of trabecular bone.

By identifying conditions of systematic bone density analysis, and establishing mean values of CT numbers and standard deviations of CT numbers as a function of gender and anatomical location, our study might help clinicians using the same type of CBCT unit in evaluating the quality of trabecular bone from prospective implant sites.

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