ORIGINAL PAPERS

Adv Clin Exp Med 2015, **24**, 6, 1071–1077
DOI: 10.17219/acem/28113

ISSN 1899–5276

Krzysztof Andruch[A, D–F], Anna Płachta[B–E]

Evaluating Maxilla Bone Quality Through Clinical Investigation of Voxel Grey Scale Values from Cone-Beam Computed Tomography for Dental Use

Department of Dental Prosthetics, Medical University of Lodz, Poland

A – research concept and design; **B** – collection and/or assembly of data; **C** – data analysis and interpretation; **D** – writing the article; **E** – critical revision of the article; **F** – final approval of article

Abstract

Background. During the study the relative bone density thickness in maxilla was evaluated in 20 patients.
Objectives. The aim of the study was to investigate relative bone density in maxilla by means of voxel value measurements.
Material and Methods. The study comprised of 20 patients in whom cone beam computed tomography scans were made for diagnostic purposes. The horizontal scans of the maxilla were used for analysis. The measurements of density of both cortical plates and trabecular bone were taken in interdental spaces. To eliminate negative values a modified grey scale was introduced in which radiological density of the air was determined as "0". For every patient relative bone density was calculated separately for anterior and posterior maxilla.
Results. Mean values of relative radiological density for cortical plates and trabecular bone were 0.849 for palatal cortical plate, 0.8978 for vestibular cortical plate and 0.5988 for trabecular bone in anterior maxilla with standard deviation (SD) 0.0931 – 0.0971 – 0.1091 respectively. In posterior maxilla the mean values were 0.5274 for palatal cortical plate, 0.6047 for vestibular cortical plate and 0.3307 for trabecular bone with SD 0.1635 – 0.1515 – 0.126 respectively. The statistically significant difference ($p < 0.001$) was found for radiological density of dental alveolus in anterior and posterior maxilla.
Conclusions. The mean of radiological densities of vestibular cortical plate is higher than that of palatal cortical plate. The mean radiological density of trabecular bone is ×2 lower than the mean radiological density of vestibular cortical plate in posterior region and ×1.5 lower in anterior region of the maxilla. The clinical use of CBCT radiological bone density measurement tool with modified grey scale voxel values creates possibility to evaluate the relative bone density of dental alveolus (**Adv Clin Exp Med 2015, 24, 6, 1071–1077**).

Key words: cone-beam computed tomography, grey levels, bone density.

Cone-beam computed tomography (CBCT) is one of the methods of radiological imaging of bone structures in three-dimensional projection. The advantages of CBCT compared to medical CT include lower radiation dose, shorter exposure time, lower cost of the device, while the limitations are connected to geometry of the beam, higher noise level, poorer imaging of soft tissues, beam hardening and scatter radiation, which impair image quality [1]. CBCT starts to be widely used in all fields of dentistry especially in surgery, implantology, orthodontics, endodontics and periodontology [2]. The software allows 3D image reconstruction, obtaining any section in all three planes and the evaluation of bone density in the selected regions. Analysis of the images helps in the assessment of the structure of trabecular bone (trabeculae number, their diameter and position), which facilitates the evaluation of tissue healing after endodontic treatment, optimizing surgical procedures or implants placement [3]. To evaluate the radiological density of tissues the Hounsfield scale is commonly used, where shades of grey in which structures are depicted are presented in Hounsfield units (HU). Radiographic density of any material in the scale of Hounsfield units is calculated according to the formula:

$$\frac{\mu_x - \mu_{H_2O}}{\mu_{H_2O} - \mu_{air}} \times 1000$$

where μ_x is a linear attenuation coefficient of the material [4]. The first reference point on the scale of the radiographic density is water (HU = 0). The values of the tissues on the scale are positive or negative when their attenuation coefficient is larger or smaller than attenuation coefficient of water. Another point of reference is the radiological density of air which takes the value –1000 HU.

The Hounsfield index was originally developed for the analysis of images obtained by medical CT, especially soft tissue [5]. In dentistry CT is still used to evaluate the alveolar bone before implant placement, and the HU values are considered to give the objective and reliable information on the amount and quality of bone [6, 7] compared to the subjective in its nature classification system of Lekholm and Zarb [8, 9] The increasing application of CBCT to bone density assessment impelled researchers to evaluate the new system in relation to CT. Some studies showed that bone density measurements of the same selected regions in jaws made by means of both methods were not corresponding to each other [10, 11] displaying higher HU values for CBCT images [8, 10]. The HU values were also different for two different CBCT devices [12]. As a consequence, the grey scale of CBCT was applied by manufacturers as a not defined equivalent of Hounsfield scale and reffered as "grey levels" or "voxel values". These two different units should not to be mistaken with each other. Mah et al. [13] in their *in vitro* study converted CBCT grey levels into Hounsfield units using calculated linear attenuation coefficients. They were derived from linear regression equation being a result of plotting original attenuation coefficients of 8 materials provided by National Institute of Standards and Technology (NIST) against the grey levels of these materials obtained from the CBCT scanner. The calculated attenuation coefficients were transformed into HU according to standard formula. The difference between HU obtained from original attenuation coefficients (actual HU) with those calculated was very small and depended on the manufacturer of CBCT scanner and conditions in which the scan was taken. *In vivo* study conducted by the same authors showed the difference between the calculated and actual HU less than 3%, whereas the relationship between grey levels (voxel values) and HU was defined as linear [14]. It should be noted that the authors used a mathematical model only, without comparing CT and CBCT scans. Linear relationship between HU values obtained in multislice computed tomography (MSCT) and CBCT grey levels was confirmed by Parsa et al who compared images made by both devices [15]. Nomura et al. described the relationship between CT numbers and the grey values as non-linear [16] and pointed out poorer reproducibility of measurements performed by the CBCT, with the potential error of measuring reaching 15.7%.

The question appears whether it is always necessary to transform grey voxels into Hounsfield units by means of calibration scales. In our study we decided to use a modified grey scale, where number "0" is ascribed to air, not water, and investigate the variability in maxilla cortical and trabecular bone density of every single patient in relation to the highest reading of his measured bone density which created relative grey values used for bone density evaluation in the region of interest.

The Aim of the Study

The aim of this study was to investigate the clinical possibility to measure the maxilla relative radiological bone density through clinical use of the grey scale voxel values of two cortical and trabecular alveolus bone tissue using CBCT radiological bone density measurement tool.

Material and Methods

Twenty CBCT scans made for clinical examination were used in this study. The group of patients consisted of 8 male and 12 female aged 19–73. Nineteen scans were obtained from PaX-Reve3D (E-Woo Vatech, Seoul, Republic of Korea) and one from i-CAT (Imaging Sciences International, Hatfield, PA). Data were analysed with Ez3D Plus software (E-Woo Vatech, Seoul, Republic of Korea). Parameters of exposition are displayed in Table 1.

Measurements were performed on a horizontal cross-section of the maxilla using spatial

Table 1. Parameters of exposition

Amperage, anode voltage	No. of scans acquired
8 mA, 85 kVp	5
8 mA, 90 kVp	5
5 mA, 85 kVp	3
2 mA, 90 kVp	2
2 mA, 85 kVp	1
6 mA, 85 kVp	1
7 mA, 85 kVp	1
6 mA, 90 kVp	1
5 mA, 120 kVp	1

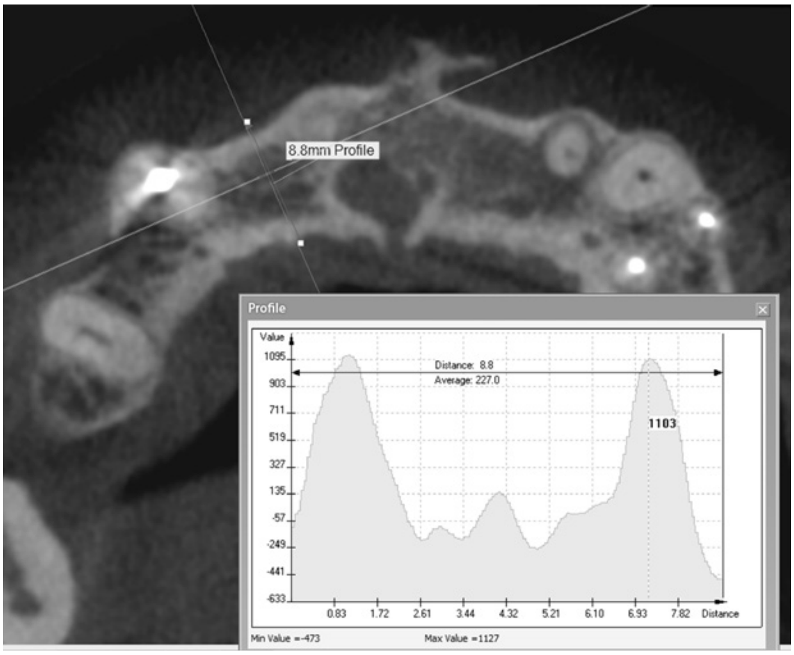

Fig. 1. The example of grey value measurement in anterior maxilla by use of Profile tool (Ez3D Plus software)

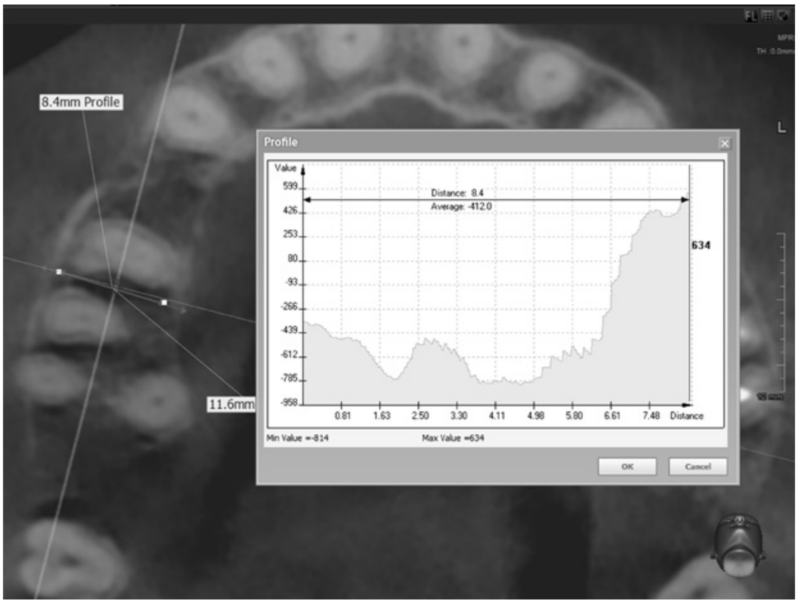

Fig. 2. The example of grey value measurement in posterior maxilla by use of Profile tool (Ez3D Plus software)

coordinate tool (x-y). The image was positioned on 3 windows: coronal, saggital and axial view. One of vertical planes (saggital in posterior maxilla and coronal in anterior maxilla) was positioned parallel to the long axis of the alveolus in the middle of its width. In the posterior part of the maxilla the alveolus was cut horizontally in the middle of its height. In the anterior part of the maxilla the horizontal plane runs in the middle of the distance between the alveolar crest and the radiological apexes of adjacent teeth. The horizontal plane was perpendicular to the long axis of the alveolus. The measurements were taken in the interradicular space where both cortical plates and trabecular bone were available. In case of the lack of teeth, the measurement was taken in edentulous alveolus merely in the middle of its height. On the horizontal cross-sections, one of the coordinates was perpendicular to both cortical plates in the middle of the interradicular space or endentulous alveolus (Fig. 1, 2). The thickness of the slices did not exceed 1 mm. The Profile tool available in Ez3D software was used to estimate the radiological density of the bone. A diagram displayed the mean and maximum value of density. Every patient had 3–4 measurements taken in interradicular spaces in the frontal part of the maxilla and 3–5 in the posterior maxilla depending on the volume of the available bone. Every time 2 segments were selected: the first one across the alveous involved both cortical and trabecular bone, the second one overlapping the first with only trabecular bone. Two maximum values for two cortical plates were read from the first diagram, and the mean value of density of the trabecular bone from the second diagram. The density line was drawn from the palatal cortical plate, so the first peak on the diagram always corresponds with the palatal cortical plate. Every measurement was made in Ez3D Plus CT scan browser and after that saved as a screenshot in PNG format. The results were collected in table (Table 2). The total number of measurements was 165: 76 in the anterior maxilla and 89 in the posterior maxilla.

As grey values used in Ez3D are not compatible with Hounsfield units, so a modified scale was used. The value for air was determined as "0". Measurements of radiological density of air outside the oral cavity were taken on every scan. The region where the measurement was taken was chosen on the horizontal scan, in the front of the upper lip. The line segment selected for the measurement was crossed by the saggital axis in the middle of its length. The obtained negative grey values of the air were subtracted from the values for cortical plates and trabecular bone that resulted in a new wide grey scale without negative numbers. Results were collected in columns A (palatal cortical plate), B (vestibular cortical plate) and C (trabecular bone) as values in new scale and base for further calculations. For every patient the highest value from cortical plate set of data was found, defined as the maximum density of the bone. This number worked as a reference measurement (D) for each patient. The ratio of radiological density of cortical plates and trabecular bone to D was calculated (respectively described as A/D, B/D and C/D). This manner allows us to reduce the potential error coming from different X-ray exposition parameters applied for different patients. The results were grouped in a table, separately for the anterior and the posterior part of the maxilla. Statistical analysis was performed using STATISTCA 10 software (StatSoft, Inc., Tulsa, OK, USA). The ANOVA test was used to determine the differences in relative bone density between the anterior and the posterior maxilla and between palatal and cortical plates. A value of $p < 0.05$ was considered significant. The mean, standard deviation, maximum and minimum were calculated.

Results

The whole range of measurements in rescaled grey values was displayed on a diagram separately for the anterior and the posterior maxilla (Fig. 3, 4). Mean values of relative radiological density for cortical plates and trabecular bone were 0.849 for A/D, 0.8978 for B/D and 0.5988 for C/D in anterior maxilla with standard deviation (SD) 0.0931–0.0971–0.1091 respectively. For the posterior maxilla corresponding values

Table 2. The table with the data of the patient no. 12

Original measurements					Rescaled grey values						
Tooth	**palatal cortical plate**	**vestibular cortical plate**	**trabecular bone**	**air (extraoral measurement)**	**palatal cortical plate (A)**	**vestibular cortical plate (B)**	**trabecular bore (C)**	**the highest value (D)**	**palatal cortical plate to the highest value (A/D)**	**vestibular cortical plate to the highest value (B/D)**	**trabecular bone to the highest value (C/D)**
posterior maxilla											
14	1180	1424	–96	–1017	2197	2441	921	**3573**	0.6149	0.6832	0.2578
17	1137	1474	729	–1017	2154	2491	1746		0.6029	0.6972	0.4887
25	911	1323	242	–1017	1928	2340	1259		0.5396	0.6549	0.3524
26	1299	1348	–161	–1017	2316	2365	856		0.6482	0.6619	0.2396
anterior maxilla											
27	1425	1741	941	–1017	2442	2758	1958		0.6835	0.7719	0.548
11	2350	2244	1706	–1017	3367	3261	2723		0.9423	0.9127	0.7621
12	1956	2518	1364	–1017	2973	3535	2381		0.8321	0.9894	0.6664
21	2355	2556	1530	–1017	3372	**3573**	2547		0.9437	1	0.7128
22	2458	2225	966	–1017	3475	3242	1983		0.9726	0.9074	0.555

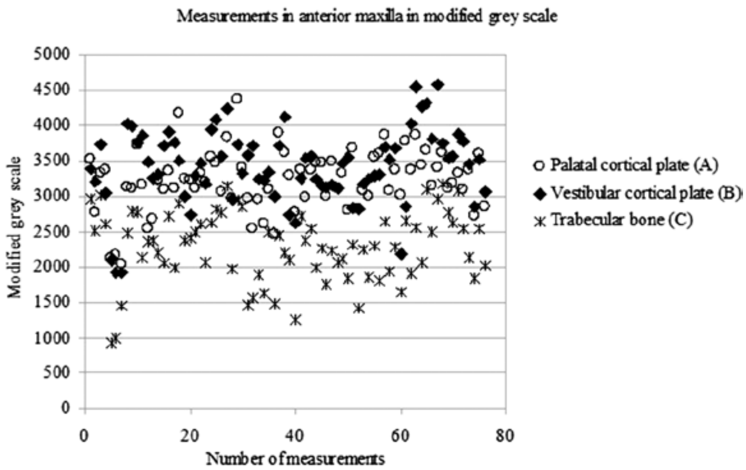

Fig. 3. The whole range of measurements in rescaled grey values for anterior maxilla

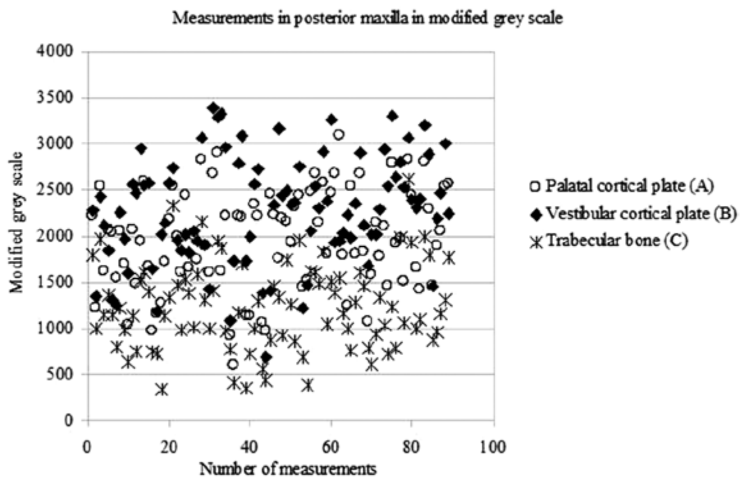

Fig. 4. The whole range of measurements in rescaled grey values for posterior maxilla

were 0.5274 for A/D, 0.6047 for B/D and 0.3307 for C/D, with SD 0.1635 – 0.1515 – 0.126 respectively (Table 3). The statistically significant difference ($p < 0.05$) was found between anterior and posterior maxilla for palatal cortical plate, vestibular cortical plate and trabecular bone. When compared to palatal cortical plate, higher relative bone density values were found for vestibular cortical plate both in anterior and posterior part of the maxilla ($p < 0.05$).

Discussion

X-ray examination is still the most frequently used mean for assessing geometrical shape and quality of the bone structure which was researched in medical fields of science. Medical CTs, available in larger medical centers, utilize prominent radiation dose in comparison to CBCTs which are gaining more popularity in dental offices. The growing number of CBCT application creates the possibility to explore this technique not only for

Table 3. Means, standard deviations and *p* value of the relative bone density for palatal cortical plate, vestibular cortical plate and trabecular bone in anterior and posterior maxilla

	Anterior maxilla		Posterior maxilla		ANOVA
	range	**mean ± SD**	**range**	**mean ± SD**	
Palatal cortical plate to the highest reading (A/D)	0.6716–1.0	0.849 ± 0.0931	0.1593–0.9134	0.5274 ± 0.1635	$p < 0.05$
Vestibular cortical plate to the highest reading (B/D)	0.5662–1.0	0.8978 ± 0.0971	0.1651–1.0	0.6047 ± 0.1515	$p < 0.05$
ANOVA	$p < 0.05$		$p < 0.05$		
Trabecular bone to the highest reading (C/D)	0.3054–0.809	0.5988 ± 0.1091	0.0805–0.6696	0.3307 ± 0.126	$p < 0.05$

bone shape evaluation, but also for bone density assessment. As the grey values can be measured the possibility to measure radiological density of bone appears. This is well correlated with its biomechanical properties [17]. There is a linear correlation between bone density (measured in g/cm^{-3} of hydroxylapatite – HA) and the grey values of CBCT [11]. In this study the modified grey value scale was used instead of Hounsfield unit scale for bone tissue evaluation. The density of two bone structures is easy to compare using grey values, but appearing negative HU or non-modified grey values create a kind of confusion. Trabecular bone structures, which are also filled with certain amount of fat, contain hydrogen and oxygen atoms in the same way water does, so trying to compare them on the water reference point is difficult. Some values appear to be above or below zero. This is the way how the Hounsfield units scale works to differentiate soft tissue structures. The cortical plates are far away from water point of reference. On the other hand, trabecular bone filled with bone marrow is a fat rich tissue and some measurements reveal negative values while using profile tool in this study. It was impossible to compare positive and negative numbers until all the values were converted to positive units. That is why the modified scale was used. Having one point of reference was not enough, so the second one was established as a maximum value from all performed measurements. This was done for every single patient, which gave the possibility for relative density comparison between patients. This kind of simplifications allowed us to overcome problems of different grey values for different exposure conditions. From a clinical point of view it is impossible to compare directly grey values readings from different exposure conditions of the same CBCT machine and, moreover, from different machines [12]. Grey values range is directly tied with applied 12 or 14 bit picture grey depth and these results in maximum range of 4,096 or 16,384 shades values. Only part of this range is used for imaging bone structures. Every change in kVp settings shifts the used image range which has direct influence on HU readings or grey scale voxel values [18]. Changes in tube current have no prominent changes on tissue attenuation in MSCT [19] but because of the prominent scatter radiation in CBCT some changes can appear. Without precise calibration procedure of CBCT equipment there is no possibility of direct density measurements. It may be noted that the second reference point should be included as a known artificial minifantom object (with known attenuation coefficient similar to the attenuation coefficient of the cortical plate) to make any further precise data comparison between different CBCT possible.

By analyzing the received data, it can be visible that the range of measured values is noticeably wide from 300 to 4,600 modified grey values (Fig. 3, 4). Looking for the mean of relative measured value for both cortical plates and trabecular bone and its standard deviation it is visible that the results fit to the clinical expectations (Table 3). Relative mean values for cortical plates are close to each other and the relative mean value for trabecular bone takes aproximately 0.6 and 0.5 of relative cortical plates values for anterior and posterior maxilla respectively. Relative mean values for the posterior maxilla are approximately 40–50% smaller than those for the anterior maxilla. Palatal cortical relative mean value is lower than vestibular one while the thickness of the palatal plate seems to be clinically greater than vestibular one. The standard deviation is nearly the same for all three measured groups, ranging from 0.09 to 0.16 (Table 3). The observations from this study seem to be very promising for clinical bone density evaluation using CBCT. The use of reference minifantom object instead of maximum reading value could probably improve direct data comparison and minimize the measuring error. Density conversion factors, introduced in this way, could probably solve this issue for a given CBCT machine [20]. Some further investigations are needed to confirm this possibility.

Clinical Significance

The data from this study demonstrates that clinical evaluating of the maxilla bone quality on the basis of relative radiological bone density measurements is possible but it has limitations. Higher values in voxel grey scale in anterior maxilla suggest better quality of the bone only in terms of its density and mineralization. Introducing modified scale of voxels is convenient, because it helps in evaluating the radiological density of bone in relation to air, which becomes sort of referential point.

Study Limitations

One of the limitations of this study is the lack of a referential point – an item with known physical density and radiological density measured in a different parameters setting. Another limitation is the lack of a scale which would describe the range of voxel values corresponding to higher or lower quality of bone. There is no data presenting the exact relation between voxel grey values and parameters of exposition on this particular CBCT device. There is also a limited number of scans to examine. In spite of this, there is great potential for using CBCT in estimating bone quality on the basis of grey scale voxel values.

The authors concluded that mean of radiological densities of vestibular cortical plate is higher than that of palatal cortical plate. The mean radiological density of trabecular bone is ×2 lower than the mean radiological density of vestibular cortical plate in posterior region and ×1.5 lower in anterior region of the maxilla. The clinical use of CBCT radiological bone density measurement tool with modified grey scale voxel values creates the possibility to evaluate the relative bone density of dental alveolus.

References

[1] **Schulze R, Heil U, Bruellmann DD, Dranischnikow E, Schwanecke U, Schoemer E:** Artefacts in CBCT: a review. Dentomaxillofac Radiol 2011, 40, 265–273.

[2] **De Vos W, Casselman J, Swennen RJ:** Cone-beam computerized tomography (CBCT) imaging of the oral and maxillofacial region: A systematic review of the literature. Int J Oral Maxillofac Surg 2009, 38, 609–625.

[3] **Ibrahim N, Parsa A, Hassan B, van der Stelt P, Aartman IHA, Wismeijer D:** Accuracy of trabecular bone microstructural measurement at planned dental implant sites using cone-beam CT datasets. Clin Oral Implants Res 2013, 00, 1–5. Epub ahead of print.

[4] **Hounsfield GN:** Nobel lecture, December 8, 1979. Computed medical imaging. J Radiol 1980, 61, 459–468.

[5] **Hounsfield GN:** Computerized transverse axial scanning (tomography): Part 1. Description of the system. Br J Radiol 1973, 46, 1016–1022.

[6] **Schreiber JJ, Anderson PA, Rosas HG, Buchholz AL, Au AG:** Hounsfield units for assessing bone mineral density and strength: a tool for osteoporosis management. J Bone Joint Surg Am 2011, 93, 1057–1063.

[7] **Turkyilmaz I, Ozan O, Yilmaz B, Ersoy AE:** Determination of bone quality of 372 implant recipient sites using Hounsfield unit from computerized tomography: a clinical study. Clin Implant Dent Relat Res 2008, 10, 238–244.

[8] **Aranyarachkul P, Caruso J, Gantes B, Schulz E, Riggs M, Dus I:** Bone density assessments of dental implant sites: 2. Quantitative cone–beam computerized tomography. Int J Oral Maxillofac Implants 2005, 20, 416–424.

[9] **Shapurian T, Damoulis PD, Reiser GM, Griffin TJ, Rand WM:** Quantitative evaluation of bone density using the Hounsfield index. Int J Oral Maxillofac Implants 2006, 21, 290–297.

[10] **Silva IM, Freitas DQ, Ambrosano GM, Bóscolo FN, Almeida SM:** Bone density: comparative evaluation of Hounsfield units in multislice and cone-beam computed tompgraphy. Braz Oral Res 2012, 26, 550–556.

[11] **Holweg-Majert B, Metzger MC, Kummer T, Schulze D:** Morphometric analysis – Cone beam computed tomography to predict bone quality and quantity. J Craniomaxillofac Surg 2011, 39, 330–334.

[12] **Holweg-Majert B, Pautke C, Deppe H, Metzger MC, Wagner K, Schulze D:** Qualitative and Quantitative Evaluation of Bony Structures Based on DICOM Dataset. J Oral Maxillofac Surg 2011, 69, 2763–2770.

[13] **Mah P, Reeves TE, McDavid WD:** Deriving Hounsfield units using grey levels in cone beam computed tomography. Dentomaxillofac Radiol 2010, 39, 323–335.

[14] **Reeves TE, Mah P, McDavid WD:** Deriving Hounsfield units using grey levels in cone beam CT: a clinical application. Dentomaxillofac Radiol 2012, 41, 500–508.

[15] **Parsa A, Ibrahim N, Hassan B, Motroni A, van der Stelt P, Wismeijer D:** Reliability of voxel grey values in cone beam computed tomography for preoperative implant planning assessment. Int J Oral Maxillofac Implants 2012, 27, 1438–1442.

[16] **Nomura Y, Watanabe H, Honda E, Kurabayashi T:** Reliability of voxel values from cone-beam computed tomography for dental use in evaluating bone mineral density. Clin Oral Implants Res 2010, 21, 558–562.

[17] **Zioupos P, Cook RB, Hutchinson JR:** Some basic relationships between density values in cancellous cortical bone. J Biomech 2008, 41, 1961–1968.

[18] **Skaug Sande EP, Trægde Martinsen AC, Olaug Hole E, Olerud HM:** Interphantom and interscanner variations for Hounsfield units – establishment of reference values for HU in a commercial QA phantom. Phys Med Biol 2010, 55, 5123–5135.

[19] **Birnbaum BA, Hindman N, Lee J, Baab JS:** Multidetector row CT attenuation measurements: Assessment of intra- and interscanner variability with an anthropomorphic body CT phantom. Radiology 2007, 242, 109–119.

[20] **Lagravére MO, Fang Y, Carey J, Toogood RW, Packota GV, Major PW:** Density conversion factor determined using a cone-beam computed tomography unit NewTom QR-DVT 9000. Dentomaxillofac Radiol 2006, 35, 407–409.

Address for correspondence:

Krzysztof Andruch
Department of Dental Prosthetics
Medical University of Lodz
Pomorska 251
92-216 Łódź
Poland
E-mail: andruchk@wp.pl

Conflict of interest: None declared

Received: 23.02.2014
Revised: 13.06.2014
Accepted: 11.07.2014