Original Article

Comparison of Tissue Density in Hounsfield Units in Computed Tomography and Cone Beam Computed Tomography

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Abstract

Objectives: Bone quality and quantity assessment is one of the most important steps in implant treatment planning. Different methods such as computed tomography (CT) and recently suggested cone beam computed tomography (CBCT) with lower radiation dose and less time and cost are used for bone density assessment. This in vitro study aimed to compare the tissue density values in Hounsfield units (HUs) in CBCT and CT scans of different tissue phantoms with two different thicknesses, two different image acquisition settings and in three locations in the phantoms.

Materials and Methods: Four different tissue phantoms namely hard tissue, soft tissue, air and water were scanned by three different CBCT and a CT system in two thicknesses (full and half) and two image acquisition settings (high and low kVp and mA). The images were analyzed at three sites (middle, periphery and intermediate) using eFilm software. The difference in density values was analyzed by ANOVA and correction coefficient test ($P<0.05$).

Results: There was a significant difference between density values in CBCT and CT scans in most situations, and CBCT values were not similar to CT values in any of the phantoms in different thicknesses and acquisition parameters or the three different sites. The correction coefficients confirmed the results.

Conclusions: CBCT is not reliable for tissue density assessment. The results were not affected by changes in thickness, acquisition parameters or locations.

Keywords: Bone Density; Cone-Beam Computed Tomography; Tomography, X-Ray Computed

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INTRODUCTION

In dental implant treatments, the outcome is influenced by both bone quality and quantity [1]. Previous studies have shown a close relationship between bone density and success of implant treatment [2-7]. Bone quality is determined by cortical bone thickness, the amount of trabeculae and mineralization [1] and can be evaluated by bone density assessment [8]. Several methods have been proposed for bone quality assessment; among which, volumetric imaging techniques are the most feasible [2]. These techniques enable the clinicians to assess bone density without any superimposition, which is a major limitation of plain radiography [9]. Computed tomography (CT) is a useful method for bone density assessment prior to dental implant surgery [2] and has been accepted as the gold standard for such evaluations [4]. However, high patient radiation dose limits its routine or multiple applications [7].

Cone-beam computed tomography (CBCT) has become a widely used imaging modality for pre-implant assessment in the recent years [10]. Compared with CT scan, CBCT images provide superior resolution and lower patient radiation dose [11,12]. Despite the wide application of CBCT in implant dentistry, its aptitude for bone

density assessment is still controversial. Some studies advocate it as a reliable substitute for CT in this respect and confirm its validity [1,2,6,7,13-16] while others have brought it into question [3,9,17,18]. Hounsfield unit (HU) is the standard scheme for scaling the reconstructed attenuation coefficient in medical CT systems. In CBCT systems, the gray values are used to represent the reconstructed values, although it has not yet been proposed as a standard system [14]. In the present study, the correlation between the gray values obtained from CBCT and the HUs in CT images was evaluated and the effect of the type of tissue, tissue thickness, acquisition parameters and location was assessed in this regard.

MATERIALS AND METHODS

In this in vitro diagnostic study, we compared the tissue density values on CBCT and CT images in four different tissue phantoms with two different thicknesses, two different acquisition settings and in three locations in the phantoms.

The phantoms used in this study simulated different densities namely hard tissue, soft tissue, water and air. Hard tissue equivalent phantom was made of bovine bone powder mixed with epoxy resin with the proportion of 0.55:1 in the laboratory of Nuclear Engineering Department of Shahid Beheshti University.

Soft tissue equivalent phantom consisted of a 1 cm-thick Plexiglas slab, suggested by the Medical Engineering and Medical Physics Department of Shahid Beheshti University. Air equivalent phantom was a sponge-like material. All were round with 54 mm radius and 10 mm thickness. They were fixed over each other and placed in a clear plastic cylindrical container (Biokips, Komax industrial Co. Ltd., Seoul, Korea) filled with distilled water to simulate body fluids. The phantoms were positioned at the center of the field of view (FOV). For easy repeatability, this position was marked on the container (Fig. 1).

Fig. 1: Different tissue phantoms placed in a cylindrical container as the water phantom.

The phantoms were scanned three times to increase precision using GE Bright Speed 16 slice multi detector CT scan system (General Electric, Schenectady, New York, USA) with two different exposure settings. It was also scanned three times with two different acquisition settings using three different CBCT units namely Scanora 3D (Soredex, Helsinki, Finland), NewTom VG (AFP, Verona, Italy) and Pro-Max 3D (Planmeca, Helsinki, Finland). All exposure parameters are shown in Table 1.

In the first phase, six different series of scans were obtained by each unit, three with high and three with low acquisition settings, all in full thickness. In the second phase, the new series of scans were obtained by the same units and the same acquisition parameters but with half thickness. In order to overcome the effect of various computer programs, all CT and CBCT images were imported into a single computer program (Workstation 2.1 Merge eMed, Merge eFilm Inc., Milwaukee, WI).

Table 1: Exposure parameters for different units

	High exposure settings	Low exposure settings
CT	100 kVp, 140 mAs	100 kVp, 100 mAs
Scanora 3D CBCT	85 kVp, 15 mAs	85 kVp, 10 mAs
NewTom VG CBCT	110 kVp, 4 mAs	110 kVp, 1 mAs
Pro-Max 3D CBCT	84 kVp, 12 mAs	84 kVp, 8 mAs

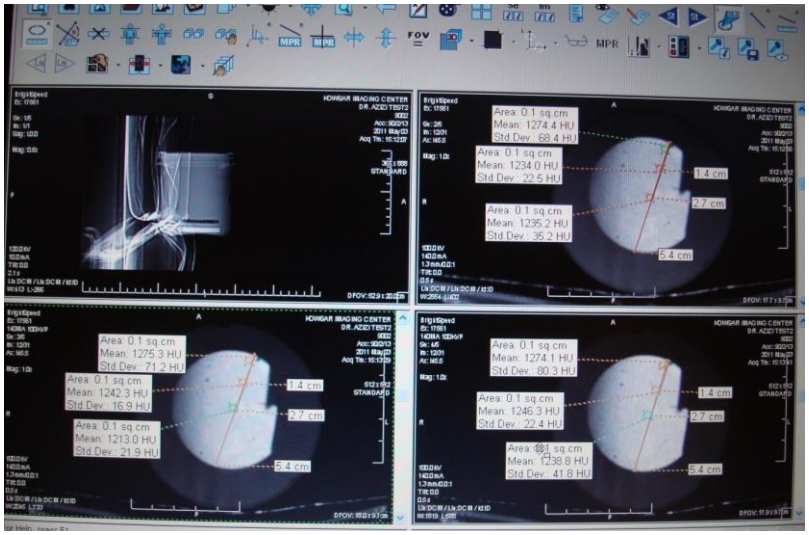

Fig. 2: Evaluation of HUs in hard tissue phantom with Merge e-Film software in three times of scanning in full thickness phantom.

The CT number of CT images and the voxel value in CBCT images were evaluated. The three central slices were selected in all phantom scans. Three definite locations were selected on each image: at the middle (M; 270 mm from the periphery), on the periphery (P), and an intermediate point between these two (INT; 140 mm from the periphery) on the radius of phantom with a constant region of interest (ROI; Fig. 2).
These points were selected on a slice and distributed to all using a software option to evaluate the same location in all slices and scans. The same was done for the half thickness images. An oral and maxillofacial radiologist observed and recorded the values in all images.

Statistical analysis:

The relationship between CT numbers on CT scans and the gray values of CBCT images was studied by ANOVA ($P<0.05$). The effects of the type of material, acquisition parameters, phantoms' thickness and location of the assessed point on the phantoms were also studied. Statistical analysis was performed using SPSS version 18 (SPSS Inc., Chicago, IL, USA).

RESULTS

In the first evaluation, the interaction effect of the variables was found to be significant using results were not the same in different conditions and each variable had to be examined separately.

Table 2: Comparison of voxel values in CBCT systems with Hounsfield units in CT in full thickness phantoms

	Full thickness low exposure settings		Full thickness high exposure settings	
	Groups	**Significancy**	**Groups**	**Significancy**
Hard tissue phantom	Scanora 3D	NS	Scanora 3D	S
	NewTom VG	S except for point P	NewTom VG	S except for point M
	Pro-Max 3D	S	Pro-Max 3D	S
Soft tissue phantom	Scanora 3D	NS	Scanora 3D	S
	NewTom VG	NS	NewTom VG	S
	Pro-Max 3D	NS	Pro-Max 3D	S
Air phantom	Scanora 3D	NS	Scanora 3D	NS
	NewTom VG	NS except for point M	NewTom VG	S
	Pro-Max 3D	NS	Pro-Max 3D	NS except for point P
Water phantom	Scanora 3D	S except for point M	Scanora 3D	NS
	NewTom VG	S	NewTom VG	NS except for point P
	Pro-Max 3D	S	Pro-Max 3D	S

NS: Non-significant S: Significant

Table 3: Comparison of voxel values in CBCT systems with Hounsfield units in CT in half thickness phantoms

	Half thickness low exposure settings		Half thickness high exposure settings	
	Groups	**Significancy**	**Groups**	**Significancy**
Hard tissue phantom	Scanora 3D	S	Scanora 3D	S
	NewTom VG	S	NewTom VG	S
	Pro-Max 3D	S	Pro-Max 3D	S
Soft tissue phantom	Scanora 3D	S except for point M	Scanora 3D	S except for point M
	NewTom VG	S	NewTom VG	S
	Pro-Max 3D	S	Pro-Max 3D	S
Air phantom	Scanora 3D	NS	Scanora 3D	NS except for point M
	NewTom VG	NS except for point INT	NewTom VG	S
	Pro-Max 3D	NS	Pro-Max 3D	NS except for point M
Water phantom	Scanora 3D	S	Scanora 3D	S
	NewTom VG	S	NewTom VG	S
	Pro-Max 3D	S	Pro-Max 3D	S

NS: Non-significant S: Significant

The results of ANOVA used to compare the CBCT and CT data are shown in Tables 2 and 3.

DISCUSSION

Bone quality and quantity assessment is critical for pre-implant surgeries; thus, reliable and precise radiographic evaluations are essential. However, despite wide use of CBCT in different fields of dentistry, it is still not a valid method for bone quality assessment [4,14-16,19-21]. Object location in CBCT systems, object volume, acquisition parameters and some other factors have been evaluated in previous studies and controversial results have been reported [7,8,10,11,13-16]. In this study, the diagnostic accuracy of three CBCT systems was compared with that of CT as the gold standard, and the effect of four factors including different tissue phantoms, object volume size, acquisition parameters and location of the objects was assessed. As the results showed, none of the CBCT systems revealed the precise bone density as the gold standard. In this study, different tissue phantoms were used to evaluate diagnostic accuracy of CBCT systems in different density ranges. Some studies used different densities of different materials [14,19,22]. Review of the literature revealed that only Mah et al, [14] used standard phantoms.

Heterogeneity of the hard tissue and air phantoms was a limitation of our study and was due to the production process. They were handmade in a laboratory and even in the best conditions, porosities were seen. Legravere et al, [20] also mentioned this limitation in their study. However, in the clinical setting, the tissues are not homogenous; thus, this factor may not be a real limitation for generalization of results to the clinical setting [14]. However, in this study, the results showed no significant effect of this restriction by comparing the data of the four phantoms.

The effect of tissue thickness is one of the main subjects for researchers to asses in density studies. Thus, we evaluated the phantoms in two phases. In the first phase, the complete thickness and in the second phase, half-thickness samples were evaluated, which showed no considerable effect on assessment of the tissue density. The results were different in the two phases and there was a significant difference in results compared with CT system. Katsumata et al, [21] showed that the thicker the tissues, the more precise the values of tissue density. They discussed that beam characteristics may be a more important factor than the tissue thickness, which is because of the 360-degree rotation of the system and changes in the intensity of the X-ray beam while

passing through different parts of an object, which causes maximum and minimum X-ray intensities. Thus, the obtained tissue density values would be invalid. Variable results in studies may be obtained by applying variable beam intensities. Considering the importance of this factor, we used different acquisition parameters to evaluate the importance of the effect of intensity of X-ray beam on tissue density. In our study, despite the changes in the values, no significant difference was shown between the various image acquisition parameters of CBCT systems and all values were different from the CT numbers. Parsa et al, [23] found a significant difference between CT and CBCT values and showed changes in CBCT values with changes in acquisition parameters. Interestingly, different systems showed different results in response to such changes. Gray values increased with increase in size of FOV in Accuitomo system but this increase was obtained with an increase in volume in NewTom system. This discrepancy between the behaviors of the two systems could be attributed to the variability in reconstruction and post-processing methods applied by the two manufacturers. However, one theory suggests that the tissue density of an object is more effective than the beam intensity and characteristics in showing the actual tissue density [13].

To evaluate and interpret the CBCT and CT images, we used only one software which can show the same level of tissue density in both systems, the point which was confirmed by Ghasemi et al [22]. By doing so, we prevented the errors due to the use of multiple software programs. Mah et al, [14] who used 11 types of CBCT systems also used only one software program (On Demand 3D) to match the observing conditions and ROI in all sections. This fact is important in density assessment studies and can affect the results. Because of the variable geometric characteristics of different systems, the density values and the selected ROI are variable in different software programs provided by the systems. Katsumata et al, [21] emphasized that the selected ROI should be the same in all sections with at least 3% error. In their study, CT images were also examined by the same software program to achieve the same situation in all conditions. Nevertheless, Mah et al, [14] believed that human error is inevitable in selecting the ROI. However, no specific method for precise selection of an area in different conditions has been suggested in studies except in a study by Naitoh et al, [16] who emphasized on selection of equal points via observation.

By choosing three different points in an object, we wanted to evaluate the effect of object location in the FOV on tissue density. Legravere et al, [20] did not report any significant difference in different locations in the tube field in their study, which was in contrast to the results of Oliveira et al, [24] who noticed that the correlation between the object density and CT number in CBCT systems was not uniform through the dental arch. We found no significant difference between different locations in the diversity between the voxel values and HUs.

Some studies have emphasized on the inefficacy of CBCT for density evaluation [3,25]. Hua et al, [3] found that some artifacts and scatter radiation are responsible for inefficacy of CBCT for density assessment, which are inevitable because of the design of CBCT systems and their detectors. Considering the inefficacy of CBCT for density evaluation, the X-ray beam heterogeneity in CBCT can affect HU values, and lead to absence of a clear relationship between voxel value in CBCT and bone mineral density provided by dual X-ray absorptiometry. The artifacts such as beam hardening or heel effect can decrease the validity of these values [25]. Several studies mentioned the difference between the CBCT values and the CT values and in most cases, the reported CBCT values were higher than the CT values [7,9,11,26]. Parsa et al, [23] mentioned higher gray value in their study

and believed that it may be due to the increased noise level, scattering and artefacts specific to the scanning technology. Scarf and Farman [17] proposed that although a sort of association was seen between the provided HUs by CT and voxel value in CBCT, the variability in measurements by CBCT was higher than that by CT. They believed that it was because of the image acquisition method in CBCT. However, Legraver et al, [20] found a linear relationship in R^2 (coefficient of relationship between two variables) between the values in CBCT and CT, and indicated that the CBCT values were generally higher. In our study, the provided values by CBCT were higher than the CT values in one of the systems (NewTom VG 3D), which is similar to the results of Legrave et al, [20] who used the same system for the same purpose. According to this point of view, the difference between the values in our study can be the result of different levels of energy in the three systems; because the systems with a lower power result in lower intensity of X-ray beam and subsequently less tissue penetration depth. In order to create parallel conditions between the experimental phases and the clinical setting, the suitable acquisition parameters for each system were determined by an expert operator. Thus, the levels of kVp and mAs were specific and different in the three systems. Haristory et al, [13] studied the effect of different exposure parameters on the voxel value of CBCT and found a strong relationship between CBCT and CT using R^2 value. However, because of different results in CBCT, they suggested that the use of calibration phantom is necessary before imaging to ensure accurate bone density values. Despite the afore-mentioned results, some studies showed inefficacy of this system in providing accurate values of bone density and found a linear relationship [3,16,19]; thus, a high correlation between the results of CBCT and CT was achieved. A study confirming the optimal efficacy of CBCT systems to estimate bone density introduced a conversion coefficient [14]. Nomura et al, [19] reported a relationship between two systems in evaluating bone mineral density and voxel value, but because of the non-linear regression obtained in their study, further studies were suggested. However, a linear relationship and high correlation coefficient between these values have been shown in several studies [14,16,21,27]. By applying the attenuation coefficient in an equation, Mah et al, [14] obtained the HU values of tested materials from the voxel values with only a small difference from the actual HU values. It seems that different methodologies and variability in statistical analyses lead to such disagreements. Considering all the above, we can say that our methodology, which is one reason for the uniqueness of this study, affected the results, and our results do not completely reflect the efficacy of the systems tested. As recently stated by Pauwels et al, [28] it is logical to postulate that although attempts have been made to correct the gray level variability, quantitative use of values provided by CBCT should be generally avoided at this time.

CONCLUSION

According to the results, the CBCT systems were not able to show the accurate value of tissue density and the factors such as type of tissue (hard, soft, water, air), thickness (full against half), image acquisition conditions (high settings against low settings) and object location (middle, peripheral and intermediate) did not affect density evaluation by CBCT systems.

REFERENCES

1- Valiyaparambil JV, Yamany I, Ortiz D, Shafer DM, Pendrys D, Freilich M, et al. Bone quality evaluation: comparison of cone beam computed tomography and subjective surgical assessment. Int J Oral Maxillofac Implants. 2012 Sep-Oct;27(5):1271-7.

2- Song YD, Jun SH, Kwon JJ. Correlations between

bone qualities evaluated by cone beam computerized tomography and implant primary stability. Int J Oral Maxillofac Implants. 2009 Jan-Feb;24(1):59-64.
3- Hua Y, Nackaerts O, Duyck J, Maes F, Jacobs R. Bone quality assessment based on cone beam computed tomography imaging. Clin Oral Implants Res. 2009 Aug;20(8):767-71.
4- Shahlaie M, Gantes B, Schulz E, Riggs M, Crigger M. Bone density assessment of dental implant sites: 1. Quantitative computed tomography. Int J Oral Maxillofac Implants. 2003 Mar-Apr;18(2):224-31.
5- Johansson P, Strid KG. Assessment of bone quality from cutting resistance during implant surgery. Int J Oral Maxillofac implants 1994 Sep-Oct; 9:279-88.
6- Turkyilmaz I, Tozum TF, Tumer C. Bone density assessment of oral implant sites using computerized tomography. J Oral Rehabil. 2007 Apr;34(4):267-72.
7- Aranyarachkul P, Caruso J, Gantes B, Schulz E, Riggs M, Dus I, et al. Bone density assessment of dental implant sites: 2. Quantitative cone beam computerized tomography. Int J Oral Maxillofac Implants. 2005 May-Jun;20(3):416-24.
8- Lekholm U, Zarb G. Patient selection and preparation. In: Branemark PI, Zarb GA, Albrektsson T (eds.). Tissue-integrated prostheses: osseointegration in clinical density. Chicago, Quintessence,1985:199-209.
9- Sarkis A, Noujeim M, Nummikoski P. Bone density measurements in cone-beam computed tomography. Oral Surg. Oral Med. Oral Pathol. 2007 Feb 28;103(2):e53.
10- Scarf WC, Farman AG, Sukovic P. Clinical Applications of Cone-Beam Computed Tomography in Dental Practice. J Can Dent Assoc. 2006 Feb;72(1):75-80.
11- Loubele M, Maes F, Schutyser F, Marchal G, Jacobs R, Suetens P. Assessment of bone segmentation quality of cone beam CT versus multislice spiral CT: a pilot study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2006 Aug;102(2):225-34.
12- Prins R, Dauer LT, Colosi DC, Quinn B, Kleiman NJ, Bohle GC, et al. Significant reduction in dental cone beam computed tomography (CBCT) eye dose through the use of leaded glasses. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2011 Oct;112(4):502-7.
13- Haristory RA, Valiyaparalmbi GV, Mallva SM. Correlation of CBCT gray scale values with bone densities. Oral Surg Oral Med Oral Pathol Oral Radiol Oral Endod 2009 Apr;107(4):e28.
14- Mah P, Reeves TE, McDavid WD. Deriving Hounsfield units using gray levels in cone beam computed tomography. Dentomaxillofac Radiol. 2010 Sep;39(6):323-35.
15- Yamashina A, Tanimoto K, Sutthiprapaporn P, Hayakawa Y. The reliability of computed tomography (CT) values and dimensional measurements of the oropharyngeal region using cone beam CT: comparison with multidetector CT. Dentomaxillofac Radiol. 2008 Jul;37(5):245-51.
16- Naitoh M, Hirukawa A, Katsumata A, Ariji E. Evaluation of voxel values in mandibular cancellous bone: relationship between cone-beam computed tomography and multislice helical computed tomography. Clin Oral Implants Res. 2009 May;20(5):503-6.
17- Scarfe WC, Farman AG. Interpreting CBCT Images for implant assessment: Part 1-Pitfalls in image interpretation. Australas Dent Pract. 2010 July-August; 20:106-14.
18- Shintaku WH, Venturin JS, Azevedo B, Noujeim M. Application of cone beam computed tomography in fractures of the maxillofacial complex. Dent Traumatol. 2009 Aug;25(4):358-66.
19- 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 May;21(5):558-62.
20- Lagravère MO, Carey J, Ben-Zvi M, Packota GV, Major PW. Effect of object location on the density measurement and Hounsfield conversion in a New Tom 3G cone beam computer tomography unit. Dentomaxillofac Radiol. 2008 Sep;37(6):305-8.
21- Katsumata A, Hirukawa A, Okumura S, Naitoh M, Fujishita M, Ariji E, et al. Relationship between

density variability and imaging volume size in cone beam computerized tomographic scanning of the maxillofacial region: an in vitro study. Oral Surg Oral Med Oral Pathol Oral Radiol Oral Endod 2009 Mar;107(3):420-5.

22- Ghasemi M, Sadat Mansouri S, Varshowsaz M, Issabiglou V. Evaluation of Planmeca Romexis and E-film software in assessing the trabecular bone density at dental implant sites using cone beam computerized tomography (CBCT). J Res Dent Sci 2010 Winter;6(4):38-45.

23- Parsa A, Ibrahim N, Hassan B, Motroni A, van der Stelt P, Wismeijer D. Influence of cone beam CT scanning parameters on grey value measurements at implant site. Dentomaxillofac Radiol. 2013;42(3): 79884780.

24- Oliveira ML, Tosoni GM, Lindsey DH, Mendoza K, Tetradis S, Mallya SM. Influence of anatomical location on CT numbers in cone beam computed tomography. Oral Surg Oral Med Oral Pathol Oral Radiol. 2013 Apr;115(4):558-64.

25- Katsumata A, Hirukawa A, Okumura S, Naitoh M, Fujishita M, Ariji E, et al. Effects of image artifacts on gray-value density in limited-volume cone-beam computerized tomography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007 Dec;104(6):829-36.

26- Chindasombatjaroen J, Kakimoto N, Shimamoto H, Murakami S, Furukawa S. Correlation Between Pixel Values in a Cone-Beam Computed Tomographic Scanner and the Computed Tomographic Values in a Multidetector Row Computed Tomographic Scanner. J Comput Assist Tomogr. 2011 Sep-Oct;35(5):662-5.

27- Nomura Y, Watanabe H, Kamiyama Y, Kurabayashi T. Physical quality evaluation of voxel values in cone-beam computed tomography for dental use: three-dimensional fluctuation of voxel values in uniform materials placed inside a phantom. Oral Radiol. 2014 Sep;30(3):226-35.

28- Pauwels R, Jacobs R, Singer SR, Mupparapu M. CBCT-based bone quality assessment: are Hounsfield units applicable? Dentomaxillofac Radiol. 2015;44(1):20140238.