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ORIGINAL ARTICLE

Reliability and accuracy of cone-beam computed tomography voxel density and linear distance measurement at different voxel sizes: A study on sheep head cadaver

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KEYWORDS
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Abstract *Background/purpose:* The reliability and accuracy of linear distance and voxel density (VD) measurements are very important in dentistry. The purpose of this study was to assess the accuracy and reliability of linear distances and VD measurements of cone-beam computed tomography (CBCT) at different voxel sizes.

Materials and methods: Eighteen-millimeter linears of size 40 gutta-percha were prepared in fresh sheep head. The head was scanned using CBCT with 0.25, 0.3, and 0.40 voxel sizes. Standard linear distances of gutta-percha were measured in panoramic CBCT images at 0.25, 0.3, and 0.4 voxel sizes. VD measurements were made separately on spongeous bone of palatal surfaces of the roots of teeth 4, 5, and 6 of maxilla and on cortical bone of teeth 4, 5, and 6 regions of the left and right hemimandibles through cross-sectional imaging.

Results: We found that linear distance measurements on panoramic image of CBCT were slightly lower than physical measurements. A significant difference was not found for the gutta-percha linear distances and cortical VD measurements at different voxel sizes ($P \geq 0.05$). The correlation between measurements of VD at different voxels in cortical bone was greater than 0.85 ($P = 0.000$).

Conclusion: Linear distance measurements on the sheep head cadaver of 0.25, 0.3, and 0.4 voxel sizes were similar and reliable when compared with physical measurements. In minimizing radiation exposure, VD measurement of cortical bone at 0.4 voxel-based CBCT could be used to estimate cortical bone density. However, studies should be performed on the human head cadaver.

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Introduction

Radiographic evaluation prior to clinical intervention is very important in dentistry. In implant planning, measurement of the distance between alveolar crest ridges and mandibular canals, alveolar crest ridges and the maxillary sinus, and the nasal cavity and incisive canal is very important, and to determine the linear distance of the canal in endodontic treatment and the linear distance of the post in prosthetic treatment.[1,2]

Cone-beam computed tomography (CBCT), an imaging method used in the past 10 years, is much less expensive than conventional computed tomography (CT) and has been applied in many fields of dentistry, such as implantology, dentomaxillofacial surgery, image-guided surgical procedures, orthodontics, periodontics, endodontics, and prosthetics. CBCT offers three-dimensional evaluation using a panoramic view, sagittal and axial sections, and cross section. In addition, CBCT offers important information about the quantity and the quality of the evaluated area.[3–5]

The radiation dose received by the patient depends on the milliamperage (mA), tube kilovoltage (kV), size of the field of view (FOV), mode full or partial rotation, and voxel size. As voxel size decreases, the radiation received by the patient increases. By contrast, as voxel size increases, the image resolution decreases. The sensitivity for detecting small changes in the image decreases with the loss of resolution. In addition, the probability of image artifacts occurring increases as the dose decreases.[6,7] The goal is to achieve the best possible image quality with the lowest possible radiation dose. CBCT imaging using 0.125 mm isotropic voxel resolution has a higher solubility compared with conventional CT.[8] Previously published studies have assessed CBCT linear distance measurement at different voxel values.[9–11] Voxel density (VD) is used to transform the radiodensity of the relevant region into numerical values.[3] Supporting studies have indicated that VD measurements can be used for evaluation of bone prior to implant treatment.[12–15] There are a few studies about VD measurement between CBCT and conventional CT and among CBCT devices of different brands.[16,17] However, there is no study reporting that cortical and spongeous VD measurements were evaluated at different voxel sizes.

This study has two aims. We investigated the reliability and accuracy of linear distance measurements in panoramic images of CBCT at different voxels. The second aim was to determine whether there was any difference and correlation between VD measurements of cross-sectional CBCT images at different voxel sizes in cortical and spongeous jaw bones.

Materials and methods

A fresh sheep head was used for the study. The left and right hemimandibles were separated from each other and glued to the head. Next, 18-mm linear distances of size 40 gutta-percha were prepared. Six gutta-percha to the buccal sides of the left and right maxilla, four gutta-percha to the lingual sides of the left and right mandibles, and two gutta-percha to the buccal sides of the left and right mandibles—in total, 12 gutta-percha were placed. Moreover, researchers noted that gutta-perchas were not curved.

Prior to imaging in the CBCT scanner, the mandibles were positioned with the mandibular plane horizontal and the midsagittal plane vertical, in accordance with the manufacturer's instructions for performing the scans in a clinical setting. The CBCT images were obtained with the i-CAT Classic 3D Dental Imaging System (Imaging Sciences International, Hatfield, PA, USA). CBCT filming was done three times at three voxel resolutions: 0.25 mm voxel 5 mA s, 7 seconds, 12.6 cm FOV, 120 kV, 0.3 mm voxel 5 mA s, 4 seconds, 12.6 cm FOV, 120 kV, and 0.4 mm voxel 5 mA s, 4 seconds, 12.6 cm FOV, 120 kV.

Image measurements

Gutta-percha linear distances measurements of mandible and maxilla were performed separately on two-dimensional panoramic images. Linear distances of gutta-perchas were measured using panoramic images with the "measurement" tool (Figure 1). Twelve gutta-percha linear distances in the panoramic image were measured using different voxel values.

VD measurements were made separately in spongeous and cortical bones. Cortical bone measurements were performed on teeth 4, 5, and 6 regions on the left and right hemimandibles through cross-sectional imaging. Spongeous bone measurements were performed on the left and right maxilla on the palatal surfaces of the roots of teeth 4, 5, and 6 regions using cross-sectional imaging (Figure 2). The measurements were performed by two blinded independent observers 15 days apart. One observer was an oral radiologist.

Statistical analysis

Agreement between observers was assessed by calculating Pearson correlation coefficients with a level of significance set at $P < 0.05$ Measurements of the gutta-percha linear

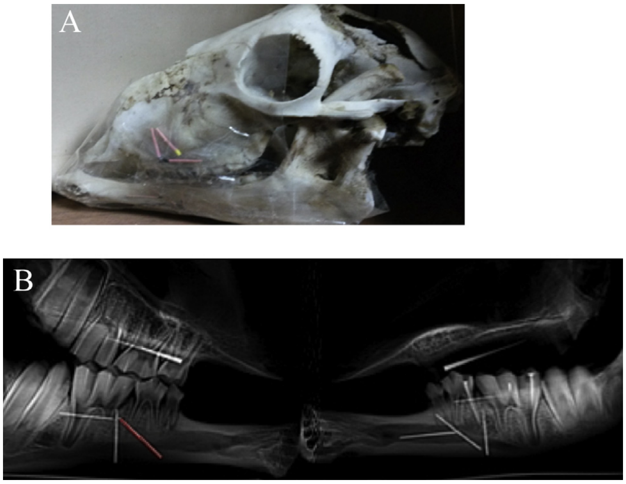

Figure 1 (A) Preparation of sheep head cadaver. (B) Measurement of gutta-percha placed on to mandible on panoramic image of cone-beam computed tomography (CBCT).

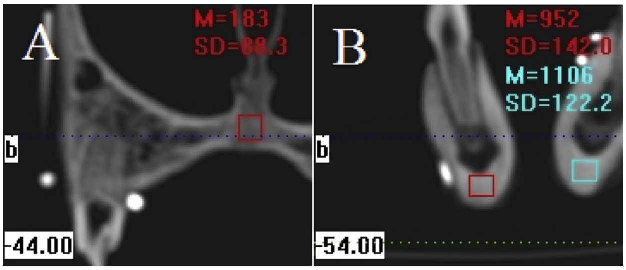

Figure 2 (A) Spongeous bone VD measurement on the palatal surfaces of the roots of teeth 4, 5, and 6 regions on the maxilla using cross-sectional imaging. (B) Cortical bone VD measurement on teeth 4, 5, and 6 regions on the mandibles using cross-sectional imaging. M = mean; SD = standard deviation; VD = voxel density.

Table 1 Interobserver correlations.

	0.25 voxel	0.3 voxel	0.4 voxel
Length measurement	0.886*	0.997*	0.985*
VD measurement	0.989*	0.963*	0.964*

*P < 0.01.
VD = voxel density.

Table 2 Intraobserver correlations.

	0.25 voxel	0.3 voxel	0.4 voxel
Length measurement (observer 1)	0.969*	0.979*	0.986*
VD measurement (observer 1)	0.996*	0.986*	0.979*
Length measurement (observer 2)	0.955*	0.975*	0.974*
VD measurement (observer 2)	0.981*	0.988*	0.982*

*P < 0.01.
VD = voxel density.

distance calculated from the CBCT sectional images taken with different voxels were compared with their physical measurements. Repeated analyses of paired *t* tests with a 95% confidence level were used to evaluate the results. Repeated-measures analysis of variance was used to compare the linear distance measurement, cortical VD measurement, and spongeous VD measurement at different voxel sizes. The correlation between the VD measurements was evaluated using Pearson's correlation coefficient.

Results

Inter- and intraobserver measurements of the gutta-percha linear distance and VD taken from the panoramic and cross-section CBCT images at different voxels are shown in Tables 1 and 2. Inter- and intraobserver correlation coefficients were found to be nearly perfect ($P < 0.05$). The interobserver correlation value for the gutta-percha linear distances and VD measurements were 0.997 and 0.989 at 0.3 and 0.25 voxel, respectively. Intraobserver 1 and intraobserver 2 correlation values for the gutta-percha linear distances were 0.986 and 0.975 at 0.40 and 0.3 voxel, respectively. Intraobserver 1 and intraobserver 2 correlation values for the VD measurement were 0.996 and 0.988 at 0.25 and 0.3 voxels, respectively.

We found that there were no differences between physical measurements and linear distances measurements of panoramic images at 0.25, 0.3, and 0.4 voxel sizes ($P = 0.208$, $P = 0.107$, and $P = 0.228$, respectively). The difference between physical and CBCT gutta-percha measurements at different voxel sizes was 0.2–0.3 mm. A significant difference was not found for the gutta-percha linear distances and cortical VD measurements at different voxel sizes. But a significant difference was found for the spongeous VD measurement ($P < 0.05$) (Table 3).

The average VD values of cortical and spongeous bones on CBCT cross-sectional images taken at different voxel sizes are shown in Table 4. Although a correlation was found between VD measurement of cortical bone at different voxels ($P < 0.05$), no correlation was found between VD measures of spongeous bone at different voxels ($P \geq 0.05$) (Table 4).

Discussion

We used gutta-percha because it is radiopaque and does not cause metallic artifacts.[3,18] However, previous studies have used metal surface models[19] or anatomical points[11] for linear distances measurement comparisons. Although CBCT uses a lower radiation dose than conventional CT, its application is still limited because its radiation dose is higher than that of conventional cephalometric and panoramic radiographs.[3,4] Clinicians should subject patients to the lowest possible radiation dose, according to the "As Low As Reasonably Achievable" principle.[6] Our study had two goals. The first was to determine the accuracy of linear distance measurements made with CBCT. Linear distance measurements are made using CBCT in endodontic treatment; implant planning; and evaluation of distances

Table 3 Mean and standard deviation (SD) of length measurements of gutta-percha and VD measurement using CBCT images at different voxel sizes.

	n	0.25 voxel Mean ± SD	0.3 voxel Mean ± SD	0.4 voxel Mean ± SD	P
Length measurement (mm)	12	17.77 ± 0.59	17.72 ± 0.54	17.70 ± 0.81	0.251
VD measurement (cortical)	30	1043.91 ± 120.597	1094.13 ± 125.150	1061.50 ± 111.063	0.238
VD measurement (spongeous)	21	97.33 ± 32.695	136.33 ± 31.479	121.30 ± 26.664	0.000

CBCT = cone-beam computed tomography; VD = voxel density.

Table 4 Correlation among VD values of CBCT taken with different voxels.

		0.3 voxel Cortical bone	0.25 voxel Cortical bone	0.4 voxel Cortical bone	0.3 voxel Spongeous bone	0.25 voxel Spongeous bone	0.4 voxel Spongeous bone
0.3 voxel	Pearson correlation	1	0.892**	0.854**	−0.189	0.152	−0.051
Cortical bone	Sig. (2-tailed)		0.000	0.000	0.412	0.511	0.831
	n	32	32	30	21	21	20
0.25 voxel	Pearson correlation	0.892**	1	0.943**	0.078	0.400	−0.063
Cortical bone	Sig. (2-tailed)	0.000		0.000	0.736	0.072	0.792
	n	32	32	30	21	21	20
0.4 voxel	Pearson correlation	0.854**	0.943**	1	0.141	0.511*	−0.142
Cortical bone	Sig. (2-tailed)	0.000	0.000		0.552	0.021	0.562
	n	30	30	30	20	20	19
0.3 voxel	Pearson correlation	−0.189	0.078	0.141	1	0.079	0.273
Spongeous bone	Sig. (2-tailed)	0.412	0.736	0.552		0.733	0.245
	n	21	21	20	21	21	20
0.25 voxel	Pearson correlation	0.152	0.400	0.511*	0.079	1	−0.304
Spongeous bone	Sig. (2-tailed)	0.511	0.072	0.021	0.733		0.192
	n	21	21	20	21	21	20
0.4 voxel	Pearson correlation	−0.051	−0.063	−0.142	0.273	−0.304	1
Spongeous bone	Sig. (2-tailed)	0.831	0.792	0.562	0.245	0.192	
	n	20	20	19	20	20	20

**$P < 0.01$; *$P < 0.05$.
CBCT = cone-beam computed tomography; sig. = significant; VD = voxel density.

between alveolar ridge edges and the mandibular canal, alveolar ridge edges and the maxillary sinus, and the nasal cavity and incisive canal.[1,2] In addition, we sought to determine whether there was any difference between physical and CBCT measurements of linear distances at different voxels, because patients are exposed to less radiation in CBCT at 0.4 than at 0.25 voxels.[7,20] Because whole gutta-percha cannot be seen on section images, we used only panoramic images to determine the accuracy of linear measurements. The second goal was to evaluate VD measurements in CBCT taken at different voxel sizes on cross-sectional images of cortical and spongeous bones. Previous studies have reported that VD measurements can be used for pretreatment bone evaluation and for the diagnosis of osteoporotic bone disease.[12–15] The results of our study can be useful for further human cadaver studies.

Our study showed intraobserver reliability in the evaluation of linear and VD measurement for both examiners, with the mean correlation for all groups above 0.95 ($P < 0.01$). Previous studies have reported either similar or slightly higher intraobserver correlation values (95% CI, 0.985–0.993).[19,21] Interobserver correlation values in our study were found to be higher than 0.95 at all points except the linear measurement of 0.25-voxel panoramic views.

This study revealed that there was no difference between physical measurements and linear distance measurements of panoramic images at different voxel sizes ($P \geq 0.05$). We found that CBCT linear measurements were lower than physical measurements. Other studies have reported similar results.[11,22,23] In our study, there were no differences in linear measurements at different voxel sizes ($P \geq 0.05$). Many studies support the conclusion that CBCT provides reliable linear measurement.[11,22,24,25] Some studies have reported no difference in the accuracy of linear measurements at different voxel sizes, and these studies do not support the results of our study.[11,19]

CBCT is used in dentistry for conventional purposes such as three-dimensional evaluation of pathology, orthodontic treatment, and periodontal treatment, and it is also a preferred modality for evaluation of bone health prior to implantation procedures and early detection of bone diseases such as osteoporosis.[3] Many reports have concluded that bone health can be assessed by VD.[12–15] There has been no correlation found in VD values between CBCT and conventional CT and among CBCT devices of different brands.[16,17] If the lack of correlation among VD values of different brand CBCT device can be resolved and supported by future research, we believe that VD can be used as a standard, especially in preimplant assessments of bone. In order to minimize radiation exposure, CBCT should be used with larger voxel sizes. Therefore, we evaluated the correlation among different voxels in our study.

We performed VD measurements obtained from CBCT cross-sectional imaging separately in cortical and spongeous bones Anatomic landmarks such as fossa, fovea foramen, and nasal cavity cannot be seen on panoramic radiographs because of their two-dimensional properties. Cross-sectional CBCT images show a thickness of 2–3 mm, and this situation demonstrates the significant advantage of CT for panoramic images. Therefore, anatomic landmarks do not affect the measurement of CT values. This study revealed that there were no differences in cortical VD measurements at different voxel sizes. However, there were differences among spongeous VD measurements. Although the correlation among VD measurements at different voxel sizes in cortical bone was higher than 0.85 ($P < 0.01$), no correlation was found among VD measurements at different voxel sizes in spongeous bone ($P \geq 0.05$).

Taylor et al[26] have examined the ability of CT to assess the relative difference of degree of bone mineralization using gray level histogram parameters of CBCT images at different voxel sizes in a VDman mandible. They reported that values of the percentage difference of gray level parameters between alveoler bone and basal vortical bone regions were not affected at the range of clinical voxel sizes (200 mm, 300 mm, and 400 mm). We do not know why different results were found on cortical and spongeous VD measurements. As known, cortical bones are far denser than spongeous bones and hence, little photon energy reaches the film. The VD scale is a linear transformation of the amount of absorbed X-rays by voxel of the relevant region into numerical values. In our opinion, a small voxel such as 0.25 mm can carry less photon energy compared with larger voxel sizes. This situation is not important for VD measurement of cortical bone because only a few photons reach the film. However, because receiving photons can exceed the capacity of voxel, this situation is important for spongeous bone because most photons reach the film. Marquezan et al[15] have reported that the bone mineral density of the region of interest for cortical bone influenced the insertion torque and the pullout test of miniscrews. However, the bone mineral density of spongeous bone presented weak and not statistically significant correlations with primary stability. Moreover, Marquezan et al's[15] study supports our result. To our knowledge, there have been no other published studies evaluating the correlation of VD at different voxels in cortical and spongeous bones. Pauwels et al[25] compared the VD values of multislice CT (MSCT) with those of CBCT images at different voxel sizes in 13 materials of different densities, such as aluminum and hydroxyapatite. The results showed a correlation greater than 0.98 between VD values of MSCT and those of nine different CBCT devices, including the i-CAT device used in our study, at different voxels.[25] These findings support the results of our study, as does the high correlation among VD values of high-density materials, such as the cortical bone examined in our study. Parsa et al[27] performed VD measurements in spongeous bone using CBCT, MSCT, and micro-CT (considered a gold standard reference) and found a correlation of 0.82 between CBCT and micro-CT.

This study had several limitations. There was no standard VD value range among CBCT devices of different brands and conventional CT.[3,18] Regarding CBCT, the value of a VD of a bone depends on the position. This indicates that the X-ray attenuation of CBCT acquisition systems currently produce different VD values for similar bones in different areas.[16] Additionally, the geometry and microstructure of the sheep head cadaver is different from that of humans. However, this study was performed with only the CBCT device brand (I-CAT; Imaging Sciences International, Hatfield, PA, USA) and positioned on the sheep head cadaver.

Linear distance measurements on the sheep head cadaver of 0.25, 0.3, and 0.4 voxel sizes were similar and reliable when compared with physical measurements. Although a correlation and no difference were found among VD measurements in cortical bone, no correlation or difference was found among VD measurements in spongeous bone at different voxels. Because CBCT at 0.4 voxel requires less radiation than at other voxel levels, it is recommended that 0.4 voxel be used in VD evaluations of cortical bone. As the geometry and microstructure of the sheep head cadaver is different from that of humans, studies should be performed on the human head cadaver for diagnosis and treatment in dentistry. In particular, findings related to VD evaluation of cortical bone would inspire further studies.

Conflicts of interest

The authors declare no conflicts of interest relevant to this article.

References

1. Woolhiser GA, Brand JW, Hoen MM, Geist JR, Pikula AA. Accuracy of film-based, digital, and enhanced digital images for endodontic linear determination. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2005;99:499—504.
2. Vazquez L, Nizamaldin Y, Combescure C, et al. Accuracy of vertical height measurements on direct digital panoramic radiographs using posterior mandibular implants and metal balls as reference objects. *Dentomaxillofac Radiol* 2013;42:1—9.
3. De Vos W, Casselman J, Swennen GR. 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—25.
4. Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis AB. A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary Results. *Euro Radiol* 1998;8:1558—64.
5. Mischkowski RA, Pulsfort R, Ritter L, et al. Geometric accuracy of a newly developed cone-beam device for maxillofacial imaging. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2007;104:551—9.
6. White SC, Pharaoh MJ. *Oral Radiology, Principles and Interpretation*, 5th ed. St. Louis, MO: Mosby Elsevier, 2004:47—68.
7. Sur J, Seki K, Koizumi H, Nakajima K, Okano T. Effects of tube current on cone-beam computerized tomography image quality for presurgical implant planning in vitro. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2010;110:29—33.
8. Boeddinghaus R, Whyte A. Current concepts in maxillofacial imaging. *Eur J Radiol* 2008;66:396—418.
9. Torres MG, Campos PS, Segundo NP, Navarro M, Crusoé-Rebello I. Accuracy of linear measurements in cone beam computed tomography with different voxel sizes. *Implant Dent* 2012;21:150—5.
10. Hu KS, Choi DY, Lee WJ, Kim HJ, Jung UW, Kim S. Reliability of two different presurgical preparation methods for implant dentistry based on panoramic radiography and cone-beam computed tomography in cadavers. *J Periodontal Implant Sci* 2012;42:39—44.
11. Fernandes TM, Adamczyk J, Poleti ML, Henriques JF, Friedland B, Garib DG. Comparison between 3D volumetric rendering and multiplanar slices on the reliability of linear measurements on CBCT images: an in vitro study. *J Appl Oral Sci* 2015;23:56—63.
12. Hohlweg-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—4.
13. Reeves T, Mah P, McDavid W. Deriving Hounsfield units using grey levels in cone beam CT: a clinical application. *Dentomaxillofac Radiol* 2012;41:500—8.

14. Mah P, Reeves TE, McDavid WD. Deriving Hounsfield units using grey levels in cone beam computed tomography. *Dentomaxillofac Radiol* 2010;39:323—35.
15. Marquezan M, Lau TC, Mattos CT, et al. Bone mineral density. *Angle Orthod* 2012;82:62—6.
16. Swennen GRJ, Schutyser F. Three-dimensional cephalometry: spiral multi-slice vs cone-beam computed tomography. *Am J Orthod Dentofacial Orthop* 2006;130:410—8.
17. Kotsumata A, Hirukawa A, Okumura S, 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;104:829—36.
18. Howerton WB, Mora MA. Advancements in digital imaging: what is new and on the horizon? *J Am Dent Assoc* 2008;139:20—4.
19. Damstra J, Fourie Z, Huddleston Slater JJ, Ren Y. Accuracy of linear measurements from cone-beam computed tomography-derived surface models of different voxel sizes. *Am J Orthod Dentofacial Orthop* 2010;137:161—6.
20. Grünheid T, Kolbeck Schieck JR, Pliska BT, Ahmad M, Larson BE. Dosimetry of a cone-beam computed tomography machine compared with a digital x-ray machine in orthodontic imaging. *Am J Orthod Dentofacial Orthop* 2012;141:436—43.
21. Tomasi C, Bressan E, Corazza B, Mazzoleni S, Stellini E, Lith A. Reliability and reproducibility of linear mandible measurements with the use of a cone-beam computed tomography and two object inclinations. *Dentomaxillofac Radiol* 2011;40:244—50.
22. Lascala CA, Panella J, Marques MM. Analysis of the accuracy of linear measurements obtained by cone beam computed tomography CBCT-NewTom. *Dentomaxillofac Radiol* 2004;33:291—4.
23. Baumgaertel S, Palomo JM, Palomo L, Hans MG. Reliability and accuracy of cone-beam computed tomography dental measurements. *Am J Orthod Dentofacial Orthop* 2009;136:19—25.
24. Stratemann SA, Huang JC, Maki K, Miller AJ, Hatcher DC. Comparison of cone beam computed tomography imaging with physical measures. *Dentomaxillofac Radiol* 2008;37:80—93.
25. Pauwels R, Nackaerts O, Bellaiche N, et al. Variability of dental cone beam CT grey values for density estimations. *Br J Radiol* 2013;86:1—9.
26. Taylor TT, Gans SI, Jones EM, Firestone AR, Johnston WM, Kim DG. Comparison of micro-CT and cone beam CT-based assessments for relative difference of grey level distribution in a human mandible. *Dentomaxillofac Radiol* 2013;42:1—8.
27. Parsa A, Ibrahim N, Hassan B, van der Stelt P, Wismeijer D. Bone quality evaluation at dental implant site using multislice CT, micro-CT, and cone beam CT. *Clin Oral Implants Res* 2015;26:1—7.