Accuracy of linear bone measurements with cone-beam and spiral computed tomography in human mandibles

Guilherme Teixeira Coelho **TERRA***
Jefferson Xavier de **OLIVEIRA****
Carlos Martins **AGRA*****
Antônio Carlos Guedes **PINTO******

Abstract

Introduction: Availability of imaging methods able to accurately reproduce the maxillo-mandibular dimensions is important for diagnosis and safe planning of surgical procedures. **Objective:** The aim of this *in vitro* study was to verify the accuracy of linear measurements in images obtained with a system of spiral and two systems of cone-beam computed tomography (CT). **Methods:** Ten dry human mandibles were subjected to three different CT scans: i-CAT® CBCT, NewTom-3G® CBCT, and Picker® SCT. Measurements in the mandible were taken with a digital caliper and measurements in the images were taken with the ImplantViewer® software. Six regions were measured in each dry mandible, being distributed into two regions in each of the lower first molar (LFM), lower first pre-molar (LFPM), and lower lateral incisor (LLI) sites. **Results**: Similar accuracy was observed among the three images at sites LLI and LFPM. Measurements obtained with the i-CAT CBCT scan at site LFM were shown to be more accurate than those obtained with the other two CT scan systems. **Conclusions**: It can be concluded that the three CTs studied herein showed similar limits of agreement and precision at sites LLI and LFPM, and i-CAT CBCT showed limits of agreement with smaller amplitude and greater accuracy than other examinations performed at site LFM. **Conclusion:** It can be concluded that the three CTs studied herein showed similar limits of agreement and precision at sites LLI and LFPM, and i-CAT CBCT at site LFM showed limits of agreement with lower amplitude and greater accuracy than other examinations performed.

Keywords: Spiral computed tomography. Cone-beam computed tomography. Dental implants. Three-dimensional imaging.

» The authors inform they have no associative, commercial, intellectual property or financial interests representing a conflict of interest in products and companies described in this article.

How to cite this article: Terra GTC, Oliveira JX, Agra CM, Pinto ACG. Accuracy of linear bone measurements with cone-beam and spiral computed tomography in human mandibles. Dental Press Implantol. 2013 Apr-June;7(2):99-106.

Contact address
Guilherme Teixeira Coelho Terra
Universidade Ibirapuera, Departamento de Odontologia - Av Interlagos, 1329.
CEP: 04.661-100 - São Paulo/SP — Brazil
E-mail: drguilhermeterra@yahoo.com.br

Submitted: February 17, 2012
Revised and accepted: March 07, 2013

* Adjunct professor, Ibirapuera University.
** Associate professor, University of São Paulo (USP).
*** Full professor, Ibirapuera University.
**** Full professor, Department of postgraduate course in Dentistry, Ibirapuera University.

Introduction

Computed tomography (CT) provides accurate and real-scale volumetric reconstruction and manipulation of images through software.[1,2,3]

In spiral computed tomography (SCT), sections in the region of interest are transformed into digital images, which are processed and reconstructed into two-dimensional and three-dimensional images. SCT allows reconstruction of images with real proportions, excellent accuracy and resolution because sections with thickness not greater than 0.5 mm can be obtained.[1-4]

In SCT multislice equipment, exposure to radiation is much smaller than in tomographies with a single slice; in addition, the time required for data acquisition is also reduced.[3,5,6]

Cone-beam computed tomography (CBCT), unlike SCT in which data are obtained by slices, is based on the emission of a X-ray conical beam in a single 360° turn around the patient's head, during which the total volume of structures is obtained. After data acquisition, images are volumetrically reconstructed in two and three dimensions by the software. According to the proponents of CBCT, patients examined with this technique receive lower effective radiation doses than those examined with SCT.[2,7,8]

Basically, CT can be divided into two categories, spiral computed tomography (SCT) and cone-beam computed tomography (CBCT).[4] Since both methods are indicated for diagnosis and treatment planning in the Medical and Dental areas, the assessment of measurements obtained with these methods and their comparison with direct measurements taken in human mandibles is justified. Thus, the aim of this *in vitro* study was to assess the accuracy of linear measurements taken by means of images obtained with a system of SCT and two systems of CBCT, comparing the results with direct measurements carried out in ten dry human mandibles.

Material and Methods

Stock teeth and tomography guides were prepared in self-polymerizing acrylic resin. The stock teeth reproduced a removable partial denture or a complete one for each mandible, depending on the presence of dental elements. As an exclusion criterion, it was established that the mandibles could not have teeth in regions corresponding to paired elements. After the teeth were mounted in wax rolls prepared with pink dental wax, the stock teeth corresponding to paired elements were all removed to simulate their absence (Fig 1).

Steel balls were placed in the cervical portion of each edentulous space, and they were used as a reference for measurements in both CT and direct measurements

Figure 1 - Mandible with teeth already mounted.

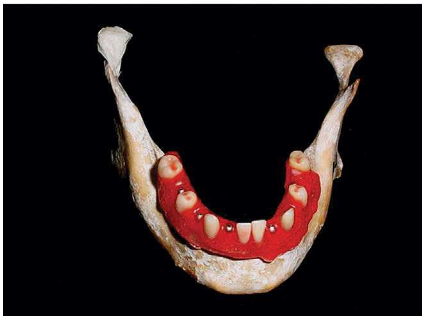

Figure 2 - Steel balls placed in the region of paired elements.

Figure 3 - Acrylised tomographic guides.

in the mandibles. The steel balls were placed in each of the ten mandibles, in the region of the paired elements (46, 44, 42, 32, 34, and 36) (Fig 2).

After the steel balls were placed, the CT guides were acrylised (Fig 3). During the tomography scans, an adhesive tape was used to properly fix the guides (at three points) in the region of the #36/37, 31/32, and 46/47 elements.

The mandibles were submitted to different CT scans: i-CAT® CBCT (Kavo, Imaging Science, Hatfield, PA, USA), NewTom-3G® CBCT (QR Srl, Verona, Italy) and Picker® SCT (Elscint, Haifa, Israel), without inclination of the gantry. For a correct positioning of the mandible in relation to the gantry, the mandibles were supported by a base of pink dental wax in the scans performed with NewTom-3G® CBCT and Picker® SCT (Fig 4). In the i-CAT® CBCT, the base for calibration of the equipment was used (Fig 5). The images were recorded in DICOM standard, converted and manipulated with an image processing software (Implant-Viewer® 2604 - Anne Solutions, São Paulo, Brazil).

Direct measurements were performed by one observer on the mandible with a digital caliper (accuracy: 0.01 mm; Lee Tools, Beijing, China). The following parameters were considered: bone height in the region of each steel ball and distance from the top of the alveolar bone crest to the lower cortical border of the basal bone (Fig 6). These same measurements were repeated by the same observer, but on tomographic images of the mandible which were obtained by means of a computer software (ImplantViewer® 2604, Anne Solutions, São Paulo, Brazil) (Fig 7).

Only one software was used (ImplantViewer 2.604®, Anne Solutions, São Paulo, Brazil) in order to eliminate any possible differences existing between more than one image manipulation software. All measurements were performed twice by one observer, within an interval of seven days.

A linear mean was calculated for all measurements. In each dry mandible, measurements were performed in six regions (right and left regions of three sites): lower first molar (LFM), lower first premolar (LFPM), and lower lateral incisor (LLI) sites. Measurements were taken twice in each region and by the same observer. Ten dry mandibles were used and each measurement protocol was repeated four times, once for each measurement technique: direct measurement with a caliper, and measurements by SCT (Picker) and CBCT (i-CAT® and NewTom-3G®).

Two measurements were performed in two regions of three sites in ten dry human mandibles using four techniques, in a total of 480 measurements. The millimeter (mm) was used as unit of measurement.

In the clinical area, "quantities" (variables), such as blood pressure and bone dimensions, will often be measured in the living body. These variables can be extremely difficult or impossible to measure directly, without adverse effects on the subject of the measure (patients) and, thus, their true values remain unknown.[9,10,11]

Instead, science provides indirect methods of measurement, and when a new method is proposed, we can assess its value only in comparison to other established techniques, and not with the "real" quantity being measured. We cannot be certain that a method gives us a measure that is unequivocally correct, that is the reason why we try to assess the degree of agreement between them.[9,10,11]

What matters is the amount by which the methods "disagree" (lack of precision). We want to know how much the new method differs from the older or the reference ones , so that, if this is not enough to cause problems in clinical interpretation, we can replace the "old" by the "new", or even alternatively use both of them.[9,10,11]

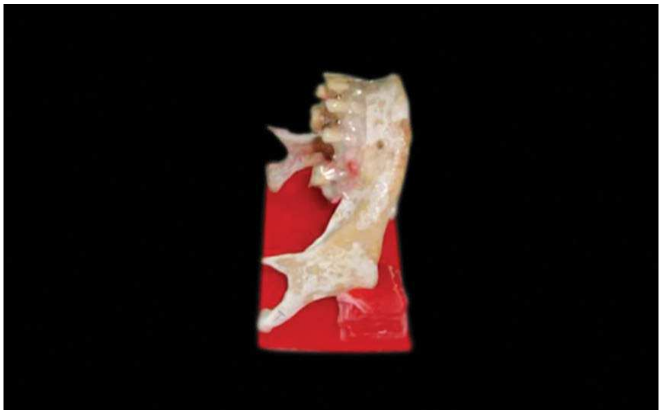

Figure 4 - Mandible placed on the sliding table (for NewTom 3G® and Picker CT Twin Flash).

Figure 5 - Mandible placed on the base for calibration of the equipment (i-CAT®).

Figure 6 - Digital caliper.

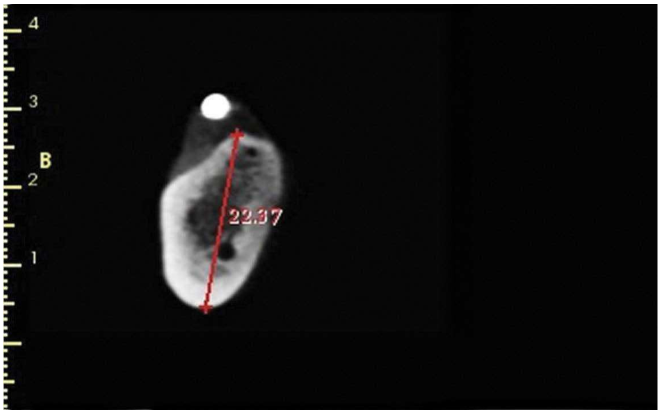

Figure 7 - Measurement taken for the tomographic images .

Limits of agreement of 95% were used for comparison between measurements using the imaging techniques and the direct measurement. The limits of agreement established the parameters within which 95% of the differences observed between the method of image and the reference method can be found in any future measurement within the same experimental conditions. The notion of accuracy between methods is based on the analysis of the amplitude of limits, so that the smaller the amplitude limits the greater the accuracy and the agreement between a given imaging method and the reference method. The key point on whether a particular imaging method, in fact, agrees with or has a greater accuracy than the reference method should be based on the clinical situation in which the method will be applied.

Results

Limits of agreement for the LFM site

Regarding the determinations made with the direct measurement, the estimates for the limits of agreement at 95% are respectively above and below the measurements obtained with SCT (2.75 to -1.08 mm), i-CAT® CBCT (0.40 to -0.90 mm), and NewTom-3G® CBCT (0.50 to -1.40 mm) (Fig 8).

Figure 8 (site LFM) reveals that the limits of agreement at 95% are larger (lower accuracy) for SCT whereas it is shorter (higher accuracy) for the i-CAT® CBCT. Furthermore, it shows the bias (the distance indicated by the vertical arrows) between the mean differences of the values determined with each tomographic technique and the direct measurement.

Limits of agreement for the LFPM site

Regarding the determinations made with the direct measurement, the estimates for the limits of agreement at 95% are respectively above and below measurements obtained with SCT (1.73 to -1.55 mm), i-CAT® CBCT (0.62 to -1.99 mm), and NewTom-3G® CBCT (0.63 to -2.59 mm) (Fig 9).

Figure 9 shows that at site LFPM the limits of agreement for the three image techniques are very close. The limits of agreement for the spiral and NewTom-3G® CBCT techniques are similar and slightly larger than those for the i-CAT® technique. Furthermore, it shows the bias (the distance indicated by the vertical arrows) between the mean differences of the values determined with each tomographic technique and the direct measurement.

Limits of agreement for the LLI site

Regarding the determinations made with the direct measurement, the estimates for the limits of agreement at 95% are respectively above and below measurements obtained with SCT (0.70 to -1.24 mm), i-CAT® CBCT (0.88 to -1.64 mm), and NewTom-3G® CBCT (0.59 to -2.16 mm) (Fig 10).

Figure 10 shows that at site LLI, the limits of agreement at 95% for SCT are lower than those for i-CAT® and NewTom-3G® CBCT, even though they are similar. Furthermore, it shows the bias (the distance indicated by the vertical arrows) between the mean differences of the values determined with each tomographic technique and the direct measurement.

Discussion

SCT presents some advantages since it is an exam with excellent accuracy and good resolution, which allows visualization of soft tissues and assessment of hard tissues in three planes.[1,2,5,6,8]

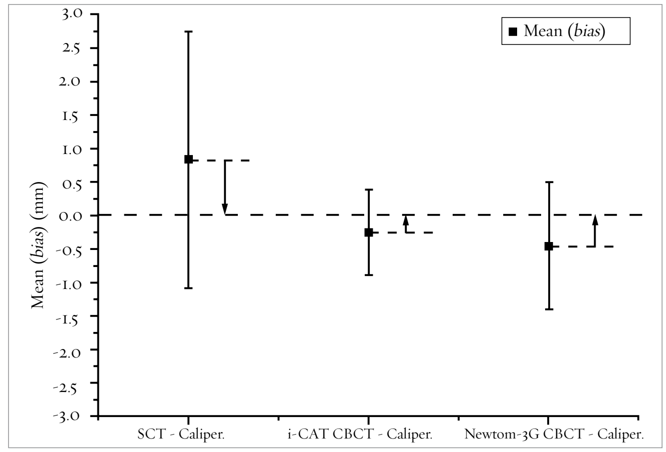

Figure 8 - Limits of agreement for the methods of image compared with direct measurement of LFM.

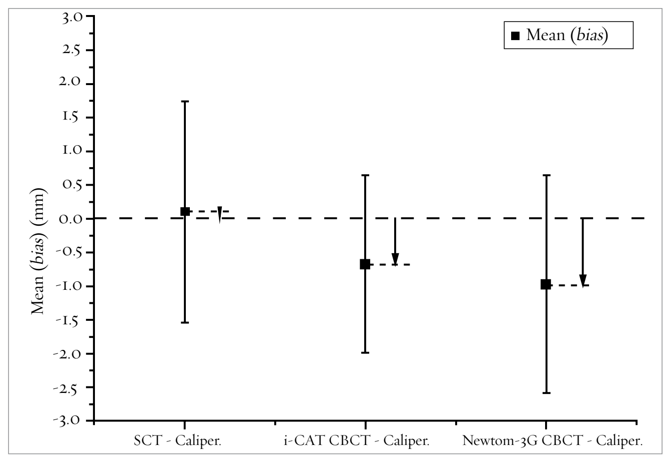

Figure 9 - Limits of agreement for the methods of image compared with direct measurement of LFPM.

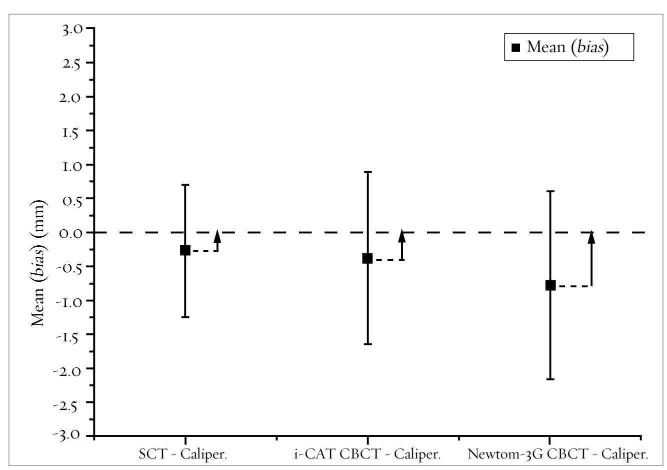

Figure 10 - Limits of agreement for the methods of image compared with direct measurement of LLI.

Imaging methods that are able to obtain and reproduce with adequate accuracy the maxillomandibular dimensions are essential for diagnosis and planning of surgical procedures, such as those commonly found in Implantology.[9,10] Due to the risks of performing operations that are inherent to Implantodontics without using rigorous tests, CTs have become a valuable tool in planning surgical procedures.[4,12-16]

In spite of the high radiation dose of SCT equipment, it is widely used for implantology surgeries, planning of procedures for maxillomandibular reconstruction and buco-maxilofacial surgeries.[13,17]

In SCT, visualization of soft tissues is clearer. However, images of hard tissues have better quality in CBCT, since the voxels (the smallest structures of an image) are anisotropic (rectangular cubes in which length is greater than height and width) in SCT; and isotropic (rectangular cubes with equal size in the three dimensions) in CBCT. Another difference between voxels is that the voxel surface can reach 0.625 mm^2 in SCT and 0.125 mm^2 in CBCT.[1,4,18,19]

As for the quality of images, it is shown in the literature[19-24] that the accuracy of both examinations is very similar. However, SCT is cited by some authors[19,24] as being slightly more accurate than CBCT. This information disagrees with the results obtained in this study which shows greater accuracy for i-CAT® CBCT, lower accuracy for NewTom-3G® CBCT, and intermediate accuracy for SCT. Nevertheless, good accuracy was shown in the three types of examination regarding direct measurements.[19-24]

Corroborating the results achieved by Ludlow et al,[25] with a difference between measures not greater than 2 mm, agreement was observed for differences of up to 2 mm(94.16%) and 1 mm (71.66%) between measurements performed with NewTom-3G® CBCT. As for CBCT, agreement was observed for a difference of up to 2 mm(97.48%) and 1 mm(82.49%) between measurements obtained with the i-CAT® system.

Indirect measurements obtained in examinations with the cone-beam technology were systematically lower than those performed with a caliper, with both the NewTom-3G® system (83.33%) and the i-CAT® CBCT (75.85%), which is in agreement with the studies of Lascala et al.[26] In SCT, indirect measurements were lower than the direct measurements in 42.5% of examinations.

Despite the fact that, in SCT, the results showed a close agreement within 1 and 2 mm, for i-CAT® CBCT the values were higher than those for the direct measurement in 56.66% of examinations (mean deviation of 0.82 mm with the greatest difference of 3.66 mm).

With regard to the limits of agreement used in this study, it was observed that the LFPM and LLI sites are similar in amplitude, with lower amplitude for SCT (LLI and LFPM sites) and i-CAT® CBCT. As for the LFM site, the amplitudes of the limits of agreement were not similar, and the lowest amplitude was observed for i-CAT® CBCT. The limits of agreement with lower amplitude indicate greater accuracy in examinations. Although greater accuracy was observed for i-CAT® CBCT and lower accuracy for NewTom-3G® CBCT and SCT, all examinations showed similar accuracy.

For the LFM, the limits of agreement were 2.75 mm above and 1.08 mm below with spiral CT. This generates some concern when borderline cases are referred for osseointegrated implants. On the other hand, a margin of error greater than 2.75 mm was observed when the direct measurement was of about 30 mm. Such a value is at least three times greater than that for a borderline case that may receive an implant. At this same site, NewTom-3G® and i-CAT® CBCT showed differences (0.50 and 0.40 mm above, respectively) with negligible differences regarding installation of dental implants, since a small change in either angle or point of election would result in a similar difference. These data are in agreement with what was stated by Baumgaertel et al[27] who describe CBCT as a reliable and accurate examination, which can be used for quantitative analysis of the remaining bone.

With regard to the LFPM site, the positive limits of agreement were estimated to be 1.73 mm (SCT), 0.62 mm (i-CAT® CBCT), and 0.63 mm (NewTom-3G® CBCT). These limits are widely acceptable in surgical planning, especially when the mean deviations for SCT (0.09 mm), i-CAT® CBCT (-0.68 mm), and NewTom-3G® CBCT (-0.98 mm) are taken into account.[28]

As for the LLI site, means with negative values were observed in the limits of agreement for SCT (0.27 mm), i-CAT® CBCT (0.38 mm), and NewTom-3G® CBCT (0.78 mm), showing a good accuracy for all examinations performed in this region.[5,19,29] The fact that all means had negative values and the upper limits of agreement were not so different from the direct measurements, increases safety in the installation of osseointegrated implants, even in borderline cases. In this region, the maximum upper limits of agreement were 0.70 mm (SCT), 0.88 mm (i-CAT® CBCT), and 0.59 mm (NewTom-3G® CBCT).

Regarding all regions examined, greater accuracy was found for i-CAT® CBCT, which is in agreement with Loubele et al[5] who stated that this system is the most accurate among the four CBCT systems.

It can be concluded that the three CTs studied herein showed similar limits of agreement and precision at LLI and LFPM sites, and the i-CAT® CBCT showed limits of agreement with lower amplitude and greater accuracy than the other examinations performed.

REFERENCES

1. Hashimoto K, Arai Y, Iwai K, Araki M, Kawashima S, Terakado M. A comparison of a new limited cone beam computed tomography machine for dental use with a multidetector row helical CT machine. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2003;95(3):371-7.
2. Ruprecht A. Oral and maxillofacial radiology: then and now. J Am Dent Assoc. 2008;139(Suppl):5s-6s.
3. Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis IAB. A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results. Eur Radiol. 1998;8(9):1558-64.
4. Scarfe WC, Farman AG, Sukovic P. Clinical applications of cone-beam computed tomography in dental practice. J Can Dent Assoc. 2006;72(1):75-80.
5. Loubele M, Jacobs R, Maes F, Denis K, White S, Coudyzer W, et al. Image quality vs. radiation dose of four cone beam computed tomography scanners. Dentomaxillofac Radiol. 2008;37(6):309-18.
6. Suomalainen A, Vehmas T, Kortesniemi M, Robinson S, Peltola J. Accuracy of linear measurements using dental cone beam and conventional multislice computed tomography. Dentomaxillofac Radiol. 2008;37(1):10-7.
7. Howerton Jr WB, Mora MA. Advancements in digital imaging: what is new and on the horizon? J Am Dent Assoc. 2008;139(Suppl):20s-4s.
8. Liang X, Jacobs R, Hassan B, Li L, Pauwels R, Corpas L, et al. A comparative evaluation of Cone Beam Computed Tomography (CBCT) and Multi-Slice CT (MSCT). Part I. On subjective image quality. Eur J Radiol. 2010;75(2):265-9.
9. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet. 1986;328(8476):307-10.
10. Bland JM, Altman DG. Measuring agreement in method comparison studies. Stat Methods Med Res. 1999;8(2):135-60.
11. Bland JM, Altman DG. Agreement between methods of measurement with multiple observations per individual. J Biopharm Stat. 2007;17(4):571-82.
12. Choi SC, Ann CH, Choi HM, Heo MS, Lee SS. Accuracy of reformatted CT image for measuring the pre-implant site: analysis of the image distortion related to the gantry angle change. Dentomaxillofac Radiol. 2002;31(4):273-7.
13. Hatcher DC, Dial C, Mayorga C. Cone Beam CT for pre-surgical assessment of implant sites. J Calif Dent Assoc. 2003;31(11):825-33.
14. White SC, Pharoah MJ. The evolution and application of dental maxillofacial imaging modalities. Dent Clin North Am. 2008;52(4):689-705.
15. Danforth RA, Peck J, Hall P. Cone Beam volume tomography: an imaging option for diagnosis of complex mandibular third molar anatomical relationships. J Calif Dent Assoc. 2003;31(11):847-52.
16. Miracle AC, Mukherji SK. Cone beam CT of the head and neck, Part 2: clinical applications. AJNR Am J Neuroradiol. 2009;30(7):1285-92.
17. Schulze D, Heiland M, Thurmann H, Adam G. Radiation exposure during midfacial imaging using 4- and 16-slice computed tomography, cone beam computed tomography systems and conventional radiography. Dentomaxillofac radiol. 2004;33(2):83-6.
18. Maki K, Inou N, Takanishi A, Miller AJ. Computer-assited simulations in orthodontic diagnosis and the application of a new cone beam X-ray computed tomography. Orthod Craniofac Res. 2003;6(suppl 1):95-101.
19. Pinsky HM, Dyda S, Pinsky RW, Misch KA, Sarment DP. Accuracy of three-dimensional measurements using cone-beam CT. Dentomaxillofac Radiol. 2006;35(6):410-6.
20. Hanazawa T, Sano T, Seki K, Okano T. Radiologic measurements of the mandible: a comparison between CT-reformatted and conventional tomographic images. Clin Oral Implants Res. 2004;15(2):226-32.
21. Stratemann SA, Huang JC, Maki K, Miller AJ, Hatcher DC. Comparison of cone beam computed tomography imaging with physical measures. Dentomaxillofac Radiol. 2008;37(2):80-93.
22. Veyre-Goulet S, Fortin T, Thierry A. Accuracy of linear measurement provided by cone beam computed tomography to assess bone quantity in the posterior maxilla: a human cadaver study. Clin Implant Dent Relat Res. 2008;10(4):226-30.
23. Brown AA, Scarfe WC, Scheetz JP, Silveira AM, Farman AG. Linear accuracy of Cone Beam CT derived 3D images. Angle Orthod. 2009;79(1):150-7.
24. Moreira CR, Sales MAO, Lopes PML, Cavalcanti MGP. Assessment of linear and angular measurements on threedimensional cone-beam computed tomographic images. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009;108(3):430-6.
25. Ludlow JB, Laster WS, See M, Bailey LJ, Hershey HG. Accuracy of measurements of mandibular anatomy in cone beam computed tomography images. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007;103(4):534-42.
26. 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(5):291-4.
27. 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(1):19-25.
28. Periago DR, Scarfe WC, Moshiri M, Scheetz JP, Silveira AM, Farman AG. Linear accuracy and reliability of cone beam ct derived 3-dimensional images constructed using an orthodontic volumetric rendering program. Angle Orthod. 2008;78(3):387-95.
29. Kobayashi K, Shimoda, S, Nakagawa Y, Yamamoto A. Accuracy in measurement of distance using limited cone-beam computerized tomography. Int J Oral Maxillofac Implants. 2004;19(2):228-31.