

Effect of Slice Thickness on the Accuracy of Linear Measurements Made on Cone Beam Computed Tomography Images (*In Vitro*)

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Abstract

Objective: Cone beam computed tomography (CBCT) is applied for the imaging of the maxillofacial and dental structures, particularly for surgical treatments and dental implants. The aim of this study was to assess the effect of slice thickness on the accuracy of CBCT linear measurements.

Methods: In this diagnostic accuracy study, forty-two titanium pins with the same dimensions were inserted into seven dry sheep mandibles. The length of the pins before the insertion was carefully measured by a digital caliper, (0.01mm accuracy). Imaging of the mandible performed using CBCT New Tom VGi. After image reconstruction by NNT Viewer, linear measurements were made on cross-sectional slices (thicknesses of 0.125, 0.5, 1 and 2mm) by three radiologists. The accuracy of measurements assessed using descriptive indices and compared between different slice thicknesses by repeated measures ANOVA.

Results: Repeated measures ANOVA showed a significant difference between different slice thicknesses ($P=0.024$). According to the least significant difference (LSD) test, the difference in absolute errors was significant in all thicknesses ($P=0.024$). Measurements at 0.125 mm thickness were significantly different from others, with a higher error rate (mean absolute error=0.17). Measurements at 0.5mm thickness showed a significant difference with those at 0.125 and 2mm (mean absolute error=0.15). Measurements at 2mm thickness were significantly different from those at 0.125 mm thickness (mean absolute error=0.13). The average error rate was lower in 2mm thickness and the measurements were more accurate.

Conclusion: A statistically significant difference was seen between CBCT measurements and actual sizes in different slice thicknesses. The differences were below 1mm, and clinically acceptable.

Key words: Accuracy, Cone-Beam Computed Tomography, Dental Implants, Dimensional Measurement

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Introduction

For many years, multi-detector computed tomography (MDCT) was regarded as the most accurate imaging modality for evaluation of implants. However, MDCT has various limitations including high radiation dose, reduced image quality due to metal artifacts and high cost. In addition, non-isotropic voxels lead to reduced resolution of reconstructed images compared

to original axial scans. In an effort to overcome CT scan limitations, CBCT systems were developed, particularly for the evaluation of the head and neck regions (1). One of the advantages of CBCT for dentists is enabling linear measurements of desired anatomical structures. Linear measurements are usually made to determine the thickness and height of the alveolar ridge prior to implant placement, measure the distance between anatomical structures in

orthodontics and assess the extent of pathologies in the mandible (2).

Since treatment planning based on the diameter and length of implants, orthodontic treatment planning and surgical treatment of oral pathological lesions all depend on linear measurements, dentists should be fully aware of the accuracy of CBCT linear measurements (2, 3). In fact, an accurate assessment of the size of implants is the key to the success of implant treatment (4).

The CBCT studies are dependent on cross-sectional imaging of the region of interest. Orientation, interval and thickness of slices are determined by the operator (task-specific imaging). Image processing is routinely performed to obtain important information, which may not be provided by axial images alone. Selection of different parameters such as the thickness and interval of cross-sectional slices is completely optional (5). In some cases, signal-to-noise ratio may determine the thickness of cross-sections; in fact, the thicker the sections, the higher the signal-to-noise ratio. Some dentists believe that thin, magnified cross-sectional images can provide more valuable information; however, no evidence is available to confirm this hypothesis (5). In some cases, thinner, magnified cross-sections may be required to obtain optimal diagnostic view. For instance, in patients with mandibular osteomyelitis, thinner slices would be of great help to identify bone sequestration, which may not be detected if thicker sections are used. On the other hand, in some cases with gross manifestation of the disease (e.g., thick, curved internal septa), thicker slices may suffice (5).

The aim of this study was to assess the effect of slice thickness on the accuracy of CBCT linear measurements.

Methods

We used the convenient sampling technique in this diagnostic accuracy study. According to the study conducted by Sherrard *et al.* in 2010 (6) and with regards to the mean difference and standard deviation, which were 0.238 and 0.167, respectively, the minimum sample was calculated by Minitab software to be 42 pins that were to be placed in seven sheep mandibles. We used the confidence coefficient option in the software to determine the sample size ($\alpha=0.05$, $\beta=0.2$).

The present study was conducted by placing 42 identical titanium pins into seven dry sheep mandibles. The length of the pins was measured by a digital caliper (Mitutoyo Corp, Kawasaki, Japan), with an accuracy of 0.01 mm before their insertion into the mandibles (Figure 1).



Figure 1- Digital Caliper (Pin Length Measurement)

In order to insert the pins, parallel holes were drilled into the bone on the ridge crest in edentulous, dry sheep mandibles. Afterwards, using fissure burs and high-speed hand piece, the holes were enlarged, based on the diameter of the pins. The pins were inserted into the desired regions (Figures 2 and 3).



Figure 2- A Sheep Mandible in Parallel Drilling



Figure 3- Titanium Pins Inserted in A Dry Sheep Mandible

In order to simulate soft tissues, the mandible was placed in a water container. Each mandible was radiographed using NewTom VGi CBCT imaging system (Quantitative Radiology, Verona, Italy). To standardize the position of the mandibles, CBCT vertical laser marker was paralleled to the midsagittal plane of the mandible and the horizontal marker was paralleled to the occlusal plane. Mandibular imaging was performed, using a high-resolution 8×12cm field of view (110 KVp).

After imaging, the images were reconstructed by NNT Viewer software, and observers made linear measurements on cross-sections with variable slice thicknesses of 0.125, 0.5, 1 and 2mm. Images were displayed on a Philips monitor with a resolution of 1024×1280mm pixels and a 32-bit color depth. Observers including three oral and maxillofacial radiologists were allowed to change the contrast, sharpness and brightness of images as desired. To determine the reproducibility of measurements, the measurements were repeated two weeks later (Figures 4 and 5). The intraclass correlation coefficient (ICC) was calculated.

The accuracy of linear measurements made

on CBCT scans was calculated by descriptive indices and repeated measures ANOVA.

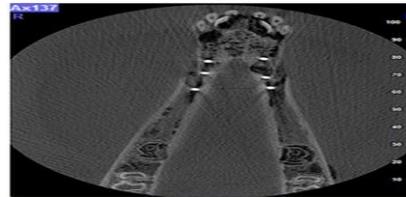


Figure 4- CBCT Image of A Sheep Mandible with Titanium Pins (Axial View)

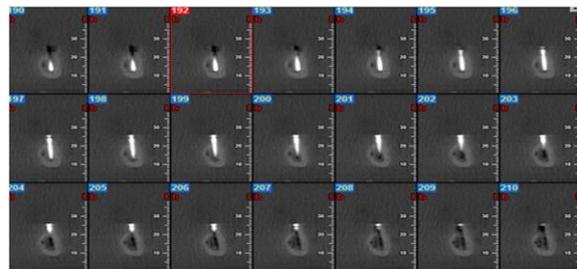


Figure 5- CBCT Image of A Sheep Mandible with Titanium Pins (Cross-sectional Slices)

Result

In the current study, since pins with similar lengths were used, the ICC ranged between 0.011 and 0.034; hence, weighted kappa was applied. In repeated observations, by taking error ranges into consideration, the repeatability coefficient was greater than 0.9 at all thicknesses, based on the weighted kappa index. Tables 1-4 demonstrate the observers' error percentage in the specified range. The measurements made by the majority of observers (64%) were 0.5-0.1 mm less than the actual values (underestimation). Also, measurements made by a small number of observers were 1mm to 0.5 mm smaller than the actual values. Measurements greater than the actual values were reported by a few observers (overestimation). The error rate was not greater than +0.5 mm in any of the measurements.

Table 1- Inter observer differences with in the error range for the slice thickness of 0.125 mm

Range	Observer 1 (%)	Observer 2 (%)	Observer 3 (%)	Total percentage
+0.5 to +1	0	0	0	0
+0.1 to +0.5	1.2	0	0	1.2
±0.1	35.7	42.5	27.4	105.6
-0.5 to -0.1	63.1	59.5	71.4	194
-1 to -0.5	0	2.4	1.2	3.6

Table 2- Inter observer differences with in the error range for the slice thickness of 0.5 mm

Range	Observer 1 (%)	Observer 2(%)	Observer 3(%)	Total percentage
+.5 to +1	0	0	0	0
+0.1 to +0.5	0	0	0	0
±0.1	36.9	35.7	33.3	105.9
-0.5 to -0.1	61.9	64.3	66.7	131
-1 to -0.5	1.2	0	0	1.2

Table 3- Inter observer differences with in the error range for the slice thickness of 1mm

Range	Observer 1 (%)	Observer 2 (%)	Observer 3 (%)	Total percentage
+0.5 to +1	0	0	0	0
+0.1 to +0.5	0	0	0	0
±0.1	32.1	40.5	47.7	120.3
-0.5 to -0.1	66.7	57.1	58.8	182.5
1 to -0.5	1.2	2.4	0	3.6

Table 4- Inter observer differences with in the error range for the slice thickness of 2mm

Range	Observer 1(%)	Observer 2 (%)	Observer 3 (%)	Total percentage
+0.5 to +1	0	0	0	0
+0.1 to +0.5	1.2	0	0	1.2
±0.1	34.5	39.3	40.5	114.3
-0.5 to -0.1	61.9	60.7	58.3	119
-1 to -0.5	2.4	0	1.2	3.6

The highest error rate (absolute value) was reported at a thickness range of 0.1 to 0.5 mm. In this range, the majority of observers made errors at a thickness of 0.125mm. The highest significant difference in the mean measurements (-0.15) was reported at a thickness of 0.125 mm; the minimum difference (-0.10) was related to 2mm thickness. All the mean measurements were slightly lower than the actual values.

Repeated measures ANOVA showed a significant difference between different slice thicknesses ($P=0.024$). For pairwise comparisons, the LSD test was used. At each thickness (four thicknesses), the absolute

errors were significantly different ($P=0.024$). Measurements at a thickness of 0.125mm were significantly different from the rest, with a higher error rate (average absolute error=0.17).

Measurements at 0.5mm thickness were significantly different from the measurements made at 0.125mm and 2mm thicknesses (mean absolute error=0.15). Measurements at 2mm thickness were significantly different from values at a thickness of 0.125mm; this difference was statistically significant (mean absolute error=0.13). This indicates the lower mean error rate (and error rate) at a thickness of 2mm, which is indicative of higher

accuracy ($P < 0.05$). The absolute differences at each thickness are shown in Table 5.

Table 5- The absolute difference at each thickness

Thickness	Maximum	Minimum	Standard deviation	The mean absolute difference
0.125	0.46	0.01	0.10	0.17
0.5	0.43	0.04	0.09	0.15
1	0.54	0.02	0.09	0.14
2	0.41	0.04	0.06	0.13

Discussion

The CBCT systems enable the radiologists to reconstruct three-dimensional images and perform different linear and angular measurements in the orofacial region (7). In the current study, we evaluated the changes in the accuracy of linear measurements on CBCT scans caused by the alterations in slice thickness. For this purpose, high-resolution scans were obtained from sheep mandibles with a field of view of 8×12 cm.

Cross-sectional images were reconstructed to determine the effect of changes on the thickness of slices on CBCT linear measurements. Since a high-resolution mode is required in CBCT NewTom VGi to use the minimum thickness (0.125mm), this study was conducted in a high-resolution mode using slice thicknesses of 0.125, 0.5, 1 and 2mm.

In a study conducted in 2014 by Nikneshan and colleagues, the accuracy of linear CBCT measurements in various reconstruction angles was evaluated. According to their study, changing the angle from +12 to -12 decreased the accuracy of linear measurements. However, since the error rate was lower than 1mm (0.5 mm), this reduction was clinically acceptable, similar to the current study (8).

In the above-mentioned study, similar to the current research, titanium pins were used; in use of these pins, due to low atomic number, the amount of artifacts decreases. The pins were inserted into dry sheep mandibles and a water chamber was employed to simulate soft tissues (8). Although complete simulation of soft tissues by water is impossible, this process was carried out to simulate the clinical setting as much as possible.

Soft tissues can affect image quality and the accuracy of linear measurements by attenuating X-ray beams. Alloys with high density such as gold with the atomic number of 79, amalgam with the atomic number of 80 (the atomic number of mercury) and silver with the atomic number of 47 significantly reduce the intensity of X-rays, producing opaque and lucent radial lines around restorations and the adjacent teeth (9). Estrela et al. in 2011 measured the dimensions of intra-canal posts using a CBCT device. They found that the measurements done on CBCT images were greater than the real sizes if the pins were made of silver or gold. This was due to the beam hardening effect, which is proportionate to the post type (10).

All dental implants are made of titanium with the atomic number of 22 (9). Hence, metal artifacts are rarely found in titanium due to its low atomic number (11, 12). Furthermore, the observers were allowed to change and adjust the contrast, sharpness, and gamma factor (which is among the features of the NNT Viewer software) of the images, and by doing so, they could further minimize the metal artifacts. Sheikhi et al. in their study used gutta-percha markers and noted various factors causing difference between actual measurements and radiographic

findings. Major CBCT artifacts such as noise, aliasing artifact, ring artifact, beam hardening and scattered beams were considered to impede the detection of the exact position of an object on a CBCT scan, leading to imprecise measurements (13).

The results of the current study showed that the accuracy of CBCT linear measurements could be enhanced by increasing the slice thickness. The maximum difference (-0.15) in the mean measurements was obtained at a thickness of 0.125mm, and the minimum difference (-0.10) was related to 2mm slice thickness. The difference in the mean measurement errors (using different slice thicknesses) and the gold standard was less than 1 mm. Ganguly *et al.*, in their study in 2011 showed that radiographic examinations are required to assess the quantity and quality of bone for implant placement and determine the exact location of anatomical structures; the accepted error range for implant placement is normally less than 1mm (7). Therefore, the accuracy of all measurements in our study was clinically acceptable at all slice thicknesses.

Intraclass correlation coefficient may not be an accurate and reliable criterion for determining the accuracy of measurements due to the low distribution of gold standards. In the current study, since pins with similar lengths were used, ICC ranged between 0.011 and 0.034; hence, weighted kappa was applied. In repeated observations, by taking error ranges into consideration, the repeatability coefficient was greater than 0.9 at all thicknesses, based on the weighted kappa index.

Several factors such as mA settings, voxel size, field of view, type of scanner detector,

presence or absence of soft tissues and bone thickness can affect image quality and the accuracy of linear measurements (14, 15). In 2012, Moshafeghi *et al.* examined the effects of voxel size on the accuracy of linear measurements in New Tom VG and concluded that changing the voxel size within the range of 0.15 to 0.3mm (minimum voxel size of the device at high resolution) had no effect on the accuracy of CBCT linear measurements.

According to the above-mentioned study, considering the correlation between voxel size and patient dose, we can obtain images with similar dimensional accuracy by increasing the voxel size while reducing the patient radiation dose (16). Although Moshafeghi *et al.* focused on the effects of factors other than thickness on the accuracy of CBCT linear measurements, no significant association was found between these parameters and measurement accuracy; this finding was consistent with the current study results.

Moshfeghi *et al.* (16) and Sheikhi *et al.* (13) in 2012 used Gutta Percha markers in their studies, while we chose titanium pins, which have higher dimensional stability and radiopacity.

In 2011, Ozer analyzed the effects of four voxel sizes (0.125, 0.2, 0.3 and 0.4mm) on detection of root fractures by i-CAT CBCT system and concluded that all voxel sizes had similar efficacy for detection of fractures; although 0.2 and 0.125mm voxel sizes had higher accuracy. Therefore, the best voxel size is regarded to be 0.2 mm due to shorter scanning time and lower patient exposure, which can be related to fine fracture lines (15).

In 2013, Sezgin and colleagues (9) examined the effect of slice thickness on the volume of bone defects by changing the thickness of CBCT slices. In their study, 0.2, 0.6, 1, 1.4 and 2.2mm thicknesses were used. Moreover, pins with a diameter of 2mm were used, which restricted the evaluation of slice thicknesses greater than 2mm. According to the study by Sezgin et al. (9) although the thinnest slice provided the most accurate measurements, CBCT had adequate accuracy for determining the volume of bone defects at a thickness of up to 1mm; also, the difference with the actual volume was not significant. However, at greater thicknesses (1.4 and 2.2mm), CBCT measurements were smaller than the actual volume of defects. This finding was in contrast to the current results, which showed higher accuracy at greater thicknesses (9).

In the current research, we used pins with 2mm diameter. Since at greater thicknesses, the whole pin can be detected, the measurements are more accurate. In the study by Sezgin et al. underestimation was reported at 1.4 and 2.2mm thicknesses, similar to the current study (9).

The findings of the current study were inconsistent with the results reported by Sirin et al. in 2010, examining the changes in the accuracy of CBCT measurements by altering the thickness of slices for detecting condylar fractures; CBCT detected all types of condylar fractures at 1 and 0.2mm thicknesses; whereas, at 2mm and 3mm thicknesses, condylar fractures were not detected. The ROC curve analysis and area under the curve (AUC) calculations were performed in their study. The AUC had the highest value at lower thicknesses, which

might be due to the fine fracture lines. Hence, by increasing the thickness of slices, these fractures faded on CBCT images, resulting in diagnostic inaccuracies (17).

Shokri et al, in 2015 studied the effect of different slice thicknesses on the accuracy of linear measurements on CBCT images in implant sites. They used 11 human dry mandibles. The width and height of bone at the central, canine, and molar teeth areas were measured on the left and right sides by using digital calipers (as gold standard) and on CBCT images with 0.5, 1, 2, 3, 4, 5, and 10-mm slice thicknesses. The highest measurement accuracy of CBCT software program was observed at 4mm slices for bone height and 5-mm slice thickness for bone width. The measurements done on CBCT images with slice thicknesses of less than 4 millimeters were shorter than the actual size of the bone. This phenomenon may have two possible explanations (18):

1. Each voxel has a particular volume and CBCT software programs measure the distance between the midpoints of the most distal and the most mesial (or the most buccal and the most lingual) voxels. Therefore, the authors assume that some parts of the measurement area may be missed while measurement is done by CBCT software. However, it seems that this problem can equally cause overestimation (18).

2. Underestimation might be related to voxel because a very small voxel size is ideal in that an exact estimate can be made of the size (18).

Fatemitabar and Nikgoo (19) in 2010 compared the accuracy of linear measurements made by CBCT (Planmeca) with that of 64 Channel CT. The mean

difference of measurements from the actual size was estimated to be +0.37mm to +0.58mm in use of CBCT, and +0.37 to +0.72mm in using CT. Similar to the present study, the distances were underestimated on both CT and CBCT images. This underestimation may not be a drawback of these modalities according to the authors.

Conclusion

In conclusion, by increasing the thickness of slices, the accuracy of CBCT measurements increased. Also, the measurements were significantly different at the specified thicknesses; however, the error range was

lower than 1mm and therefore, it was clinically acceptable.

Suggestions

Further studies with a larger sample size on other CBCT systems and pins with different diameters and greater thicknesses are recommended. Moreover, in order to be able to better generalize the results to the clinical settings, further investigations are essential.

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Conflict of Interest: “None Declared”

References:

1. Al-Ekrish AA, Ekram M. A comparative study of the accuracy and reliability of multidetector computed tomography and cone beam computed tomography in the assessment of dental implant site dimensions. *Dentomaxillofac Radiol.* 2011 Feb;40(2):67-75
2. Cavalcanti MGP, Rocha SS, Vannier MW. Craniofacial measurements based on 3D-CT volume rendering: implications for clinical applications. *Dentomaxillofac Radiol.* 2004 March; 33(3):170–6.
3. Scarf WC, Farman AG, Sukovic P. Clinical application of cone-beam computed tomography in dental practice. *J Can Dent Assoc.* 2006 Feb;72(1):75-80
4. Sabban H, Mahdian M, Dhingra A, Lurie AG, Tadinada A. Evaluation of linear measurements of implant sites based on head orientation during acquisition: An ex vivo study using cone-beam computed tomography. *Imaging Sci Dent.* 2015 Jun;45(2):73-80.
5. Chadwick JW, Lam EW. The effect of slice thickness and interslice interval on reconstructed cone beam computed tomographic images. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 2010 Oct;110(4):e37-42
6. Sherrard JF, Rossouw PE, Benson BW, Carrillo R, Buschang PH. Accuracy and reliability of tooth and root lengths measured on cone-beam computed tomographs. *Am J Orthod Dentofacial Orthop.* 2010 Apr;137(4 Suppl):S100-8.
7. Ganguly R, Ruprecht A, Vincent S, Hellstein J, Timmons S, Qian F. Accuracy of linear measurement in the Galileos cone beam computed tomography under simulated clinical conditions. *Dentomaxillofac Radiol.* 2011 Jul;40(5):299-305.

8. Nikneshan S, Aval SH, Bakhshalian N, Shahab S, Mohammadpour M, Sarikhani S. Accuracy of linear measurement using cone-beam computed tomography at different reconstruction angles. *Imaging Sci Dent*. 2014 Dec;44(4):257-62.
9. Sezgin OS, Kayıpmaz S, Sahin B. The effect of slice thickness on the assessment of bone defect volumes by the Cavalieri principle using cone beam computed tomography. *J Digit Imaging*. 2013 Feb;26(1):115-8.
10. Esterla C, Bueno MR, Silva JA, Porto OCL, Leles CR, Azevedo BC. Effect of intracanal posts on dimensions of cone beam computed tomography images of endodontically treated teeth . *Dent. press endod*. 2011;1(1):28-36.
11. MacDonald D. *Oral and Maxillofacial Radiology—diagnostic approach*. 1st Ed. Wiley-blackwell 2011; Chap 15: 296-8.
12. Boas EF, Flieschmann D. CT artifact: Cause and reduction techniques. *Imaging Med*. 2012; 4(2): 229-40.
13. Sheikhi M, Ghorbanizadeh S, Abdinian M, Goroohi H, Badrian H. Accuracy of linear measurement of galileos cone beam computed tomography in normal and different head position. *Int J Dent*. 2012;2012:214954.
14. Wood R, Sun Z, Chaudhry J, Tee BC, Kim DG, Leblebicioglu B, et al. Factors effecting the accuracy of buccal alveolar bone height measurements from cone-beam computed tomography images. *Am J Orthod Dentofacial Orthop*. 2013 Mar;143(3):353-63.
15. Ozer SY. Detection of vertical root fractures by using cone beam computed tomography with variable voxel sizes in an in vitro Model. *J Endod*. 2011 Jan;37(1):75-9.
16. Moshfeghi M, Tavakoli MA, Hosseini ET, Hosseini AT, Hosseini IT. Analysis of linear measurement accuracy obtained by cone beam computed tomography (CBCT-NewTom VG). *Dent Res J (Isfahan)*. 2012 Dec;9(Suppl 1):S57-62.
17. Sirin Y, Guven K, Horasan S, Sencan S, Bakir B, Barut O, et al. The influence of secondary reconstruction slice thickness on NewTom 3G cone beam computed tomography–based radiological interpretation of sheep mandibularcondylefractures.*Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2010 Nov;110(5):638-47.
18. Shokri A, Khajeh S. In vitro comparison of the effect of different slice thicknesses on the accuracy of inear measurements on cone beam computed tomography images in implant sites. *J Craniofac Surg*. 2015 Jan; 26(1):157–60.
19. Fatemitabar SA, Nikgoo A. Multichannel computed tomography versus cone-beam computed tomography : linear accuracy of in vitro measurements of the maxilla for implant placement. *Int J Oral Maxillofacial Implants*. 2010 May-Jun;25(3):499-505.