DOI: 10.22037/jds.v37i4.28953

Original Article
ISSN 2645-4351

Reliability of Linear Measurements Made on Reconstructed CBCT Images

Hourieh Bashizadeh Fakhar[a], Milad Soleimani[b], Mohammad Haj Seyyed Nasrollah[c]

[a]Assistant Professor, Dept. of Oral & Maxillofacial Radiology, School of Dentistry, Tehran University of Medical Sciences, Tehran, Iran.
[b]Postgraduate Student, Dept. of Orthodontics, School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
[c]Dentist, Tehran, Iran.
Correspondence to Milad Soleimani (email: miladsoleimani91@gmail.com).
(*Submitted: 08 February 2020 – Revised version received: 15 July 2020 – Accepted: 21 July 2020– Published online: Fall 2020*)

Objectives Repeatability and accuracy of measurements made on cone-beam computed tomography (CBCT) images are critical in dental practice especially in implantology. The aim of this study was to investigate the reproducibility of linear measurements made on reconstructed CBCT images.

Methods In this in vitro, experimental study, 5 radiopaque markers were attached to the molars (left and right side), premolars (left and right side) and midline areas of 10 human cadaver dry mandibles. The distance between the markers and the lower border of the mandible was measured by a digital caliper and considered as the gold standard. CBCT images were taken, and the distance between the markers and the lower mandibular border was measured on cross-sectional images by three maxillofacial radiologists using Romexis software. The same measurements were made 1 month later to assess the reproducibility of measurements. The intra-class correlation coefficient was calculated to assess the repeatability and agreement between the observers.

Results Compared with the gold standard, the mean error percentage in linear measurements was calculated to be 3.25%. The overall reproducibility of CBCT linear measurements was 0.865. The inter-observer agreement was calculated to be 0.972.

Conclusion CBCT showed acceptable accuracy, repeatability and reliability for linear measurements, and can be used as an accurate tool for this purpose.

Keywords Reproducibility of Results; Image Processing, Computer-Assisted; Cone-Beam Computed Tomography

Introduction

Radiographic evaluation is an important part of implant treatment planning. Imaging provides valuable information about the supporting bone quality and quantity, and anatomical structures, as well as the position of the mandibular canal and maxillary sinuses [1-3]. The standard process of implant treatment planning starts with clinical evaluation and two-dimensional imaging [4], but two-dimensional information is not typically adequate to accurately show three-dimensional (3D) structures. Nowadays, cone-beam computed tomography (CBCT) is the choice for three-dimensional evaluations before implant surgery [5-10]. For placement of dental implants, the surgeons mostly rely on 3D CBCT images and choose proper fixture size based on CBCT measurements [11, 12]. However, due to variations in preforming the measurements on CBCT images, it is necessary to evaluate the accuracy and repeatability of these measurements [12]. The operator adjusts the occlusal plane of the sagittal image horizontally, and determines a series of sequential dots on a selected axial scan. The operator usually connects the dots and develops a customized arch for each jaw in the CBCT software. A series of perpendicular lines to this arch are generated by a computer program with constant intervals. Cross-sectional reconstructions are made at the location of these lines. Different operators may change the head image tilt and draw the arch in their own way. These variations may influence the reproducibility of the technique when linear measurements are performed. The aim of this study was to determine the reproducibility of linear alveolar measurements made on reconstructed cross-sectional CBCT images.

Materials and Methods

The study was performed at the Department of Dentomaxillofacial Radiology, Faculty of Dentistry and approved by the Ethics Committee of Tehran University of Medical Sciences (IR.TUMS.VCR.REC.1395.357).

Five radiopaque mammographic markers, each measuring 1 mm in diameter, were attached to first molars, first premolars and midline areas of 10 dry mandibles (Figure 1).

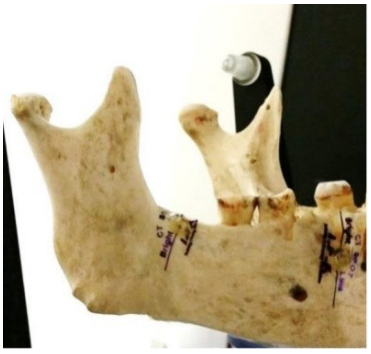

Figure 1- Dry human mandible in CBCT scanner

The distance between the center of the markers and the lower border of the mandible was measured by a digital caliper (SN: 67646993; Mitutoyo, Tokyo, Japan) with 0.001 mm accuracy to serve as the gold standard. CBCT images

were obtained by Alphard (Asahi, Japan) CBCT scanner in I mode with the exposure settings of 80 kVp and 4 mA. DICOM data were imported to Romexis software version 2.9.2 (Planmeca, Finland). Three dentomaxillofacial radiologists adjusted the mandibular tilt horizontally and traced the panoramic arch in the software. The measurements were made by three observers independently (Figure 2).

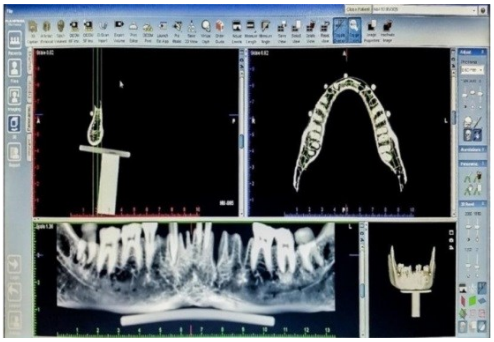

Figure 2- Multiplan reconstructions of CBCT data: Radiographic markers are seen on the bone

Mandibular plane adjustments, panoramic reconstructions and measurements were repeated 1 month later. The percentage of error was determined for each case [13]. Intra-class correlation coefficient (ICC) was calculated to determine the intra and inter-observer reliability. The ICC value more than 0.75 was considered as good reliability and P-values >0.05 were considered significant. Negative values represented underestimation.

Results

The dimensions were compared to direct measurements made on the samples. The percentage of error of measurements is shown in Table 1. The maximum and minimum errors were recorded at the right premolar (5.15%) and left molar (1.1%) areas, respectively. The mean percentage of errors was calculated to be 3.25%. The intra-observer reliability according to the ICC is shown in Table 2. The maximum and minimum values were recorded at the left molar (0.987) and right premolar (0.938) areas, respectively (P<0.001). The mean intraobserver reliability was calculated to be 0.96. The inter-observer reliability according to the ICC is presented in Table 3.

Table 1- Measurements made by the observers (mm) at the first and second observations in different regions of the mandible

Region	Gold standard	Observer 1		Observer 2		Observer 3	
		First stage	Second stage	First stage	Second stage	First stage	Second stage
Left molar	24.9±2.4	25.1±2.3	25.3±2.6	24.6±2.7	24.5±2.7	24.8±2.5	24.8±2.4
Left premolar	26.2±2.8	25.4±2.6	26.1±2.8	25.4±2.6	25.1±2.5	25.3±2.5	25.2±2.6
Midline	23.6±2.2	22.9±2.2	23.4±2.2	22.8±2.4	22.5±2.2	22.6±2.1	22.7±2.2
Right premolar	25.7±2	24.6±2	25.5±2	24.1±2.3	23.9±2.3	24.2±2.4	24.2±2.4
Right molar	26.1±1.7	25.5±2.0	26.3±2.3	25.2±2.4	25.1±2.4	25.2±2.0	25.1±2.1

The maximum and minimum values were recorded at the left molar (0.989) and right premolar (0.942) areas, respectively (P<0.001). the mean inter-observer reliability was calculated to be 0.972.

Figure 3 shows the Bland-Altman plot of the correlation between the observers' measurements and the gold standard values in the first observation (Figure 3).

.

Table 2- Error percentage of measurements made by the observers in the first and second observations

Region	Observer 1		Observer 2		Observer 3		Average
	First stage	Second stage	First stage	Second stage	First stage	Second stage	
Left molar	-0.48	-1.61	1.36	1.92	0.48	0.72	1.1
Left premolar	3.2	0.22	3.09	4.15	3.31	3.62	2.93
Midline	2.98	0.96	3.71	4.98	4.34	4.00	3.5
Right premolar	4.3	1.02	6.35	7.12	5.96	6.15	5.15
Right molar	2.2	-0.83	3.35	3.66	3.28	3.58	3.58

Table 3- Interobserver agreement in CBCT linear measurements

Region	ICC	Confidence interval	P value
Left molar	0.989	0.974-0.997	<0.001
Left premolar	0.959	0.901-0.988	<0.001
Midline	0.988	0.971-0.997	<0.001
Right premolar	0.942	0.860-0.983	<0.001
Right molar	0.981	0.954-0.995	<0.001
Mean	0.972	0.860-0.997	<0.001

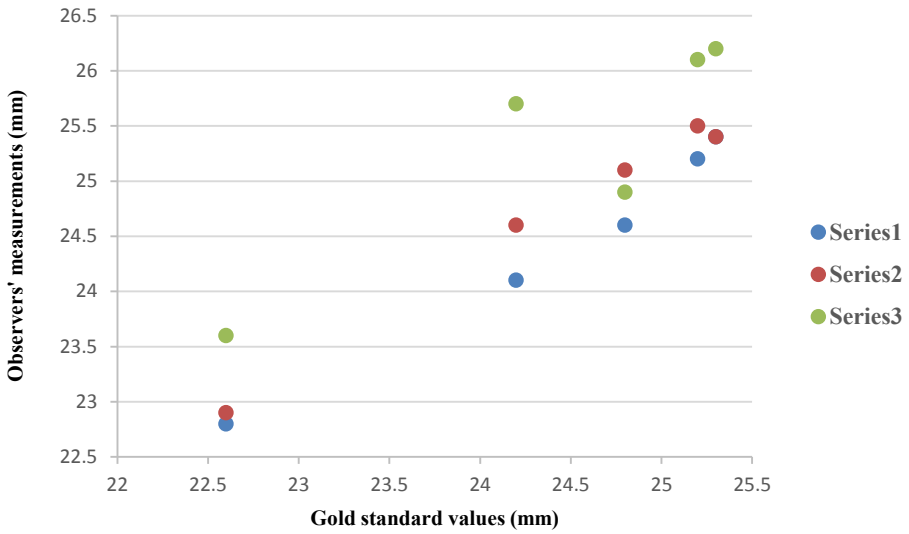

Figure 3- Bland-Altman plot showing correlations between the observers' measurements and the gold standard values at the first observation

Discussion

Linear measurements are among the most popular applications of CBCT images. Many clinicians utilize images to detect anatomical structures and measure the bone thickness and height before the surgical procedures. Therefore, any inaccuracy in measurements may alter the surgical plan erroneously. Although the accuracy and reliability of CBCT have been evaluated in different studies, in this study, the reliability of CBCT was evaluated regarding panoramic reconstruction prior to cross-sectional image reconstruction of the alveolar ridge.

To have a trustworthy gold standard, dry mandibles were used as samples in this study. Although, patient evaluations are more generalizable to clinical situations, motion blur, metal artifacts, and soft tissue attenuation may harshly affect the results. Furthermore, direct measurement of bone during surgical procedures is almost impossible because of bleeding and infection control problems. Furthermore, we used radiopaque mammographic markers as reference points on the bone in this study. For sure, such accurate marking is impossible during surgical procedures [14].

According to the results, the mean error rate was minimal in different regions, 1.1% in the first molar to 5.15% in premolar regions. The overall accuracy of the procedure was calculated to be 96.75%. Accordingly, the technique could be evaluated as highly accurate. Fourie et al. [15] reported high accuracy for surface soft tissue models of CBCT images, which was consistent with the results of this study. Ghafari and Mokhtari [16] evaluated the effect of position of the mandible during image acquisition on reliability of CBCT linear measurements. They reported less than 10% underestimation in the majority of cases before and less than 8% underestimation after tilt correction by the software. Keatmanee et al. [17] used a segmentation procedure named adaptive diffusion flow active contour model to evaluate bone dimensions, and found it to be more accurate than the conventional measurements. This method had significantly improved insertion accuracy for dental implants. Flores-Mir et al. [18] reported 4% underestimation in CBCT measurements, which was consistent with the results of the present study. Safi et al. [19] evaluated the accuracy and inter- and intra-observer reliability of linear measurements made by radiologists and periodontists. They found the observers' experience to be the most important factor in reliability. More accurate localization of anatomical landmarks and boundaries positively affected the results. The CBCT accuracy was not 100% in any study. Safi and colleagues believed that inaccuracy was due to voxel extension and the fact that the observers might include different parts of a voxel in the measurement[19].

In the present study, the highest repeatability was seen in the left molar (0.987), left premolar (0.985) and central regions (0.983). The lowest repeatability was seen in the right premolar area (0.938). The mean repeatability of CBCT linear measurements was calculated to be 0.865 ($P<0.001$). Fourie et al. [15] reported that CBCT linear measurements of soft tissue surface model were even more repeatable than anthropometric measurements. According to Safi et al, [19] and the present study, the repeatability of optimized CBCT images is excellent.

In this study, the highest external agreement was found in the left molar (0.989), midline (0.988), and right molar (0.981) regions. The lowest external agreement was obtained in the right premolar region (0.942). The mean external agreement in CBCT linear measurements was excellent (0.972) ($P <0.001$). Moshfeghi et al. [20] found high inter- and intra-observer reliability even with different voxel sizes. Ghaffari and Mokhtari [16] reported high inter- and intra-observer agreements in linear measurements before and after tilt correction. Safi and colleagues [19] reported almost complete inter and intra-observer agreements. They concluded that the observer's experience and skills are the most important factors concerning inter

and intra-observer agreements.

Conclusion

According to the results, it seems that CBCT linear measurements are highly accurate and reliable, and redrawing the panoramic line at different times does not significantly impair the repeatability of linear measurements.

Conflict of Interest

No benefits have been or will be received from a commercial party related directly or indirectly to the subject matter of this article. ■

References

1. Mallya SM, Lam EW. Oral radiology: Principles and interpretation. 8th ed., St Louis: Mosby/Elsevier; 2019; 10:151-179
2. Weiss R, Read-Fuller A. Cone beam computed tomography in oral and maxillofacial surgery: An evidence-based review. Dent J (Basel) 2019 May;7(2):52.
3. Jain S, Choudhary K, Nagi R, Shukla S, Kaur N, Grover D. New evolution of cone-beam computed tomography in dentistry: Combining digital technologies. Imaging Sci Dent 2019 Sep;49(3):179-90.
4. Worthinigton P, Lang BR, Rubenstein JF: Osseo integration in dentistry: An overview. 2nd Ed., Chicago: Quintessence Publishing Co., 2003; 3:145-175
5. 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 May;4:244-50.
6. Jacobs R. Preoperative radiologic planning of implant surgery in compromised patients. Periodontol 2000.2003;33:12-25.
7. Marmulla R, Wörtche R, Mühling J, Hassfeld S. Geometric accuracy of the NewTom 9000 Cone Beam CT. Dentomaxillofac Radiol 2005 Jan;34(1):28-31.
8. Flores-Mir Carlos, Rosenblatt Mark R, Major Paul W, Carey Jason P, Heo G. Measurement accuracy and reliability of tooth length on conventional and CBCT reconstructed panoramic radiographs. Dental Press J Orthod. 2014 Sep-Oct;19(5):45-53.
9. 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 Nov; 44(4):257-62.
10. Shavit I, Juodzbalys G. Inferior alveolar nerve injuries following implant placement. Importance of early diagnosis and treatment: a systematic review. J Oral Maxillofac Res. 2014 Oct-Dec;5(4):e2.
11. Morad, G, Behnia H, Motamedian SR, Shahab S, Gholamin P, Khosraviani K, et al. Thickness of labial alveolar bone overlying healthy maxillary and mandibular anterior teeth. J Craniofac Surg 2014 Nov; 25(6): 1985-91.
12. Behnia, H, Motamedian SR, Kiani MT, Morad G, Khojasteh A. Accuracy and reliability of cone beam computed tomographic measurements of the bone labial and palatal to the maxillary anterior teeth. Int J Oral Maxillofac Implants 2015 Nov-Dec;30(6):1249-55.
13. Berco M, Rigali PH Jr, Miner RM, DeLuca S, Anderson NK, Will LA. Accuracy and reliability of linear cephalometric measurements from cone-beam computed tomography scans of a dry human skull. Am J Orthod Dentofacial Orthop 2009 Jul;136(1):17.e1-9
14. 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 May;78(3):387-95.
15. Fourie Z, Damstra J, Gerrits PO, Ren Y. Accuracy and repeatability of anthropometric facial measurements using cone beam computed tomography. CLEFT PALATE-CRAN J Sep 2011;48(5):623-30.
16. Ghaffari R, Mokhtari M. Effect of mandible orientation on reliability and reproducibility of linear measurements using cone-beam computed tomography. J Res Dent Sci. 2014 Winter;10(4):218-27.
17. Keatmanee C, Makhanov SS, Kotani K, Kondo T, Thongvigitmanee SS. Inferior alveolar canal segmentation in cone beam computed tomography images using an adaptive diffusion flow active contour model. MVA2015 IAPR International Conference on Machine Vision Applications, May 18-22, 2015, Tokyo, JAPAN.
18. Flores-Mir C, Rosenblatt MR, Major PW, Carey JP, Heo G. Measurement accuracy and reliability of tooth length on conventional and CBCT reconstructed panoramic radiographs. Dental Press J Orthod. 2014 Sep-Oct;19(5):45-53.
19. Safi Y, Kadkhodazadeh M, EsmaeilNejad A, Vasegh Z, Amid R, Khalighi HM, et al. Reliability and Reproducibility of Linear Measurements of Alveolar Ridges Using Cone-beam CT Made by Radiologists and Periodontists. J Periodontol Implant Dent. 2015;7(2):35-39.
20. Moshfegh M, Tavakoli MA, Tavakoli Hosseini E, Tavakoli Hosseini A, Tavakoli Hosseini I. 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.

How to cite:
Hourieh Bashizadeh Fakhar, Milad Soleimani, Mohammad Haj seyyed Nasrollah. Reliability of Linear Measurements Made on Reconstructed CBCT Images. J Dent Sch 2019;37(4):108-111.