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A Robust Model to Test the Accuracy of Cone Beam Computed Tomography Linear Measurements

Mohamed Ahmed Alkhodary[1,2,*], Abd Elaleem Hassan Elsantawy[3], Abeer Mohamed Ettesh[3]

[1]Department of Prosthetic Dental Sciences, College of Dentistry, Qassim University, Al Mulidaa, Kingdom of Saudi Arabia
[2]Department of Prosthodontics, Faculty of Dentistry, Alexandria University, Alexandria, Egypt
[3]Department of Oral and Maxillofacial Surgery & Diagnostic Sciences, College of Dentistry, Qassim University, Al Mulidaa, Kingdom of Saudi Arabia
*Corresponding author: dr.mohamed.alkhodary@qudent.org

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Abstract In planning for placement of dental implants in edentulous mandibles, the accuracy of the linear measurements of the cone beam computed tomography (CBCT) has been questioned. This study used a digital caliper as the gold standard to which linear measurements taken from CBCT were compared. Customized aluminum screws, 2.8 mm in diameter and 11-12 mm in length, were used as dental implant analogues in the canine, premolar, and molar regions in completely edentulous synthetic polyurethane mandibles. A 2 mm aluminum wire was used as the mandibular canal. A total of 240 readings by the digital caliper and the CBCT were recorded for the screws length and diameter, mandibular canal wire diameter, and the distance from the apices of the screws to the superior border of the mandibular canal wire. The statistical analysis was performed using the paired sample T test, with a p value of .05 considered statistically significant. Statistically significant differences between the digital caliper readings and those of the CBCT were recorded in the canine, premolar and molar regions where all the over-and under-estimations did not exceed half a millimeter. The statistically significant discrepancies found in the linear measurements of the CBCT were less than 1 mm, and therefore did not exclude the CBCT from being a beneficial tool in the planning for dental implant placement. However, it is important to note that the results of this study and cannot be generalized to all CBCT machines as they are not created equal by different manufacturers.

Keywords: *cone beam computed tomography, linear measurements, completely edentulous mandibles*

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1. Introduction

Accuracy of the linear measurements provided by radiographs are major contributors in the success of dental implant treatment. [1,2] After the extraction of teeth, the alveolar process resorption becomes a continuous process until almost all of it is lost, and presurgical planning becomes crucial for evaluation of the remaining bone width and height, and for proximity to the adjacent mandibular canal or the sinus floor in the maxilla. [3-9].

Orthopantomography is a valuable diagnostic imaging modality, however, its two dimensionality renders the reconstruction of cross sectional images impossible. Tomograms on the other hand provide three dimensional visualizations with the possibility of reconstruction of axial and para-axial images. An example of such tomograms is the computed tomography (CT), and its more recent form adopted for dentistry that is the cone beam computed tomography (CBCT) which provides accurate imaging and lower radiation doses than the CT. [3,10-24].

Nevertheless, several studies have doubted the accuracy of the CBCT images in the determination of the actual sizes during the assessment of the implant site, accordingly, the accuracy of the CBCT data obtained related to distance measurements needed further investigation [8,25-29].

Meanwhile, Industrial calipers provide direct measurements of linear distances and are considered the gold standard to which virtual measurements can be compared. [6,8,10,23]

This study aimed to compare the CBCT linear measurements to digital caliper readings in a custom developed model made up of an artificial mandible, customized screws used as implant analogues, and a metal wire representing the mandibular canal.

2. Materials and Methods

Forty aluminum threaded screws, 2.8 mm in diameter, cut to an approximate length of 11-12 mm, were used as implant analogues in the locations of the canines, premolars, and the first and second mandibular molars in three completely edentulous synthetic polyurethane mandibles. To simulate the mandibular canal, a trough

was drilled near the inferior end of the mandibles and a 2mm aluminum wire was placed in it, and secured at both end with white epoxy resin. Finally, vertical sluts were drilled from the created mandibular canal toward the alveolar process to expose the inferior ends of the implants analogs as seen in Figure 1.

A plastic tube of 150 cm length and 20 cm diameter, with one of its ends covered with a transparent plastic sheet, was used as a stand for the artificial mandibles. The occlusal planes of the mandibles were made parallel to the floor, while the midsagittal plane was perpendicular to the floor. The CBCT unit GALILEOS Comfort Plus (Sirona, Germany) was used to scan the artificial mandibles. The CBCT unit operated at 98 kV, 3-6 mA, a focal spot size of 0.5 mm, and reconstructed the cross sectional images with the software SIDEXIS XG (Sirona, Germany) which was used for acquisition and processing of the images, and for measurement of the linear distances specified as seen in Figure 2, and Figure 3.

Figure 1. The polyurethane synthetic mandible with the implant analogues and the wire representing the mandibular canal

Figure 2. The mandible mounted in the focal trough of the CBCT unit GALILEOS Comfort Plus

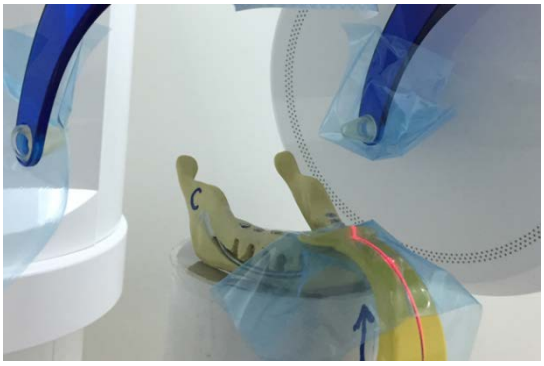

Figure 3. The occlusal plane of the mandible mounted parallel to the floor and their midsagittal plane perpendicular to the floor

A total of 120 digital caliper readings and 120 CBCT readings were recorded. The implant analogues length and diameter, the mandibular canal wire diameter, and the distance from the apices of the implant analogues to the superior border of the wire in the mandibular canal in a vertical direction through the vertical sluts. The direct caliper measurements were considered as the control values to which the CBCT linear measurements were compared.

In order to avoid intra-examiner bias and inter-examiner variability, the digital caliper and the CBCT readings were recorded twice, in a two-week interval, with the examiners repeating each other's readings. The readings of the linear measurements were collected, tabulated and statistically analyzed using the paired sample *T* test, with a level of significance of $p \leq 0.5$.

3. Results

The caliper and the CBCT measurements were considered for the region rather than individual tooth site. The measurements in each region were statistically analyzed using the paired *T* test. In the canine region, there were no significant differences between the recorded linear measurements except for the overestimation in the CBCT reading by 0.033 mm in the distance from the apices of the implant analogues to the top of the wire as seen in Table 1.

In the premolar region, there was also an overestimation in CBCT measurements of the screw length by 0.47 mm, and an underestimation in the wire diameter by 0.31 mm as seen in Table 2. However, the rest of the readings did not show any statistically significant differences.

In the molar region, there was a significant underestimation in the CBCT readings, by 0.09 mm, in the screw diameter as compared to the digital caliper measurement as seen in Table 3.

Table 1. Caliper and CBCT measurements in the canine region

Measured item	Measurement tool	Mean	Std. Deviation	t	p
Screw length	Caliper	11.8600	0.00000	0.122	0.908
	CBCT	11.8933	0.10875		
Screw diameter	Caliper	2.0000	0.00000	-0.751	0.487
	CBCT	1.9000	0.28858		
Wire diameter	Caliper	4.8983	0.50980	0.849	0.435
	CBCT	5.3533	0.38224		
Distance from screw to wire	Caliper	2.8600	0.00000	-2.911	0.033*
	CBCT	2.8933	0.10875		

*Paired t test, $p \leq .05$ is considered significant.

Table 2. Caliper and CBCT measurements in the premolar region

Measured item	Measurement tool	Mean	Std. Deviation	t	p
Screw length	Caliper	11.4067	0.67590	-3.127	0.010*
	CBCT	11.8767	0.48775		
Screw diameter	Caliper	2.8450	0.05196	-1.260	0.234
	CBCT	2.8683	0.03215		
Wire diameter	Caliper	2.0000	0.00000	12.355	P<0.001*
	CBCT	1.7133	0.08038		
Distance from screw to wire	Caliper	6.6058	0.97064	2.016	0.069
	CBCT	6.1108	0.41456		

*Paired t test, $p \leq .05$ is considered significant.

Table 3. Caliper and CBCT measurements in the molar region

Measured item	Measurement tool	Mean	Std. Deviation	t	p
Screw length	Caliper	11.6783	0.78365	-2.144	0.055
	CBCT	11.8958	0.72883		
Screw diameter	Caliper	2.8600	0.00000	3.352	0.006*
	CBCT	2.7733	0.08958		
Wire diameter	Caliper	2.0000	0.00000	-0.687	0.507
	CBCT	2.0467	0.23546		
Distance from screw to wire	Caliper	5.8967	1.29223	-0.786	0.448
	CBCT	6.2125	0.50554		

*Paired t test, p≤.05 is considered significant.

4. Discussion

This study was conducted to test the accuracy of the CBCT linear measurements, especially in completely edentulous mandibles, where alveolar bone resorption brings the implants to the near vicinity of the inferior alveolar nerve canal. The study used artificial polyurethane mandibles, basically used for training on placement of dental implants, and the implant analogues were not placed in the inter-mental foramen region since this region has no intervening anatomic structures, and represent a region where the CBCT readings are considered most accurate as proved by Antar et al. [30].

The digital caliper used in this study, to measure direct readings of length, was considered a gold standard of a high accuracy and precision up to 0.01 mm as shown by Shaibah et al. [10].

In this study, the CBCT readings in the canine region have shown an overestimation of 0.033 mm in the length of the space between the apices of the implant analogues to the top of the wire representing the mandibular canal, this discrepancy was consistent with the findings of Antar et al [30] who found deviations in the CBCT linear measurements in the same region.

In the mandibular premolar region, this study has found an over estimation of 0.47 mm in the implant analogues length as recorded by the CBCT, and an underestimation in the diameter of the wire representing the mandibular canal by 0.31 mm. The overestimations in the implant analogues length came in contrast to the findings of Lascala et al, [8] Stratemann et al, [25] Lagravère et al, [26] and Da Silva NC et al [29] on human adult skulls and synthetic mandibles that recorded an underestimation with CBCT images with respect to the reference caliper measurements, and to the findings of Salem et al [3] who did not find any significant difference between the caliper and the CBCT measurements in the mandibular premolar region.

In the molar region, there was an underestimation in CBCT measurement of the implant analogues width by 0.09 mm, this came in contrast to the findings of Amarnath et al [7] who found an overestimation in the width measured in the same region by 0.5 mm. However, the results of this study, and those of Amarnath et al, [7] found that the vertical measurements of the CBCT and caliper were not statistically different.

Considering these contradicting results of the different studies about the accuracy of the CBCT linear measurements, errors in the readings that did not exceed one millimeter were considered accurate and reliable by Da Silva NC et al, [29] Ganguly R et al, [21,34] and Torres MG et al [35].

The minor errors in the linear measurements of the CBCT were attributed to the fact that movement of the patient head exceeding a one voxel can lead to errors in the image reconstruction as have been shown by Brüllmann et al, [16] who also showed that an accuracy greater than a half millimeter cannot be guaranteed due to the slow movement of the image detector in some CBCT units. Based on such explanations, these minor discrepancies do not represent a violation to the validity of the CBCT measurements, which are further proven to be reliable by the work of Gonzalez Cortes et al, [6] Tarazona-Álvarez et al, [23] and Tang et al [24].

Other factors in favor for the CBCT are the low radiation dose, the short scanning time and the appropriate image quality make the CBCT a helpful tool for presurgical planning prior to dental implant insertion.

Finally, the last thing to consider is whether all CBCT scanners are created equal as far as accuracy, and whether the CBCT scanner used in this research is a more accurate or less accurate scanner than those used in the other commercially available CBCT machines, a question which would require further investigation as also has been shown by Abboud et al [36].

5. Conclusions

Within the limitations of this study, and from a clinical perspective, the followings can be concluded:

1. The discrepancies found the in the linear measurements obtained from the CBCT machine used in this study were in the range of a less than one millimeter and can easily be avoided once are known and taken into consideration.
2. The benefits of the CBCT 3 dimensional visualization, and presurgical navigation in dental implant computer guided surgery, make it an indispensable tool, especially with its low radiation dose compared to the medical grade computed tomography.
3. The results of this study cannot be generalized to all CBCT machines, and further investigations are required.

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Statement of Competing Interests

The authors state that there is no conflict of interest.

References

[1] Moshiri, M., Scarfe, W.C., Hilgers, M.L., Scheetz, J.P., Silveira, A.M., and Farmanf, A.G. “Accuracy of linear measurements from imaging plate and lateral cephalometric images derived

from cone-beam computed tomography", *American Journal of Orthodontics and Dentofacial Orthopedics*, 132. 550-560. 2007.

[2] Da Silva, M.B.G., Gois, B.C., Sant'Anna, E.F. "Evaluation of the reliability of measurements in cephalograms generated from cone beam computed tomography", *Dental Press J Orthod*, 18. 53-60. 2013.

[3] Salem, W.S., Dahaba, M.M., Khalifa, S. "Precision of Measurements from Computed Tomography (CT), Cone Beam Computed Tomography (CBCT) and their Reformatted Images in Pre-Operative Implant Assessment: *Int J Surg Res Pract*, 1. 004. 2014.

[4] Daniel Deluiz, *et al*. "Validation of a method using cone beam computed tomography for measuring bone block grafts for the alveolar ridge augmentation" *Musculoskelet Regen*, 2. 1312. 2016.

[5] Purtaji, B., Panjnoush, M., Shamshiri, A., Purtaji, M. "Difference in implant measurements made on cone beam computed tomography scans taken with and without radiographic stent" *Int J Med Res Health Sci*, 12. 84-91. 2016.

[6] Gonzalez Cortes, A.R., Monteiro Gomes, A.F.A., Tucunduva, M.A.P., Arita, E.S. "Evaluation of linear tomography and cone beam computed tomography accuracy in measuring ridge bone width for planning implant placement" Braz J Oral Sci, 11. 116-119. 2012.

[7] Amarnath, G.S., Kumar, U., Hilal M., Muddugangadhar, B.C., Anshuraj, K., Shruthi, C.S. "Comparison of cone beam computed tomography, orthopantomography with direct ridge mapping for pre-surgical planning to place implants in cadaveric mandibles: An *ex-vivo* study" *J Int Oral Health*, 1. 38-42. 2015.

[8] Lascala, C.A., Panella, J., and Marques, M.M. "Analysis of the accuracy of linear measurements obtained by cone beam computed tomography (CBCT-New Tom)" *Dentomaxillofacial Radiology*, 33. 291-294. 2004.

[9] Sisman, Y., Ercan-Sekerci, A., Payveren-Arıkan, M., Sahman, H. "Diagnostic accuracy of cone-beam CT compared with panoramic images in predicting retromolar canal during extraction of impacted mandibular third molars" *Med Oral Patol Oral Cir Bucal*, 20. 74-81. 2015.

[10] Shaibah, W.I., Yamany, I.A., and Jastaniah, S.D. "Physical Measurements for the Accuracy of Cone-Beam CT in Dental Radiography" *Open Journal of Medical Imaging*, 4. 57-64. 2014.

[11] Abu Osman, N.A., Ibrahim, S., Wan Abas, W.A.B., Abd Rahman, H.S., Ting, H.N. "Validation of Cone Beam CT Scan for Measurement of Palatal Depth in Study Casts" *Biomed Proceedings*, 21. 758-76. 2008.

[12] Wikner, J., Hanken, H., Eulenburg, C., Heiland, M., Gröbe, A., Assaf, A.T., et al. "Linear accuracy and reliability of volume data sets acquired by two CBCT-devices and an MSCT using virtual models: a comparative in-vitro study" *Acta Odontol Scand*, 74. 51-9. 2016.

[13] Sabban, H., Mahdian, M., Dhingra, A., Lurie, A.G., 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*, 45. 73-80. 2015.

[14] Thönissen, P., Ermer, M.A., Schmelzeisen, R., Gutwald, R., Metzger, M.C., Bittermann, G. "Sensitivity and specificity of cone beam computed tomography in thin bony structures in maxillofacial surgery-A clinical trial" *J Craniomaxillofac Surg*, 43. 1284-8. 2015.

[15] Maroua, A.L., Ajaj, M., Hajeer, M.Y. "The accuracy and reproducibility of linear measurements made on CBCT-derived digital models", *J Contemp Dent Pract*, 17. 294-9. 2016.

[16] Brüllmann, D., Schulze, R.K. "Spatial resolution in CBCT machines for dental/maxillofacial applications-what do we know today?" *Dentomaxillofac Radiol*, 44. 20140204. 2015.

[17] Menezes, R.F., Araújo, N.C., Santa Rosa, J.M., Carneiro, V.S., Santos Neto, A.P., Costa, V., et al. "Detection of vertical root fractures in endodontically treated teeth in the absence and in the presence of metal post by cone-beam computed tomography" *BMC Oral Health*, 16. 48. 2016.

[18] Khoury, H.J., Andrade, M.E., Araujo, M.W., Brasileiro, I.V., Kramer, R., Huda, A. "Dosimetric study of mandible examinations performed with three cone-beam computed tomography scanners", *Radiat Prot Dosimetry*, 165. 162-5. 2015.

[19] Lukat, T.D., Perschbacher, S.E., Pharoah, M.J., Lam, E.W. "The effects of voxel size on cone beam computed tomography imag-es of the temporomandibular joints" *Oral Surg Oral Med Oral Pathol Oral Radiol*, 119. 229-37. 2015.

[20] Shokri, A., Khajeh, S. "In vitro comparison of the effect of different slice thicknesses on the accuracy of linear measure-ments on cone beam computed tomography images in implant sites" *J Craniofac Surg*, 26. 157-60. 2015.

[21] Ganguly, R., Ramesh, A., Pagni, S. "The accuracy of linear measurements of maxillary and mandibular edentulous sites in cone-beam computed tomography images with different fields of view and voxel sizes under simulated clinical conditions" *Imaging Sci Dent*, 46. 93-101. 2016.

[22] Ludlow, J.B., Laster, W.S., See, M., Bailey, L.T.J., Hershey, H.G. "Accuracy of measurements of mandibular anatomy in cone beam computed tomography images", *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*, 103(4). 534-42. 2007.

[23] Tarazona-Álvarez, P., Romero-Millán, J., Peñarrocha-Oltra, D., Fuster-Torres, M.Á., Tarazona, B., Peñarrocha-Diago, M. "Comparative study of mandibular linear measurements obtained by cone beam computed tomography and digital calipers", J *Clin Exp Dent*. 6(3). E 271-4. 2014.

[24] Tang, Z., Liu, X., and Chen, K. "Comparison of digital panoramic radiography versus cone beam computerized tomography for measuring alveolar bone", *Head & Face Medicine*, 13. 2. 2017.

[25] Stratemann, S.A., Huang, J.C., Maki, K., Miller, A.J., Hatcher, D.C. "Comparison of cone beam computed tomography imaging with physical measures", Dentomaxillofac *Radiol*, 37. 80-93. 2008.

[26] Lagravère, M.O., Carey, J., Toogood, R.W., Major, P.W. "Three-dimensional accuracy of measurements made with software on cone-beam computed tomography images", *Am J Orthod Dentofacial Orthop*, 134. 112-6. 2008.

[27] Brown, A.A., Scarfe, W.C., Scheetz, J.P/, Silveira, A.M., Farman, A.G. "Linear accuracy of cone beam CT derived 3D images" *Angle Orthod*, 79. 150-7. 2009.

[28] Scarface WC, Farman AG, Sukovic P. Clinical applications of cone-beam computed tomography imaging with physical measures. Dentomaxillofac Radiol. 2008; 37: 80-93.

[29] Da Silva, N.C., Barriviera, M., Junqueira, J.L.C., Panzarella, F.K., Ricardo Raitz, R. "Intraobserver and interobserver reproducibility in linear measurements on axial images obtained by cone-beam computed tomography", *Imaging Science in Dentistry*, 47. 11-5. 2017.

[30] Antar, E., Khalifa, M., Hosny, S. "Determination of the Accuracy of Linear and Volumetric Measurements on Cone Beam Computed Tomography Images (In-vitro study)" *EDJ*. 57. 2917-2925. 2011.

[31] Damstra, J., Fourie, Z., Huddleston Slater, J.J., Ren, Y. "Accuracy of linear measurements from cone-beam computed tomography-derived surface models of different voxel sizes", *Am J Orthod Dentofacial Orthop*, 137: 1-7. 2010.

[32] Baumgaertel, S., Martin, J., Palomo, L., Hans, M.G. "Reliability and accuracy of cone-beam computed tomography dental measurements", *Am J Orthod Dentofacial Orthop*, 136. 19-28. 2009.

[33] Glover, G.H., Pelc, N.J. "Nonlinear partial volume artefacts in x-ray computed tomography", *Med Phys*, 7. 238-48. 1980.

[34] 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 condi-tions", *Dentomaxillofac Radiol*, 40. 299-305. 2011.

[35] Torres, M.G., Campos, P.S., Segundo, N.P., Navarro, M., Crusoé-Re-bello, I. "Accuracy of linear measurements in cone beam com-puted tomography with different voxel sizes", *Implant Dent*, 21. 150-5. 2012.

[36] Abboud, M., Calvo Guirado, J.L., Orentlicher, G., Wahl, G. "Comparison of the Accuracy of Cone Beam Computed Tomography and Medical Computed Tomography: Implications for Clinical Diagnostics with Guided Surgery", *J Oral Maxillofac Implants*, 28. 536-542. 2013.