RESEARCH ARTICLE

Accuracy of linear measurements around dental implants by means of cone beam computed tomography with different exposure parameters

^{1,2}Lauren O L Bohner, ¹Pedro Tortamano and ²Juliana Marotti

¹Department of Prosthodontics, School of Dentistry, University of São Paulo, São Paulo, Brazil; ²Department of Prosthodontics and Biomaterials, Center for Implantology, University Hospital RWTH Aachen, Aachen, Germany

Objectives: The aim of this study was to determine the accuracy of linear measurements around dental implants when using CBCT unit devices presenting different exposure parameters.

Methods: Dental implants ($n = 18$) were installed in the maxilla of human dry skulls, and images were obtained using two CBCT devices: G1—Care Stream 9300 (70 kVp, 6.3 mA, voxel size 0.18 mm, field of view 8×8 cm; Carestream Health, Rochester, NY) and G2—R100 Veraview[®] (75 kVp, 7.0 mA, voxel size 0.125 mm, field of view 8×8 cm; J Morita, Irvine, CA). Measurements of bone thickness were performed at three points located (A) in the most apical portion of the implant, (B) 5 mm above the apical point and (C) in the implant platform. Afterwards, values were compared with real measurements obtained by an optical microscopy [control group (CG)]. Data were statistically analyzed with the significance level of $p \leq 0.05$.

Results: There was no statistical difference for the mean values of bone thickness on Point A (CG: 4.85 ± 2.25 mm, G1: 4.19 ± 1.68 mm, G2: 4.15 ± 1.75 mm), Point B (CG: 1.50 ± 0.84 mm, G1: 1.61 ± 1.27 mm; G2: 1.68 ± 0.82 mm) and Point C (CG: 1.78 ± 1.33 mm, G1: 1.80 ± 1.09 mm; G2: 1.64 ± 1.11 mm). G1 and G2 differed in bone thickness by approximately 0.76 mm for Point A, 0.36 mm for Point B and 0.08 mm for Point C. A lower intraclass variability was identified for CG (Point A = 0.20 ± 0.25 ; Point B = 0.15 ± 0.20 ; Point C = 0.06 ± 0.05 mm) in comparison with G1 (Point A = 0.56 ± 0.52 ; Point B = 0.48 ± 0.50 ; Point C = 0.47 ± 0.56 mm) and G2 (Point A = 0.57 ± 0.51 ; Point B = 0.46 ± 0.46 ; Point C = 0.36 ± 0.31 mm).

Conclusions: CBCT devices showed acceptable accuracy for linear measurements around dental implants, despite the exposure parameters used.

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Introduction

Monitoring of the buccal bone that surrounds dental implants is important to ensure the high predictability

of treatment during the follow-up period,¹ as one of the pre-requisites to ensure a successful implant rehabilitation is the determination of an adequate peri-implant bone volume. Especially with the anterior maxilla, which usually presents a limited bone quantity, the buccal wall dimension must be considered to ensure optimal aesthetics and function, as a thickness lower than 2 mm is associated with bone loss and dehiscence.²

Correspondence to: Ms Lauren Oliveira Lima Bohner. E-mail: lauren@usp.br

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Table 1 Description of parameters utilized for CBCT unit devices

CBCT devices	Tube voltage (kVp)	Tube current (mA)	Exposure time (s)	Voxel size (mm)	Field of view
G1	70	6.3	8.03	0.180	8 × 8
G2	75	5	9.40	0.125	8 × 8

G1, Care Stream 9300 (Carestream Health, Rochester, NY); G2, R100 Veraview® (J Morita, Irvine, CA).

CBCT has been widely used in the post-operative phase of dental implants due to its ability in providing tridimensional images of the bone with lower radiation and cost than conventional CT.^{3–5} Several studies reported the use of CBCT to evaluate peri-implant defects^{6–10} and bone wall configuration.^{2,7,11–14} Even though linear measurements performed at tomographic images seem to be slightly lower than real measurements,¹¹ the technique is considered an appropriate method to determine the buccal bone dimension with submillimetre accuracy.¹²

However, in the presence of metallic objects, CBCT is prone to show artefacts, which may jeopardize image quality¹⁵ and hamper the visualization of the implant–bone surface.¹⁶ Hence, it is still questionable whether the measurement performed near dental implants is adequate.¹⁷ Parameters of CBCT devices may be of outmost importance to improve image quality and to enhance evaluation accuracy.^{11,17} Although previous studies evaluated the accuracy of CBCT devices, they usually present different parameters of acquisition, such as a protocol to evaluate dental implants has not yet been determined. Thus, the aim of this study was to determine whether linear measurements around dental implants were accurate when using CBCT unit devices presenting different exposure parameters. The null hypothesis is that there is no difference between the CBCT unit devices.

Figure 1 Implant impression performed in skulls with polyvinyl siloxane.

Methods and materials

Experimental and statistical design

After approval of the Human Research Ethics Committee of the University of São Paulo, Brazil (Protocol 1.121.872), 18 dental implants (Morse Taper 3.75 × 9 mm, Master AR–Morse Porous, Conexão, Arujá-SP, Brazil) were installed in the maxilla of 6 human dry skulls provided by the Institute of Biomedical Sciences from the University of São Paulo. The implants were distributed according to bone availability.

To avoid damage to the skulls, the real measurements (control group) were taken in a cast model, as previously described by Shiratori *et al.*¹² Radiographic images were obtained with two CBCT devices ($n = 18$): G1—Care Stream 9300 (Carestream Health, Rochester, NY) and G2—R100 Veraview® (J Morita, Irvine, CA). The CBCT parameters are described in Table 1.

Acquisition of control group

To fabricate accurate cast models for the control group (CG), an impression from the maxilla of each skull was obtained with individual acrylic resin trays (Figure 1). With this purpose, the maxilla's retentive zones were covered with wax (Asfer, São Caetano do Sul-SP, Brazil) and the uniform thickness of the impression material was assured with the distribution of putty wash (Zetalabor; Zhermack, Rovigo, Italy) on the maxilla before individual tray fabrication. Then, acrylic resin (JET; Clássico, São Paulo, Brazil) was manipulated in accordance with the manufacturer's instructions and applied over the putty wash material. Perforations on the implants were made to allow pick-up implant impression technique.

An impression coping (Pilar Speed; Conexão, São Paulo, Brazil) was fitted for each implant, and the impression was taken with a polyvinyl siloxane impression

Figure 2 (a) Insertion of stone block containing dental implant into a cast base. Stone block (b) before and (c) after the wear, showing the centre of the buccal–lingual diameter of the dental implant, on which measurements were performed.

Figure 3 Cross-sectional images from (a) G1 and (b) G2. G1, Care Stream 9300 (Carestream Health, Rochester, NY); G2, R100 Veraview® (J Morita, Irvine, CA).

material (Futura AD; Rio de Janeiro, RJ, Brazil). Dental stone (Type IV, Durone, Dentsply, Petrópolis, RJ, Brazil) was manipulated according to the manufacturer's instructions and carefully poured onto the impression. After material curing, the stone block containing the implant was individualized with the aid of a saw.

To maintain an adequate measurement plan, each stone block was included into a cast base. For this purpose, the stone block was fitted in the delineator's vertical rod with the assistance of an impression coping. A cylindrical polystyrene structure was perpendicularly coupled to a metal block with accurate measurements ($15.5 \times 10.5 \times 5$ cm), which was used as a holder to determine the perpendicular insertion position of the stone block into the cast base. The set was positioned over the delineator, and a perforation was made on the top of the polystyrene structure to allow the inclusion of the dental stone and of the block

containing the implant into the set. A green dye (Xadrez Lanxess, Porto Feliz, Brazil) was added to the dental stone to enable cast visualization and the material was poured into the perforation. The stone block containing the implant was positioned into the set, and after material curing, the final model was worn out with a mechanical lathe (IDE20-ROMI, Santa Barbara d'Oeste, Brazil) until it reached the centre of buccal–lingual diameter, on which the buccal bone thickness was determined (Figure 2).

Acquisition of CBCT images

CBCT acquisitions were performed with each skull positioned over a plastic box used as a holder. The standardized position of the skull was ensured with silicon guides fitted over the box and a duct tape around the skull. All the skull images were obtained by a specialist in oral radiology. For the measurement, cross-sectional images containing the centre of each dental implant were obtained and saved as digital imaging and communications in medicine files. The same image was used for all measurements (Figure 3).

Measurement of bone thickness

Buccal bone thickness was determined at three points: (A) bone thickness from the apical portion of the implant; (B) bone thickness from the outer surface of the implant threads located 5 mm above the apical point of the implant; (C) vertical distance between the implant platform and the alveolar crest (Figure 4). Each sample was measured three times (repeated measurements) with the interval of 1 week between measurements.

Figure 4 Points of measurements: Point A, horizontal distance between the most apical point of implant and the bone surface; Point B, horizontal distance between a reference point positioned 5 mm above the apical point of the implant and the bone surface; and Point C, vertical distance between the top of implant and the bone surface.

Table 2 Mean $\pm$ standard deviation values (mm) for measurements of bone thickness at each point (A, B and C)

	Point A	Point B	Point C
CG	4.85 ± 2.25	1.50 ± 0.84	1.78 ± 1.33
G1	4.19 ± 1.68	1.61 ± 1.27	1.80 ± 1.09
G2	4.15 ± 1.75	1.68 ± 0.82	1.64 ± 1.11

CG, control group; G1, Care Stream 9300 (Carestream Health, Rochester, NY); G2, R100 Veraview® (J Morita, Irvine, CA).

Table 3 Estimated regression coefficients of bone thickness (mm) at Points A, B and C

Point	Coefficient	Estimated	Standard error	p-value
A	(Intercept)	4.93	0.46	0.00
	G1	-0.74	0.43	0.09
	G2	-0.78	0.43	0.08
	$\sigma = 1.41$	$\sigma_a = 1.42$		
B	(Intercept)	1.46	0.26	<0.001
	G1	0.40	0.35	0.27
	G2	0.32	0.365	0.37
	$\sigma = 0.93$	$\sigma_a = 0.37$		
C	(Intercept)	1.73	0.29	<0.001
	G1	0.07	0.35	0.83
	G2	-0.09	0.35	0.79
	$\sigma = 1.04$	$\sigma_a = 0.57$		

σ , model variability; σ_a , individual variability; G1, Care Stream 9300 (Carestream Health, Rochester, NY); G2, R100 Veraview® (J Morita, Irvine, CA).
 $p < 0.05$ means statistical significant difference.

For the control group, measurements were performed by an experienced examiner with the aid of an optical microscopy (Mituoyo, Santo Amaro, Brazil). For the CBCT devices, images from the region of each implant were obtained and evaluated with specific software (OsiriX; Pixmeo, Geneva, Switzerland), as described by Kim et al.¹⁸

Statistical analysis

Initially, a linear mixed-effect model was individually applied for repeated measurements and for the mean values of bone thickness. In both cases, a random effect of dental implant was regarded. Analyses included the agreement between each CBCT technique and the

Figure 5 95% Confidence interval (95% CI) plots for measurement values of bone thickness determined by CBCT devices at each point (A, B and C). CG, control group; G1, Care Stream 9300 (Carestream Health, Rochester, NY); G2, R100 Veraview® (J Morita, Irvine, CA).

Table 4 Intraclass variability (mm) for repeated measurements on each point (A, B and C)

	Point A	Point B	Point C
CG	0.20 ± 0.25	0.15 ± 0.20	0.06 ± 0.05
G1	0.56 ± 0.52	0.48 ± 0.50	0.47 ± 0.56
G2	0.57 ± 0.51	0.46 ± 0.46	0.36 ± 0.31

CG, control group; G1, Care Stream 9300 (Carestream Health, Rochester, NY); G2, R100 Veraview® (J Morita, Irvine, CA).

control group (CG × G1, CG × G2 and G1 × G2). These analyses were performed with Bland–Altman plots, concordance correlation and Pearson correlation coefficients.¹⁹ The concordance correlation coefficient is related to measurements accuracy, as it determines how the mean value deviates from the 45° line, whereas Pearson correlation coefficient allows evaluating exactness, based on the deviation of each measurement from the 45° line. Statistical analysis was performed with the specific software (R v. 3.2; R Core Team, 2015), with a statistical significance level of $p \leq 0.05$.

Results

There was no statistical difference for the mean values of bone thickness, although both groups (G1 and G2) differed in bone thickness by approximately 0.76 mm for Point A, 0.36 mm for Point B and 0.08 mm for Point C (Tables 2 and 3). The 95% bone thickness confidence intervals are shown in Figure 5.

A lower intraclass variability was identified for CG in comparison with G1 and G2 for all points (A, B and C), as shown in Tables 4 and 5. When compared with CG, both CBCT groups showed high measurement value accuracy; however, moderate exactness values were found for Points A, B and C (Table 6, Figures 6–8).

Table 5 Estimated regression coefficients for intraclass variability (mm) on Points A, B and C

Point	Coefficient	Estimated	Standard error	DF	T-value	p-value
A	(Intercept)	0.19	0.11	32.00	1.74	0.09
	G1	0.36	0.13	32.00	2.84	0.08
	G2	0.37	0.13	32.00	2.91	0.07
	$\sigma = 0.37$	$\sigma_a = 0.26$				
B	(Intercept)	0.12	0.07	21.00	1.53	0.13
	G1	0.25	0.10	21.00	2.43	0.02
	G2	0.28	0.10	21.00	2.59	0.01
	$\sigma = 0.28$	$\sigma_a = 0.11$				
C	(Intercept)	0.06	0.06	32.00	0.63	0.53
	G1	0.41	0.41	32.00	3.23	0.00
	G2	0.30	0.30	32.00	2.38	0.02
	$\sigma = 0.37$	$\sigma_a = 0.05$				

σ , model variability; σ_a , individual variability; DF, degree of freedom; G1, Care Stream 9300 (Carestream Health, Rochester, NY); G2, R100 Veraview® (J Morita, Irvine, CA).
 $p < 0.05$ means statistical significant difference.

Table 6 Estimated bias, concordance correlation coefficient (C_b) and Pearson correlation coefficient (r) for comparison of groups CG, G1 and G2

Comparison	Point	Estimated bias	Confidence interval (95%)		C_b	r
			Inf.	Sup.		
G1 $\times$ CG	A	0.73	-2.16	3.63	0.86	0.77
	B	0.87	-3.03	3.20	0.89	0.29
	C	1.26	-3.67	3.34	0.96	0.31
G2 $\times$ G1	A	0.04	-3.36	3.45	0.99	0.50
	B	0.84	-2.63	2.77	0.90	0.44
	C	0.72	-1.91	2.24	0.98	0.54

CG, control group; G1, Care Stream 9300 (Carestream Health, Rochester, NY); G2, R100 Veraview[®] (J Morita, Irvine, CA); inf., inferior; sup., superior.

Discussion

The evaluated CBCT devices showed reliability for linear measurements around dental implants. Hence, the results rely on the indication of CBCT as an accurate technique for post-operative follow-up of dental implants. The choice of an imaging technique is clinically important to determine the need of surgical correction procedures if the implant is not covered by bone. In this case, an accurate measurement of bone volume and crestal bone changes is essential to determine the

stability of the treatment and to define treatment planning.^{20,21}

In this study, linear measurements performed by CBCT showed good reproducibility, as similar values were found on repeated measurements. These results were previously confirmed by Shiratori *et al*,¹² who showed excellent CBCT reliability for the evaluation of buccal bone thickness. However, the authors evaluated results from a single CBCT device, which does not reflect the accuracy of different systems in clinical practice, as the CBCT devices may differ according to their settings and image resolution. The comparison performed in the present study extended the results to CBCT devices with different exposure parameters.

The first question reported in this study was whether CBCT unit devices could perform accurately to measure the buccal bone thickness and crestal alveolar defects closer to dental implants. No statistically significant difference between the CBCT measurements and the reference standard was found. Previous researches already reported the accuracy of CBCT for linear measurements using different devices.^{1,2,11–13}

Image resolution is determined by exposure parameters, such as the field of view (FOV) and voxel size.²² In this sense, better resolution will be prone to a reduced measurement error.¹⁴ In this study, the exposure parameters were chosen based on the manufacturer's

Figure 6 Bland-Altman plots for Point A. C_b , concordance correlation coefficient; CG, control group; G1, Care Stream 9300 (Carestream Health, Rochester, NY); G2, R100 Veraview[®] (J Morita, Irvine, CA); r , Pearson correlation coefficient.

Figure 7 Bland-Altman plots for Point B. C_b , concordance correlation coefficient; CG, control group; G1, Care Stream 9300 (Carestream Health, Rochester, NY); G2, R100 Veraview® (J Morita, Irvine, CA); r , Pearson correlation coefficient.

recommendation and after a pilot test, on which the image quality was visually analyzed. Although both CBCT unit devices allow multiple FOVs, the one used here was considered appropriate for dental implants imaging. However, further studies should include the comparison of different FOVs when used for this purpose.

The different voxel sizes provided by the CBCT unit devices did not affect the accuracy of linear measurements. Similarly, Torres *et al*²² showed comparable accuracy among four devices with voxel sizes of 0.2, 0.25, 0.3 and 0.4 mm. However, Razavi *et al*¹¹ found reliable results with a voxel size of 0.12 mm, whereas a voxel size of 0.3 mm was not accurate to determine vertical and horizontal measurements of bone thickness around dental implants. The main contrast between these studies was that Razavi *et al*¹¹ presented greater difference of voxel sizes, which may explain the contradicting results.

A different response was expected according to the quantity of metal artefact, as it is considered dependent on the X-ray tube voltage¹⁴ and on the CBCT device.²⁰ Beam-hardening artefacts usually occur around metallic materials due to the absorption of X-ray photons by high-density materials such as titan dental implants and may affect the bone linear measurement reliability.¹⁷ In

this study, no method of artefact reduction was used. Although it was not the scope of this study to evaluate the presence of metal artefacts, it seems they did not affect linear measurements. Similar studies already reported no influence of artefacts in the evaluation of buccal bone thickness¹² or peri-implant defect size.²⁰

A second aspect observed in this study was whether the location of measurement could influence CBCT accuracy. Thus, points of interest presenting different thicknesses were considered for evaluation. The results suggested no influence of bone thickness on accuracy of measurements.

However, it is still unknown whether CBCT is accurately reproducible in sites with thinner buccal bone.¹ Gonzales-Martins *et al*⁹ evaluated measurement of buccal bone with three CT devices with different voxel sizes (0.6, 0.3 and 0.2 mm). The authors reported that bone thickness influenced radiographic visibility, as all devices showed an underestimation of buccal bone thickness. The lower the bone thickness, the lower was the accuracy of CBCT devices.

Similarly, Torres *et al*²² found a different measurement error for bone thickness and height and attributed this finding to the difficulty to accurately measure smaller bone distances when using voxel measuring between 0.2 and 0.4 mm. In this study, this underestimation was

Figure 8 Bland-Altman plots for Point C. C_b , concordance correlation coefficient; CG, control group; G1, Care Stream 9300 (Carestream Health, Rochester, NY); G2, R100 Veraview® (J Morita, Irvine, CA); r , Pearson correlation coefficient.

not observed. It must be noted that none of the evaluated region had a bone thickness <0.9 mm. Furthermore, the voxel size was lower in comparison to previous studies. Based on these data, it is suggested that the voxel size should be less or at least equal to the threshold thickness to ensure visibility of the bone-implant interface.

The need of developing a protocol for implant therapy is based on clinical efficacy of CBCT for outcome assessment and treatment decision. Different imaging protocols result in different radiation doses. An imaging protocol should provide acceptable diagnostic quality with minimal radiation dose, which is achieved by the smallest FOV and optimal exposure parameters.²³

Recently, the American Academy of Oral and Maxillofacial Radiology recommended the use of cross-sectional imaging for post-operative imaging of dental implants in the presence of implant mobility or clinical signals and symptoms of failure. It should not be used, however, for periodic review of asymptomatic implants. In this case, intraoral periapical radiography and panoramic images are indicated for the assessment of dental implants.²³

These recommendations are based on the “as low as reasonably achievable” principle, as the dose radiation provided by CBCT are greater than the one provided by intraoral imaging. Whereas the effective dose reported for the CBCT unit devices used in this study is up to

$76 \mu\text{Sv}$,²⁴ a previous study reported an effective dose from 1 to $5 \mu\text{Sv}$ for periapical radiography.²⁵

It must be considered that one of the most important criteria of a high-predictability treatment is to ensure bone coverage around the dental implant. CBCT allows diagnosing bone changes, which leads to appropriate treatment planning and avoids serious complications.⁶

Conclusions

CBCT devices showed acceptable accuracy to perform linear measurements around dental implants, which was comparable among CBCT unit devices using different exposure parameters.

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