Assessing the Accuracy of Cone-Beam Computerized Tomography in Measuring Thinning Oral and Buccal Bone

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The aim of this study was to assess the accuracy and reliability of cone-beam computerized tomography (CBCT) in measuring thinning bone surrounding dental implants. Three implants were inserted into the mandible of a domestic pig at 6 different bone thicknesses on the vestibular and the lingual sides, and measurements were recorded using CBCT. The results were obtained, analyzed, and compared with areas without implants. Our results indicated that the bone thickness and the neighboring implants decreased the accuracy and reliability of CBCT for measuring bone volume around dental implants. We concluded that CBCT slightly undermeasured the bone thickness around the implant, both buccally and orally, compared with the same thickness without the implant. These results support that using the i-CAT NG with a 0.2 voxel size is not accurate for either qualitative or quantitative bone evaluations, especially when the bone is thinner than 0.72 mm in the horizontal dimension.

Key Words: cone-beam computerized tomography, dental implants, i-CAT, implant imaging

INTRODUCTION

Cone-beam computerized tomography (CBCT) has been used for implantation in the craniofacial region since 1998. Each CBCT system has different features, including field of view, voxel size, patient positioning system, and imaging durations.[1] These parameters affect the diagnostic image quality, noise, high and low contrast resolution, and artifacts.[2]

With CBCT, image data are acquired in a digital format using a single 360° rotation scan. Voxel sizes are determined by width, height, and thickness.[3] The most effective way to decrease the influence of partial volume averaging is to decrease the voxel size. However, there is a trade-off when using smaller voxel sizes, as they require more radiation and are more prone to noise.[4]

Beam-hardening artifacts, such as scatter and noise, are the most prominent artifacts induced by high-density objects in the beam. The polychromatic X-ray beam gradually becomes harder because of its absorption by matter. In other words, the sensor records high energy because only the higher-energy rays penetrate the implant.[5] Thus, beam hardening, caused by the predominant absorption of low-energy X rays[2] increases the mean beam energy after the beam passes through the metal object.

The main applications for CBCT are presurgical evaluation of bone quantity and quality for implant dentistry and implant placement planning.[2,6] Bone quality and quantity also influenced resultant stress distribution; furthermore, in the presence of peri-implant inflammation, bone quantity and characteristics may influence the progression of peri-implantitis bone loss at dental implants.[7,8] Thus, CBCT is primarily used to measure the volume of buccal bone around dental implants as well as the height between the implant platforms. It can also be used to measure the thickness of the alveolar bone contacting the implant. Compared with the basal bone in the jaws, the alveolar bone is more difficult to visualize and measure because it is thin and located in close proximity to the teeth and the periodontal ligament.[9]

Understanding the accuracy of CBCT is critical; hence, many researchers have tried to evaluate it.[3] Several studies have demonstrated that CBCT measurements of the dimensions of peri-implant bony defects differ slightly from direct measurements.[10] Additionally, it has been shown that voxel size influences the resolution of the thin cortical bone adjacent to dental implants. As a result, the measurements may not be accurate.[1]

The aim of this study was to evaluate the accuracy of CBCT in measuring cortical bone thickness adjacent to dental implants by using a bone-thinning procedure on the buccal and oral sides.

MATERIALS AND METHODS

We examined the peri-implant alveolar bone quantity in a fresh domestic pig mandible; we used a young domestic pig (6

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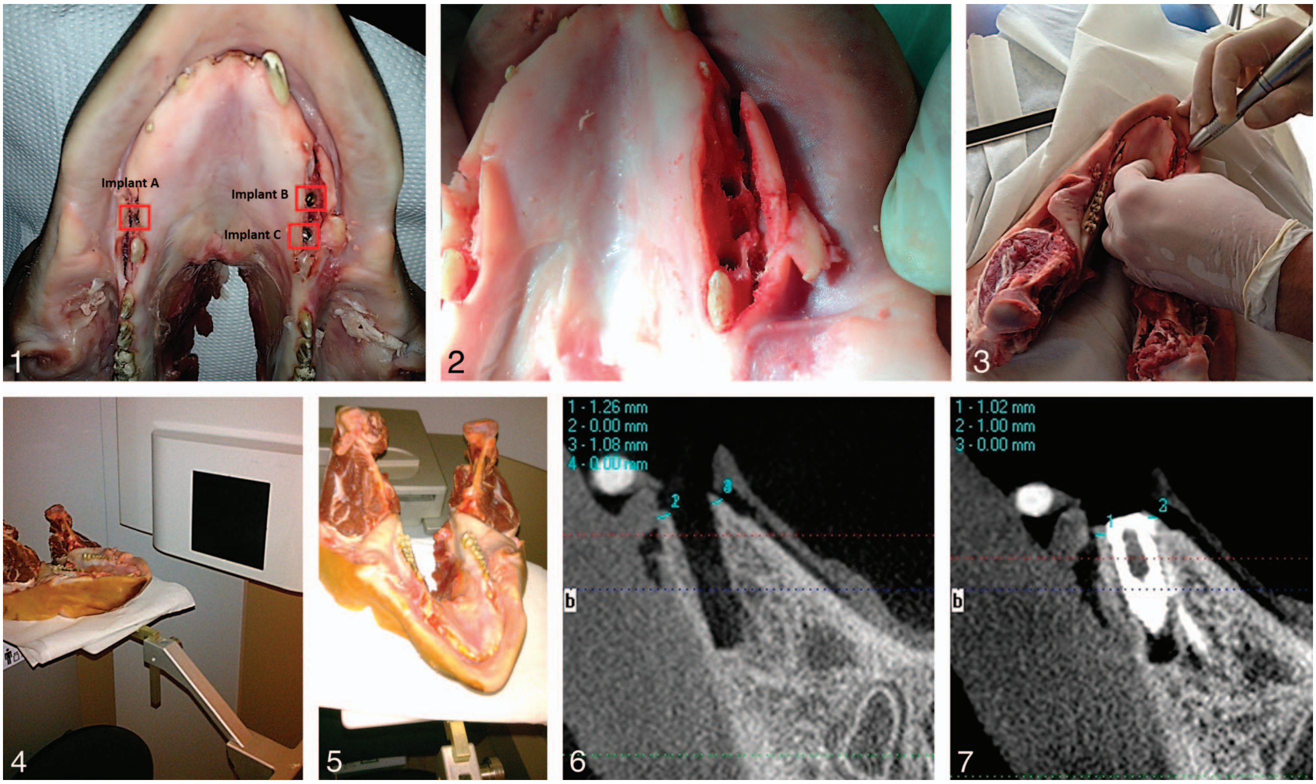

Figures 1–7. Figure 1. Implants A, B, and C in the pig mandible. **Figure 2.** Thinning conditions in the mandible. **Figure 3.** Thinning in progress. **Figure 4.** The pig mandible seen in the cone-beam computerized tomography imaging. **Figure 5.** Close-up of the pig mandible in the cone-beam computerized tomography imaging scan. **Figure 6.** A single cross-sectional image without the implant at midline. **Figure 7.** A single cross-sectional image with the implant at midline.

months old; 140 kg) with healthy muscles, gingiva, and skin. Pigs' anatomic features are similar to those of humans, and the pig is an established animal model in several areas of biomedical and pharmacologic research.[11,12]

Implant site preparation

All implants were inserted using a full-thickness flap elevation technique with Camlog surgical instruments (Camlog Biotechnologies AG, Basel, Switzerland) at the bone level and, in some places, with minimal submersion (depth <0.5 mm). The position of the implants was determined by the bone volume, as the protocol used defined a distance <2 mm from the implant neck on both the buccal and the oral sides. The flap elevation was made gently with a surgical scalpel and raspatorium to ensure the correct placement and depth. A constant internal cooling procedure was used during the implant site preparation to avoid overheating the implant-bone interface and causing any measurement distortion. All implant-site preparation steps were made following the Camlog protocols to avoid any distortion in implant quantity and quality.

The following 3 Camlog Screwline implants were included in the study: (1) 4.3-mm diameter, 11-mm length on the left side (implant A); (2) 3.8-mm diameter, 11-mm length on the right side (implant B); and (3) 3.8-mm diameter, 13-mm length on the right side (implant C). In total, 3 implants were used (marked as implants A to C).

Bone thinning around the implants

Three implants were placed in the pig mandible. The implant with the largest diameter was placed on the left side (implant A); the 2 implants placed on the right side were slightly thinner (implants B and C; Figure 1). The purpose of using thicker implants was to understand how their thickness influenced the evaluation of peri-implant bone volume and quality using CBCT, particularly at the edge of the alveolar process. The purpose of using 2 implants on one side was to examine the scattering of the X rays by metal artifacts and the effect on evaluation of bone volume and quantity. The 2 neighboring implants located on the right side were placed more than 3 mm from each other, according to surgical protocols.

After placing the first implant, the dental implants were removed, and the buccal and oral cortical plates of alveolar bone were flattened using a Lindeman bur drill (DDS Gadget, Aventura, Fla) for forming and shaping. This made the surface uniform and ensured accurate measures (Figures 2 and 3). The gradual thinning was executed in 5 phases; measurements were obtained after each phase. As a control measurement, the horizontal dimensions of both the buccal and oral cortical plates were taken after each of the 5 phases to generate 5

Table

Standard deviations of cone-beam computerized tomography (CBCT) measures with and without implants

	Implant A							Implant B							Implant C						
	Bone Thickness Measurements on CBCT Without Implants			Bone Thickness Measurements on CBCT With Implants			SD	Bone Thickness Measurements on CBCT Without Implants			Bone Thickness Measurements on CBCT With Implants			SD	Bone Thickness Measurements on CBCT Without Implants			Bone Thickness Measurements on CBCT With Implants			SD
B0	1.34	1.34	1.34	1.28	1.34	1.26	4%	1.61	1.65	1.65	1.46	1.41	1.41	12%	1.22	1.26	1.28	1.17	1.22	1.22	4%
B1	1.22	1.22	1.26	1.08	1.26	1.22	7%	1.26	1.26	1.26	1.26	1.22	1.24	2%	1.00	1.08	1.08	1.02	1.00	1.04	4%
B2	0.89	1.00	0.89	0.85	0.82	0.78	8%	0.98	0.92	0.92	0.89	0.85	0.89	4%	0.82	0.85	0.85	0.82	0.84	0.84	1%
B3	0.72	0.82	0.82	0.72	0.45	0.63	14%	0.82	0.82	0.82	0.63	0.63	0.55	12%	0.72	0.68	0.72	0.45	0.45	0.41	15%
B4	0.45	0.45	0.45	0.36	0	0	22%	0.60	0.60	0.64	0	0	0	34%	0.32	0.32	0.36	0	0	0	18%
B5	0.28	0.26	0.28	0.28	0	0	14%	0.32	0.28	0.32	0	0	0	17%	0.28	0.28	0.28	0	0	0	15%
O0	1.56	1.56	1.61	1.41	1.44	1.44	8%	1.34	1.34	1.26	1.27	1.2	1.22	6%	1.41	1.40	1.41	1.46	1.41	1.46	3%
O1	1.28	1.34	1.34	1.12	1.28	1.28	8%	1.28	1.28	1.26	1.26	1.22	1.17	4%	1.12	1.14	1.12	1.08	1.06	1.06	3%
O2	1.13	1.15	1.15	0.92	1.08	1.02	9%	1.17	1.12	1.12	0.89	0.92	0.92	13%	0.89	0.89	0.92	0.89	0.85	0.85	3%
O3	0.72	0.85	0.85	0.63	0.63	0.63	11%	1.02	1.00	1.02	0.72	0.72	0.68	17%	0.63	0.58	0.63	0.52	0.45	0.45	8%
O4	0.63	0.72	0.63	0.45	0	0	33%	0.60	0.63	0.63	0	0	0	34%	0.45	0.35	0.45	0	0	0	23%
O5	0.41	0.41	0.34	0.26	0	0	19%	0.45	0.41	0.41	0	0	0	23%	0.28	0.26	0.26	0	0	0	15%

thickness levels to compare with the control ($T_{0\text{-}5}$). The purpose of thinning the bone was to determine how beam-hardening artifacts influenced bone-thickness evaluation.

Scanning

A series of CBCT images were taken around the pig mandible. The domestic pig head was placed on the prepared platform, as shown in Figures 4 and 5, using laser orientation to accurately align the mandible. A 120 kV and 18 mA exposure was selected, with the following scanning parameters: voxel size, 0.2 mm; acquisition time, 8.9 seconds; scan height, 8 cm; scan width, 16 cm; and slice thickness, 0.2 mm. The CBCT measurements were made with a postprocessing software tool in i-CAT NG, known as i-CAT Vision (Imaging Sciences International, Hatfield, Pa).

Measurements using the scans

The 3 implant sites were scanned and the cross-sectional images measured with CBCT (M_1) without the implants (I), before implant placement in the mandible. The measures were taken at each thickness level on both the buccal and oral sides, which generated 36 measures to evaluate ($N = T \times M \times I \times 2 = 6 \times 1 \times 3 \times 2 = 36$).

Each implant cross-sectional image was taken using CBCT, both with implants (M_2) and without implants (M_3), at every thickness level as closely as possible to the implant center. The images were taken 3 times on both the buccal and the oral sides ($N = T \times M \times I \times 2 \times 3 = 6 \times 2 \times 3 \times 2 \times 3 = 216$). This approach generated 216 measures to analyze, as shown in Figures 6 and 7. We used SD to assess the measure variance.

Results

The Table shows the SDs of the CBCT measures, both with and without the implants. As the bone thickness decreased, the deviation increased consistently for all 3 implants. The largest difference was observed in the fifth thickness level. The oral side showed more deviations for all implants. The implant size also influenced the SDs; implants with smaller diameters showed higher variances.

Discussion

The success of an implant depends on the bone volume and quality, which are frequently evaluated using 3-dimensional visualization. Thus, a clear understanding of visual artifacts is essential. In this study, we used CBCT, which is a popular technology because of its good performance, low cost, and lower radiation dose required,[3] and because it provides accurate 3-dimensional visualization for early detection of peri-implant bone defects.[10]

We used a pig mandible to assess the relationship between cortical and cancellous bone, as the density of pig and human mandibles is similar.[11,12] Furthermore, the domestic pig mandible accurately represents the soft tissue covering of the alveolar bone and attenuates the beam to soft tissue. Although the pig mandible presented tooth eruptions in the areas where the bone quantity was sufficient for dental implantation, it is more complicated to determine the correct implant site in humans with toothless mandibles. Thus, to ensure uniformity and increase the accuracy of measurements, the buccal and oral cortical plates of the alveolar bone were flattened before implant placement.

We used the same CBCT mounting position throughout the scanning; the head console was not changed between the phases. The preview function was used to adjust and set the exact same position of the pig head in the machine for each scan, and the implant sites were always in the middle of the field of view.

Thinning of the bone was found to influence the diagnostic accuracy of CBCT. With thinner bones, the implant site is an air-containing space that leads to overradiation of the buccal and oral cortical bones. This excess radiation makes the scanned image darker and the measurements smaller.

When X-ray photons pass through the dental implant, the lower-energy photons are preferentially absorbed. This affects bone and soft tissue visualization and results in inaccurate assessment of peri-implant regions. The cupping artifact can also occur when the X rays passing through the center of the dental implant become harder than those passing through the edges,[1] causing dark streak artifacts to appear between 2 dental implants.

Further, the large flat panel detector increases the scatter radiation, and thus limits the soft tissue boundaries.[13] The higher the spatial resolution in CBCT images, the higher the diagnostic accuracy, because actual cross-sectional images use isotropic voxel size.[14] Additionally, higher applied voltage can reduce the contrast in CBCT images.[1]

Our data show that thinner bone results in greater discrepancy between the measurements with and without implants and that these differences are driven by beam-hardening artifacts, which cause gray-level reduction both buccally and orally. Only the thinnest level showed differences, and the i-CAT software could not handle the small anatomic details. Thus, there were inaccuracies in defining the border of the thin bone wall.

The presence of 2 neighboring implants also affected evaluation of peri-implant bone quality negatively because of cupping artifacts. The size of the implants did not affect the evaluation of bone quantity.

Conclusions

We determined that thinning of the alveolar bone around the implant site reduces the diagnostic accuracy of CBCT. Further, a thicker alveolar bone (0.72–1.6 mm) around the dental implant causes the CBCT to underestimate bone volume by approximately 10%. For thinner alveolar bone ($<$0.72 mm), the underestimation is approximately 70%.

Abbreviation

CBCT: cone-beam computerized tomography

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