Accuracy of Implant Size Prediction Based on Edentulous Ridge Dimension on Cone-beam Computed Tomography - A Retrospective Study

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Abstract

Introduction: Cone-beam computed tomography (CBCT) is the recommended imaging modality for implant planning. It is important to evaluate the accuracy of CBCT-based implant size prediction. This study aims to correlate projected implant sizes from CBCT alveolar ridge measurements with the actual sizes of placed implants, to determine the accuracy of the prediction. **Materials and Methods:** CBCTs taken for implant placement were included. The heights and widths of edentulous ridges were measured with Anatomage *in vivo* dental three-dimensional software, and actual implant size data were retrieved from treatment notes. Central incisor, canine, first premolar and first molar locations were analysed. One-way analysis of variance (ANOVA) was run to determine the average sizes for edentulous ridges and implants and Pearson correlation was conducted to determine the accuracy of CBCT-based implant size prediction. **Results:** Of 544 cases analysed, the average implant diameter was 4.17 mm (standard deviation [SD] =0.38) and the length was 10.05 mm (SD =1.17). Alveolar width and height were 3.74 mm and 4.31 mm larger than the implant diameters and lengths, respectively providing approximately 1.5–2 mm of extra space on either side of the implant in relation to adjacent anatomical structures. Implants placed at mandibular canine and first molar and maxillary first premolar demonstrated significant correlations with the sizes of the edentulous ridges ($P < 0.05$). **Discussion:** CBCT-based alveolar ridge measurements have been demonstrated as reliable parameters to predict implant sizes. However, its accuracy may be limited by the factors such as edentulous ridge morphology and proximity to vital anatomic landmarks.

Keywords: Cone-beam computed tomography, edentulous ridge, implant

Introduction

The significant advances in dental implantology in the last decades make implant placement a popular methodology to restore missing teeth. Implant osseointegration and stability are affected by factors such as alveolar bone quality and quantity, osteotomy preparation, implant geometry and surface.[1] Crestal bone loss proximal to dental implants is influenced by parameters such as arch site and prosthetic design.[2] The survival rate of dental implants for 10 years has been reported to be higher than 95%.[3] The global dental implant market is expanding exponentially and is expected to increase more dramatically due to accelerated aging phenomena worldwide.[4,5]

Precise implant treatment planning is indispensable for success in implant placement. Previously, periapical and panoramic radiography were captured to analyse edentulous sites. However, distortion, magnification, superimposition and lack of buccolingual dimensional information impair the applicability of these imaging modalities in implant treatment planning.[6] Cone-beam computed tomography (CBCT), however, has gained great popularity in the dental imaging arena since it generates high-resolution three-dimensional (3D) imaging with rapid scanning time, lower radiation

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dose, reduced metal artefacts, as well as lower cost, easy accessibility and easy handling.[6,7] The American Academy of Oral and Maxillofacial Radiology recommends that cross-sectional imaging be used to assess all dental implant sites and that CBCT is the imaging method of choice to obtain this information.[8]

For implant planning purposes, CBCT data are generally reconstructed into panoramic, axial and a series of cross-sectional views, and heights and widths of edentulous ridges are measured to project the sizes of the implants in the proposed placement sites.[9] Various proprietary software, such as Simplant® Pro (Dentsply Sirona; Charlotte, North Carolina, United States), NobelClinician® (Nobel Biocare; Zurich, Switzerland), Implant Studio® (3Shape; Copenhagen, Denmark) and coDiagnostiX® (Straumann Group; Basel, Switzerland),[10,11] are utilised with satisfactory outcomes. However, many dental practitioners still perform freehand implant placement without the assistance of third-party implant planning software or surgical guide, due to personal experience, training and factors such as cost and accessibility to the technology.[12,13] They choose implant sizes empirically based on edentulous ridge dimensions. Therefore, it is critical to investigate the accuracy of implant size determination based on CBCT imaging. Although the accuracy of linear measurements on CBCT for presurgical implant planning has been established in *ex vivo* studies either on dry skulls or cadaver samples, few clinical studies have been conducted in the field.[14,15]

The objective of this investigation is to correlate the projected implant sizes based on the CBCT measurements with the actual sizes of the implants placed in the edentulous alveolus in patient populations, to determine the accuracy of CBCT-based implant size determination.

Materials and Methods

CBCT scans taken at East Carolina University School of Dental Medicine from January 1, 2017 to December 31, 2022 were screened. Patients with diagnostic-quality CBCT scans for implant placement were included. Institutional review board exemption was obtained from the institution before the start of the project (UMCIRB 22-000390). It was deemed that patient consent was also not required due to the nature of the study.

The CBCT scans were acquired at 85 kVp, 6 mA, 160 mm voxel size with a Sirona Orthophos SL 3D CBCT scanner (Dentsply Sirona Inc.; Charlotte, North Carolina, USA), or at 89.8 kVp, 6 mA, 200 mm voxel size with an Instrumentarium OP300 CBCT scanner (KaVo Dental Excellence, Biberach, Germany). CBCT images were reconstructed with Anatomage *in vivo* Dental 3D version 6 software (Anatomage Co.; Santa Clara, California, USA) at a thickness of 1 mm. Images were viewed on a 32 inch LG HDR screen (LG Electronics Inc.; Seoul, South Korea) with a 2560 × 1080 pixels resolution under dimly lit conditions.

All clinically relevant information was collected from axiUm® (Exan Software – Henry Schein, Inc.; Melville, New York, USA), the institutional electronic health record system. The alveolar ridge dimensions were measured on the reconstructed cross-sectional views from CBCT scans, with ridge height measured from the alveolar crest to critical anatomic landmarks such as the superior border of the mandibular canal, the floor of nasal fossa or maxillary sinus and ridge width measured from the buccal to lingual/palatal cortical plate [Figure 1]. The sites for the central incisor, canine, first premolar and first molar of the maxilla and mandible were analysed. The number of measured edentulous sites depended on each patient's missing tooth/teeth. The information on the heights and widths of edentulous ridges was retrieved from CBCT reports, which were generated by two experienced oral and maxillofacial radiologists. The data on actual implant sizes were extracted from the treatment notes in axiUm®.

Statistical analysis

The normal distribution of data was determined by Skewness analysis. One-way analysis of variance (ANOVA) was run to determine the average sizes of edentulous alveolar ridges and implants. Pearson correlation analysis was conducted to determine the correlation between alveolar ridge dimensions and implant sizes. Data were reported as mean and standard deviation. The reliability of the ridge measurements by the two radiologists was evaluated by kappa statistics. The level of statistical significance was set at $P < 0.05$. All of the statistical analyses was run with the Statistical Analysis Software (SAS) version 9.2 programme (SAS Institute Inc.; Cary, North Carolina, USA).

Results

A total of 544 patients were included, comprising 288 males and 256 females, with an age range of 19–86 years and a peak age of 61–70 years [Figure 2]. The patients were predominantly Caucasians, followed by African-Americans

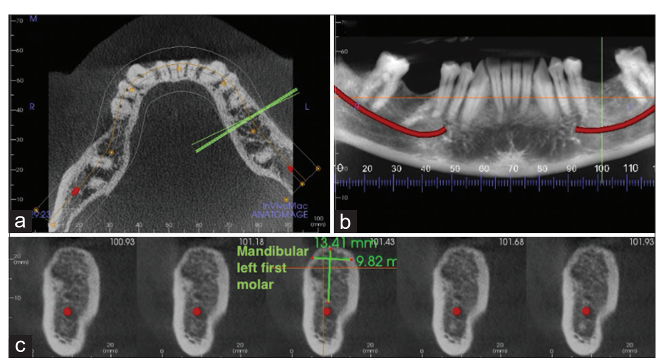

Figure 1: Edentulous ridge dimension measurements from reconstructed cone-beam computed tomography views. (a) Axial view; (b) Panoramic view; (c) Cross-sectional views. At the left mandibular first molar location, the ridge height was measured from the alveolar crest to the superior border of the mandibular canal. The ridge width was measured from the buccal to the lingual cortical plate approximately 2 mm below the alveolar crest

and Asians [Figure 3]. Skewness analysis indicated that ridge dimensions and implant sizes followed a normal distribution. On average, implants had diameters of 4.17 (0.38) mm and lengths of 10.05 (1.17) mm. Edentulous ridges had an average ridge width of 7.91 (2.22) mm and a ridge height of 14.36 (4.85) mm. The ridge width and height were 3.74 mm and 4.31 mm larger than the implant diameter and length, respectively [Table 1]. The kappa coefficient was 0.9, which indicated high agreement of the evaluations by the radiologists. Of the analysed locations, implants placed at mandibular canine and first molar and maxillary first premolar regions demonstrated significant correlations with the dimensions of the edentulous ridges [$P < 0.05$, Table 2].

Discussion

Our study found that, in general, the width and height of the edentulous ridge are 3–4 mm larger than the diameter and length of the implant.[16] Since the measurements were taken on two-dimensional cross-sectional views, this gives 1.5–2 mm spare space on either side of the implant when placed in the edentulous ridge. It is widely accepted practice to place the implant at least 1.5 mm from the adjacent teeth and 2 mm from vital anatomic structures, such as the inferior alveolar canal.[17-20] Our observation concurs with the guidelines for implant placement and validates the accuracy of CBCT-based implant size prediction.

The present study analysed the correlation between the dimensions of edentulous ridges and the sizes of implants placed at various locations. Interestingly, of the seven sites evaluated, only the mandibular first molar and canine and maxillary first premolar demonstrated significant correlations between these two parameters. It is speculated that the morphology/angulation of edentulous ridges and the proximity of the proposed implant sites to vital anatomical landmarks contribute to the discrepancy. In the posterior mandible, 53.6–69.3% of the population has a straight alveolar ridge and the implant is placed along the long axis of the ridge.[21,22] Therefore, molar sites are relatively predictable, and CBCT planning can be executed without much deviation with pre-operative planning and post-operative outcomes in most cases. However, in the anterior maxilla, the ridge is more buccally proclined. The angle of implant placement may not fully correlate with the long axis of the ridge and is placed more palatally inclined to follow the slope of natural roots.[23,24] This may explain the discrepancy between ridge dimensions and implant size, as ridge heights were measured along the long axis of edentulous ridges. In these circumstances, alveolar angulation is an important factor to consider in addition to ridge width. CBCT evaluation may reveal the need for ridge modification through adjunct procedures such as grafting or ridge splitting to ensure that the prepared ridge becomes an ideal recipient site and that implant fixtures of the appropriate type and dimensions can be pre-ordered. In addition, the anatomical relationship may also affect the correlation between ridge dimensions and implant sizes. For example, the majority of maxillary first molars have roots close to the maxillary sinus and the ridge heights are often limited, especially in patients with periodontitis or long-term tooth loss.[25,26] Bone graft and sinus lift may be necessary to augment the alveolar dimension to host the implant, resulting in inconsistent ridge-implant correlation. In the mandible, the mental foramen is commonly

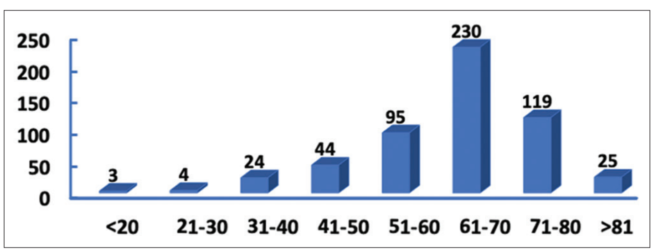

Figure 2: Age of the patients. The peak age is 61–70 years

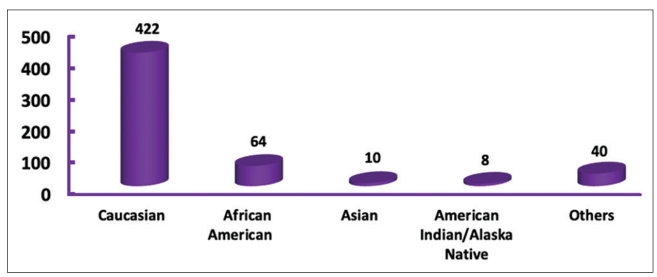

Figure 3: Races of the patients. Caucasians are dominating, followed by African Americans and Asians

Table 1: Implant size and edentulous alveolar ridge dimension measurements

Tooth locations	Sample size (*n*)	Implant diameter (mm), mean (SD)	Alveolar ridge width (mm), mean (SD)	Width difference (mm)	Implant length (mm), mean (SD)	Alveolar ridge height (mm), mean (SD)	Length difference (mm)
Mandibular first molar	131	4.61 (0.43)	9.62 (2.09)	5.01	9.62 (1.2)	12.55 (2.45)	2.93
Maxillary first molar	56	4.78 (0.54)	8.29 (2.38)	3.51	9.34 (1.25)	9.8 (3.43)	0.46
Mandibular first premolar	20	4.01 (0.34)	8.07 (2.3)	4.06	9.75 (1.01)	19.65 (9.71)	9.9
Maxillary first premolar	75	3.95 (0.38)	7.41 (1.69)	3.46	10.38 (1.36)	13.7 (3.46)	3.32
Mandibular canine	116	3.95 (0.36)	7.4 (1.61)	3.45	10.45 (1.06)	14.92 (3.31)	4.47
Maxillary canine	42	3.91 (0.29)	7.25 (1.85)	3.34	10.45 (1.21)	15.62 (3.54)	5.17
Maxillary central incisor	26	3.98 (0.3)	7.36 (1.7)	3.38	10.37 (1.11)	14.3 (3.81)	3.93
Average		4.17 (0.38)	7.91 (2.22)	3.74	10.05 (1.17)	14.36 (4.85)	4.31

SD: Standard deviation

Table 2: Pearson correlation coefficients (*r*) and *P* values

Tooth location	Implant versus alveolar ridge			
	Width		Length	
	r	*P*	*r*	*P*
Mandibular first molar	0.375	<0.0001[a]	0.449	<0.0001[a]
Maxillary first molar	0.006	0.966	0.206	0.127
Mandibular first premolar	0.002	0.995	0.119	0.617
Maxillary first premolar	0.307	0.007[a]	0.421	0.0002[a]
Mandibular canine	0.29	0.002[a]	0.178	0.05[a]
Maxillary canine	0.141	0.374	0.261	0.096
Maxillary central incisor	0.408	0.06	0.028	0.89

[a]Indicates a statistically significant correlation between implant width and length and edentulous ridge dimension measurements at mandibular first molar, maxillary first premolar and mandibular canine ($P<0.05$)

found to be apical to the mandibular premolar area.[27,28] When placing the implant in this region, the implant may be placed more mesial, distal or lingual than the actual tooth location to avoid interference with the mental foramen. Therefore, the ridge dimension at the original first premolar site may not correlate well with the size of the implant placed.

Although designed as carefully as possible, there are limitations to the study. The sample sizes are relatively small for certain tooth locations, such as the mandibular first premolar, maxillary central incisor and canine. Over 50% of the samples were in the mandibular molars and canines (247 sites out of 466), likely due to a greater need for implants in these regions. Large sample sizes for other tooth locations are necessary to further verify the findings. In addition, the pre-operative CBCT measurements were not fully standardised. Only a few cases were provided with radiographic stents; therefore, the ridges were measured at the proposed implant sites. For most cases where a stent was not provided, ridge measurements were taken in the middle of edentulous ridges without considering factors such as occlusion from opposing teeth. A more standardised method, such as using radiographic stents to indicate future recipient sites, would certainly improve the accuracy of the observations. Moreover, operator variability in ridge measurements can potentially affect the consistency of the outcome, and more stringent calibration would be beneficial. Furthermore, in the present study, the widths of edentulous ridges were measured approximately 2 mm below the crest bone level, without considering ridge concavities that may occur more inferiorly, such as lingual undercut at the posterior mandible and buccal concavity at the maxillary lateral incisor region. Taking multiple ridge width measurements at different levels in future studies would add more value to the investigation. Also, considering variations in ridge morphology, for locations with thin ridges or where the maxillary sinus pneumatises approximating the alveolar crest, simultaneous guided bone regeneration or bone graft/sinus lift could be performed together with implant placement, making the correlation between actual ridge dimensions and implant size less consistent. This confounding factor would complicate our data interpretation. In addition, two CBCT scanners, Sirona Orthophos and Instrumentarium OP300 and one 3D view software Anatomage *in vivo* were used in the study. No statistically significant difference was found in the performance of these two scanners. However, more CBCT units with different settings and third-party viewing software, such as Simplant or Noble Biocare, would need to be tested before the generalisation of the observations since findings from one CBCT machine or software may not necessarily apply to other products in the market.[29]

Conclusions

CBCT-based alveolar ridge measurements have been demonstrated as an accurate index to determine the size of the proposed implant. However, factors such as ridge morphology and proximity to vital anatomic landmarks may interfere with the prediction. More investigations with larger sample sizes, a variety of hardware and software and the presence/absence of radiographic stents will help to generalise the observation and identify strategies to further improve the precision of CBCT-based implant size prediction.

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Conflicts of interest

There are no conflicts of interest.

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