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Cone Beam Computed Tomography and SimPlant Materialize Dental Software Versus Direct Measurement of the Width and Height of the Posterior Mandible: An Anatomic Study

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Cone beam computed tomography (CBCT) has proved to be a useful tool in many aspects of oral and maxillofacial surgery and in implant dentistry.[1-4] In addition to implant dentistry, CBCT has been valuable in dentoalveolar surgery, temporomandibular joint evaluation, orthodontics, orthognathic surgery, clefts, trauma, and benign and malignant pathologic processes of the maxillofacial region.[5-17]

The purpose of this study was to investigate the accuracy of measurements of mandibular height and width of bone using a CBCT machine (I-CAT) and a dental implant planning software (SimPlant) compared with direct digital caliper measurements on cadaveric mandibles (anatomic).

With the emergence of CBCT and its applications for placement of endosteal implants, there is a need to determine the accuracy of CBCT in determining the height and width of the mandibular alveolar bone above the inferior alveolar nerve (IAN). In 2000, the American Academy of Oral and Maxillofacial Radiology issued a position paper recommending cross-sectional imaging for treatment planning of implant cases.[18] CBCT patients would undergo medical-grade spiral CT for 3-dimensional analysis of the bone before implant placement when 3-dimensional imaging was indicated. With CBCT surgeons can attain 3-dimensional imaging of patients for implant treatment planning and lower the dose of radiation, as low as 20% of conventional CT or comparable to a full-mouth series of periapical radiographs.[18-20] CBCT has also been shown to provide superior and more accurate detail of teeth and supporting hard tissues at a more cost-efficient price compared with conventional CT.[13,21]

As CBCT machines and software using data from CBCT are becoming more accessible to practitioners for treatment planning of implant cases, these are being used more to determine the amount of bone available for placement of dental implants. This study tested the hypothesis that vertical and horizontal measurements using CBCT and SimPlant in the posterior cadaveric mandible are accurate compared with direct digital caliper measurements.

Materials and Methods

Eleven cadaveric mandibles were obtained from the Albert Einstein College of Medicine Anatomic Laboratory. Measurements were made from the posterior aspect of the mental foramina to distances 1.0 cm (point A) and 1.5 cm (point B) posteriorly. The 24-gauge stainless steel wires were then placed 360° circumferentially around the mandible at the A and B positions (Fig 1). Each mandible was then scanned with CBCT. The DICOM data were then imported into SimPlant (SimPlant 3-D Pro; Materialize, Leuven, Belgium), and the IAN was drawn onto the scan. Using the CBCT (I-CAT; Imaging Science International, Hatfield, PA) and SimPlant programs, the stainless steel

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wires were then located, and the slices corresponding to the wires at the A and B positions were identified. Then, using the software programs for CBCT (I-CAT) and SimPlant, 3 different measurements were made on the A plane and the B plane (Fig 2). The first measurement (low horizontal [LoHor]) was the width of the mandible at the level of a line drawn tangent to the most superior aspect of the IAN. The second measurement (high horizontal [HiHor]) was the width of the mandible at 5 mm inferior to the crest. The third measurement was from the most superior aspect of the IAN to the mandibular crest using a line drawn vertically through the center of the IAN (Vert). The mandibles were then sectioned at the location of the A and B planes. For each whole mandible, there were 4 blocks. The blocks were labeled (right A plane, right B plane, left A plane, left B plane) to correspond to where they had been sectioned. The horizontal and vertical measurements were made at the A and B blocks using a digital caliper. All 3 methods of making measurements were performed independently by 3 different examiners. Two examiners were senior attendings in oral and maxillofacial surgery and 1 was a chief resident in oral and maxillofacial surgery. Data from the CBCT and SimPlant measurements were compared with the gold standard of direct caliper measurement (anatomic) to determine the accuracy of CBCT and SimPlant compared with direct measurement.

Two sets of analyses were performed. The first examined the interrater reliability among the 3 raters by deriving intraclass correlation coefficients for each of the 3 outcomes (LoHor, HiHor, and Vert) by block. The second analysis was used to determine the significance of the difference among methods using the mean measurement for the 3 raters for each cadaver/block/outcome combination. Because each outcome (distance measured) is a continuous variable, and repeated measurements for each method were taken on

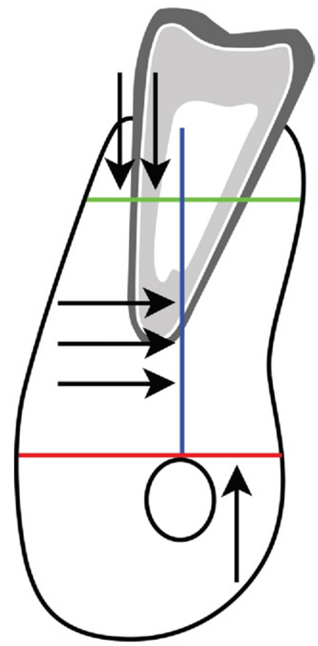

FIGURE 2. Three measurements made at each cross section. Low horizontal (*single arrow*) is the width of the mandible at the most superior aspect of the inferior alveolar nerve. Upper horizontal (*double arrows*) is the width of the mandible at 5 mm inferior to the mandibular crest. Vertical (*triple arrows*) is from the most superior aspect of the inferior alveolar nerve to the mandibular crest.

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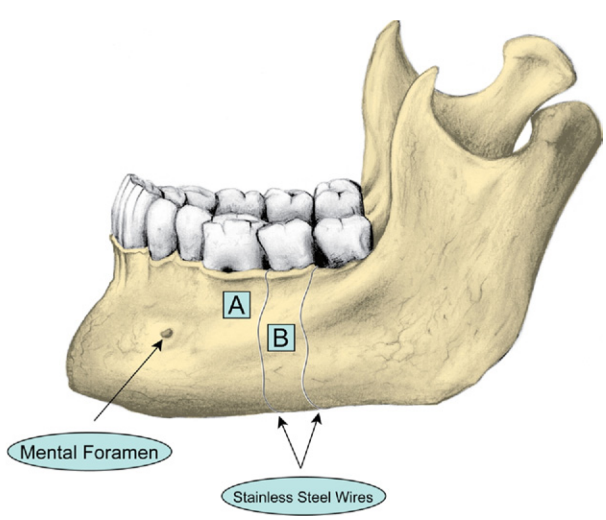

FIGURE 1. Point A is 1.0 cm posterior and point B is 1.5 cm posterior to the mental foramen. After cone beam computed tomography, the mandibles were sectioned at planes A and B.

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Table 1. INTRACLASS CORRELATION COEFFICIENTS

Block	Outcome	Intraclass Correlation Coefficients
RA	LoHor	0.96968
RA	HiHor	0.97350
RA	Vert	0.97856
RB	LoHor	0.98091
RB	HiHor	0.96948
RB	Vert	0.98504
LA	LoHor	0.90772
LA	HiHor	0.98375
LA	Vert	0.98638
LB	LoHor	0.93382
LB	HiHor	0.98406
LB	Vert	0.99330

Abbreviations: HiHor, upper horizontal measurement; LA, left A plane; LB, left B plane; LoHor, low horizontal measurement; RA, right A plane; RB, right B plane; Vert, vertical measurement.

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Table 2. LEAST SQUARES MEANS

Effect	Outcome	Group	Least Squares Mean	SE	Difference Between Group and Anatomic
Group	LoHor	Anatomic	10.9104	0.4324	0
Group	LoHor	I-CAT	10.6114	0.4324	0.299
Group	LoHor	SimPlant	10.6276	0.4324	0.2864
Group	HiHor	Anatomic	10.0590	0.5924	0
Group	HiHor	I-CAT	10.1684	0.5924	−0.1094
Group	HiHor	SimPlant	9.9374	0.5924	0.1216
Group	Vert	Anatomic	14.5915	0.9638	0
Group	Vert	I-CAT	14.5327	0.9638	0.0588
Group	Vert	SimPlant	14.5197	0.9638	0.0718

Abbreviations: HiHor, upper horizontal measurement; LoHor, low horizontal measurement; SE, standard error; Vert, vertical measurement.

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each cadaver by block and rater, a mixed-effects model was used to determine differences among the 3 methods. Statistical significance was set at $P < .05$.

Results

Eleven cadaveric mandibles were used. Forty-four sections of cut mandibular blocks were made. Sections were excluded if the IAN was not clearly defined on the I-Cat and/or SimPlant program. Twenty-eight of 44 blocks were used with all 3 measurements made using the direct digital caliper (anatomic), I-Cat, and SimPlant on each block by the 3 different examiners. In total 756 different measurements were made using the 3 methods by 3 different examiners. The intraclass correlation coefficient or interrater reliability was very close to 1 for the 3 examiners, indicating excellent agreement among the 3 examiners (Table 1).

A mixed-effects analysis was performed for each of the 3 measurements (LoHor, HiHor, and Vert). A least squares means was performed for the 3 different techniques used to perform the measurements, which was the mean of all observations for each modality taking into account the differences in all blocks (Table 2).

The *P* value for the LoHor group was .1084, which was not significant. The *P* value for the HiHor group was .5933, which was not significant. The *P* value for the Vert group was .9465, which was also not significant.

The smallest difference in the least squares means compared with the anatomic measurement was in the Vert distances measured, which had the largest standard error. The HiHor and LoHor measurements had the greatest differences and the smallest standard errors.

The power in Table 2 was computed for each observed difference and standard deviation. For example, using 0.3 mm as the smallest clinically notable difference between the LoHor and anatomic methods with a standard deviation of the difference of 0.50, the probability of being able to detect this difference or a difference larger than this is 0.99, or 99% power. This high level of power indicates the sample size is sufficient to detect a difference if there was one, and thus, the measures are considered to have statistical equivalence ($P < .05$).

In total 252 measurements were made for each method (252 anatomic, 252 SimPlant, 252 CBCT). All measurements using CBCT and SimPlant that differed from the anatomic measurements by more than 1.0 mm were reviewed. Using CBCT there were 13 measurements that were larger than the anatomic measurement by more than 1.0 mm. Eleven of these measurements were 1.16 to 1.44 different from the anatomic measurements, with 2 outliers of 2.68 and

Table 3. DESCRIPTIVE STATISTICS FOR DIFFERENCES BETWEEN ANATOMIC AND SIMPLANT AND I-CAT97

Means Procedure

Difference	n	Mean	SD	Power (%)*
LoHor A vs S	28	0.2828571	0.5072582	99
LoHor A vs I	28	0.2990476	0.4641820	99
HiHor A vs S	28	0.1215476	0.5608830	99
HiHor A vs I	28	−0.1094048	0.4786117	99
VHor A vs S	28	0.0718333	0.6725838	99
VHor A vs I	28	0.0588095	0.6123954	99

Abbreviations: A vs I, difference between anatomic and cone beam computed tomographic measurements; A vs S, difference between anatomic and SimPlant measurements; HiHor, upper horizontal measurement; LoHor, low horizontal measurement; SD, standard deviation; VHor, vertical and horizontal measurements.

*Power to demonstrate equivalence for $\alpha = 0.05$ and the smallest clinically important difference of 1.0 mm.

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3.42. In the CBCT group there were 22 measurements that were smaller than the anatomic measurement by more than 1.0 mm. Four of the numbers were 2.06 to 2.59. Eighteen of these were 1.1 to 1.83.

In the SimPlant category there were 19 measurements that were larger than the anatomic measurement by more than 1.0 mm. Fourteen of these numbers were 1.07 to 1.87. Three numbers were 2.1 to 2.53. One number was 3.23 and another 4.63 larger. In the SimPlant group there were 27 numbers that were smaller than those obtained with the anatomic measurement by more than 1.0 mm. All of these numbers were 1.0 to 1.74 mm different, except for 1 that was 2.15 mm smaller (Table 3).

In the SimPlant category the numbers were underestimated more often than overestimated (27/252, 11%, and 13/252, 5.2%, respectively). In the CBCT group there was more underestimation than overestimation (22/252, 8.7%, and 19/252, 7.5%, respectively).

In the SimPlant group the measurements were within 0 to 0.99 mm of the anatomic measurement 84% (212/252) of the time and were within 0 to 1.99 mm in 99% (249/252) of the time. In the CBCT group the measurements were within 0 to 0.99 mm 84% (211/252) of the time and within 0 to 1.99 mm 97% (244/252) of the time (Table 4).

In total 168 width measurements were made using the 3 different methods (168 anatomic, 168 CBCT, 168 SimPlant).

In the SimPlant group 12 horizontal measurements were at least 1.0 mm larger than the anatomic measurement. Nine of these were 1.12 to 1.87 larger. Two numbers were 2.19 and 2.53. One number was 3.23. Twenty numbers in the SimPlant group were at least 1.0 mm smaller than the anatomic measurement. Nineteen of these were 1.0 to 1.71 mm smaller than the anatomic measurement. One number was 2.15 mm smaller.

In the CBCT group there were 6 numbers that were more than 1.0 mm larger than the anatomic numbers. Five of these were 1.07 to 1.37. One of these numbers was 2.68 larger. In the CBCT group 11 measurements were at least 1.0 mm smaller than the anatomic measurement. Nine of these were 1.10 to 1.83 mm smaller. One number was 2.17 and 1 was 2.59 mm smaller.

In the SimPlant group 137/168 (82%) of the distances were within 0.99 mm of the anatomic numbers. Ninety-eight percent (165/168) of the time the distance was within 0 to 1.99 mm of the anatomic measurement.

In the CBCT group 90% (151/168) of the time the measurement was within 0.99 mm of the anatomic number. Ninety-eight percent (165/168) of the time the distance was within 0 to 1.99 mm of the anatomic measurement (Table 5).

Table 4. NUMBER OF TOTAL MEASUREMENTS DIFFERENT FROM ANATOMIC MEASUREMENTS

Method	0–0.99 mm Larger/Smaller Than Anatomic Measurement	1.0–1.99 mm Larger Than Anatomic Measurement	2.0–2.99 mm Larger Than Anatomic Measurement	3.0–5.0 mm Larger Than Anatomic Measurement	1.0–1.99 mm Smaller Than Anatomic Measurement	2.0–2.99 mm Smaller Than Anatomic Measurement	3.0–5.0 mm Smaller Than Anatomic Measurement
SimPlant	212 (84%)	11 (4.4%)	1 (0.40%)	1 (0.40%)	26 (10%)	1 (0.40%)	—
CBCT	211 (84%)	14 (5.5%)	3 (1.2%)	2 (0.80%)	18 (7.1%)	4 (1.6%)	—

Abbreviation: CBCT, cone beam computed tomography.

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Table 5. NUMBER OF WIDTH MEASUREMENTS DIFFERENT FROM ANATOMIC MEASUREMENTS

Method	0–0.99 mm Larger/Smaller Than Anatomic Measurement	1.0–1.99 mm Larger Than Anatomic Measurement	2.0–2.99 mm Larger Than Anatomic Measurement	3.0–5.0 mm Larger Than Anatomic Measurement	1.0–1.99 mm Smaller Than Anatomic Measurement	2.0–2.99 mm Smaller Than Anatomic Measurement	3.0–5.0 mm Smaller Than Anatomic Measurement
SimPlant	137 (82%)	9 (5.4%)	2 (1.2%)	—	19 (11%)	1 (0.60%)	—
CBCT	151 (90%)	5 (3.0%)	1 (0.60%)	—	9 (5.4%)	2 (1.2%)	—

Abbreviation: CBCT, cone beam computed tomography.

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In 84 measurements were made of the Vert distance using the direct caliper, CBCT, and SimPlant (84 anatomical, 84 CBCT, and 84 SimPlant).

In the SimPlant group, 7 were at least 1.0 mm larger than the anatomic measurement. Five of these were 1.07 to 1.72 mm larger. One number was 2.1 mm larger and 1 was 4.63 larger. In the SimPlant Vert group, 7 were at least 1.0 mm smaller. They were all 1.12 to 1.74 mm smaller.

In the CBCT Vert group, 7 numbers were larger than the anatomic measurement. Six of these were 1.16 to 1.44 mm larger. One number was 3.42 mm larger.

In the CBCT Vert group, 11 numbers were smaller than the actual anatomic measurement. Seven of these were 1.01 to 1.78 mm smaller. Four of these were 2.07 to 2.49 smaller.

SimPlant measured within 0 to 0.99 mm 83% (70/84) of the time and within 0 to 1.99 mm 98% (82/84) of the time.

CBCT measured within 0 to 0.99 mm 79% (66/84) of the time and 0 to 1.99 mm 94% (79/84) of the time (Table 6).

Discussion

Placement of endosteal implants in the posterior mandible requires precise knowledge of the location of the IAN to prevent injury.[22] Also of importance is the width of bone to ensure osseointegration and prevention of damage to the sublingual region and floor of the mouth.[23,24] The purpose of this study was to determine how reliable CBCT and SimPlant are in providing measurements of the height and width of mandibular bone in the posterior mandible.

Twenty-eight of 44 blocks that were sectioned from mandibles were used to perform measurements. Although 12 of 44 sections (36%) were excluded because of an inability to identify the IAN using CBCT and/or SimPlant, this has not been our experience with live subjects. This was attributed to dehydration of the samples. The present study showed no statistically significant difference in measuring the width of mandibular bone at 2 places and the vertical height of the mandibular bone using a direct caliper measurement or using CBCT or SimPlant.

Kamburoğlu et al[25] used 6 hemimandibles to measure specific distances around the mandibular canal in 6 directions. They used direct digital caliper measurements and CBCT measurements (ILUMA CBCT system; 3M ESPE, St Paul, MN) to measure mandibular width, length, upper distance, lower distance, buccal distance, and lingual distance relative to the IAN canal. They concluded that the CBCT measurements were comparable to those performed with the digital caliper. Doran et al[26] compared the accuracy from measurements taken from the floor of the maxillary

Table 6. NUMBER OF VERTICAL MEASUREMENTS DIFFERENT FROM ANATOMIC MEASUREMENTS

Method	0–0.99 mm Larger/Smaller Than Anatomic Measurement	1.0–1.99 mm Larger Than Anatomic Measurement	2.0–2.99 mm Larger Than Anatomic Measurement	3.0–5.0 mm Larger Than Anatomic Measurement	1.0–1.99 mm Smaller Than Anatomic Measurement	2.0–2.99 mm Smaller Than Anatomic Measurement	3.0–5.0 mm Smaller Than Anatomic Measurement
SimPlant	70 (83%)	5 (6.0%)	1 (1.5%)	1 (1.5%)	7 (8.3%)	—	—
CBCT	66 (79%)	6 (7.1%)	—	1 (1.5%)	7 (8.3%)	4 (4.8%)	—

Abbreviation: CBCT, cone beam computed tomography.

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sinus and localization of the IAN using direct digital panoramic radiographs and CBCT. They used 10 cadaver heads and made 2 measurements on each. The first was at the first molar position, where the distance from the IAN to the crest of the mandible was measured. The second measurement was from the floor of the maxillary sinus to the crest of the maxilla. Results were analyzed using a paired *t* test. There was no statistically significant difference between the CBCT and physical measurements.[26] Miet et al[27] compared jaw dimensions and quality of bone characteristics using CBCT (Accuitomo; J. Morita, Irvine, CA) and spiral tomography. They used 25 cadaver mandibles to measure the buccal lingual width in different areas of the mandible. These thicknesses were measured with CBCT and spiral CT and compared with the gold standard of direct digital caliper measurement. Differences between the direct measurement and the 2 radiographic modalities were compared using a paired 1-tailed *t* test. They found that CBCT and spiral tomography presented statistically significant underestimations; however, they did feel that the width measurements using CBCT and spiral tomography were reliable.

In the present analysis, the CBCT measurements that were larger and smaller than the anatomic measurements were not compared with the same SimPlant measurements. Future studies should analyze these measurements to determine if measurements differing from the anatomic measurements are due to the CBCT measurements or the software analyzing the DICOM data.

The clinical relevance of this study is that when CBCT and SimPlant are used as a clinical tool, they are highly accurate in determining the height and width of bone in the posterior mandible, with an overall accuracy within 0 to 1.99 mm 97% and 99% of the time, respectively. CBCT and SimPlant are accurate to within 0 to 1.99 mm 98% of the time in predicting the width of mandibular bone in the posterior mandible. The accuracy of these 2 methods is important when estimating the diameter of endosteal implants. CBCT and SimPlant are accurate within 0 to 1.99 mm 94% and 98%, respectively, of the time in determining the height of bone from the IAN to the crest of the mandible. If endosteal implants were planned according to CBCT to be placed within 2.0 mm of the IAN in all the blocks, 99% of cases would avoid IAN injury, because only 1 measurement of 84 was overestimated by more than 1.99 mm. If endosteal implants were planned according to SimPlant to be placed within 2.0 mm of the IAN in all blocks, 98% of cases would avoid IAN injury, because only 2 measurements of 84 were overestimated by more than 1.99 mm.

These results show that CBCT and SimPlant are accurate in predicting the height and width of bone in the posterior mandible compared with the anatomic method. CBCT with or without SimPlant is a highly accurate tool for planning endosteal implants in the posterior mandible. Furthermore, measurements among different raters are highly reliable.

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