Accuracy of Linear Measurement Provided by Cone Beam Computed Tomography to Assess Bone Quantity in the Posterior Maxilla: A Human Cadaver Study

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ABSTRACT

Purpose: The aim of this study was to assess, for implant placement in the posterior maxilla, the accuracy of linear measurements provided by cone beam computed tomography (CBCT) using an image intensifier tube and television (TV) chain as an X-ray detector despite a loss of contrast resolution. The NewTom® 9000 (Quantitative Radiology, Verona, Italy) was used to explore the posterior maxilla.

Materials and Methods: Fourteen measurements were taken in three dry maxillaries. On every anatomical site, three fiducial markers were placed on the bony crest to define a plane. Dry maxillaries were submitted to CBCT imaging examination. The maxillaries were then sawn according to the previously defined planes, and bone height and width were assessed using a caliper. The same measurements were taken on images.

Results: Clinical analysis demonstrated no difference between real measurements and image measurements.

Conclusions: Although cadaver bone density may not correspond to the density of vital bone, this in vitro study indicates that CBCT images provided by technique using image intensifier tube and TV chain as an X-ray detector are reliable to define the bone volume of the posterior maxilla for the purpose of planning the implant axis.

KEY WORDS: accuracy, computed tomography, cone beam, implant planning

Intraoral or panoramic radiographs are commonly accepted as suitable to assess bone height at the operation site. In some cases with severe resorption, a markedly concave crest, where the location of vital structures cannot be properly detected, or for completely edentulous maxilla, cross-sectional slices can be requested.[1–6]

To combine the advantages of computed tomography (CT), which provides images without superimposition and blurring, and to reduce the radiation risk, cone beam computed tomography (CBCT) has been proposed to provide the surgeon with both axial or reformatted and volumetric images of CT data.[7] The use of an X-ray image intensifier tube and a charge-coupled device (CCD) television (TV) camera as a two-dimensional detector increases the noise from scatter radiation and limits the dynamic range, which results in a loss of contrast resolution.[8] This might have a significant impact on the diagnostic task by hindering proper detection of anatomical structure borders, and thus, reducing the device's ability to provide accurate distance measurements.

The aim of this human cadaver study was to evaluate the accuracy of linear measurement on images provided by a CBCT machine that uses the image intensifier tube and TV chain as an X-ray detector.

MATERIALS AND METHODS

Three dry maxillaries of human heads of subjects who had donated their bodies for scientific research to the

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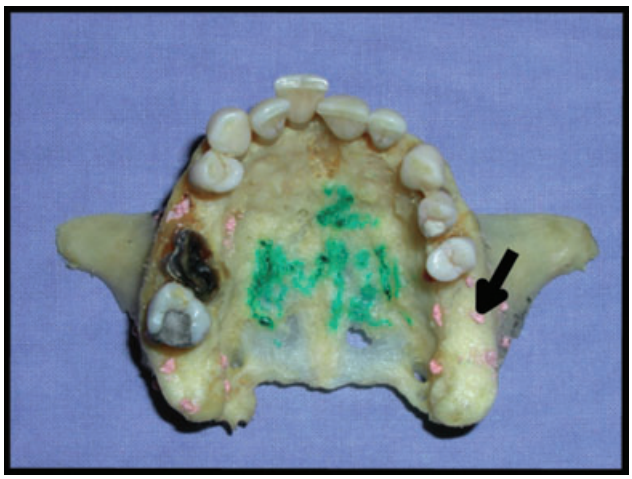

Figure 1 Bottom view of a dry maxillary. For reference purposes, three holes were drilled on the cortical plate of the maxillary, one at the top of the crest (black arrow), one on the buccal plate, and one on the palatal plate so that they make a plane.

department of anatomy (Laennec School of Medicine, University of Lyon, Lyon, France) were selected for the study.

Fourteen sites were selected, located under the maxillary sinus. For reference purposes, three holes were drilled on the cortical plate of the maxillary, one at the top of the crest, one on the buccal plate, and one on the palatal plate, so that they made a plane. No attention was paid to placing these planes perpendicular to the lower border of the crest. These holes were filled with radio-opaque markers (gutta-percha) (Figures 1 and 2).

The dry maxillaries were placed in mineralized water inside a plastic bag to simulate soft tissue of both the gum and the sinus. The maxillaries were immobilized with the median sagittal plane perpendicular to the horizontal plane, as recommended by the manufacturer. Images were acquired using the NewTom® 9000 CBCT (Quantitative Radiology, Verona, Italy) with a single scan time of 70 seconds (7 mA, 85 kV). From volumetric primary data obtained using the CBCT scan by means of what is called a primary reconstruction, axial images are obtained. These images are oriented so that they are approximately parallel to the occlusal plane of the maxillary. They are then transferred to a planning software program that can provide reformatted slices passing through planes previously defined on the dry maxillaries.

Figure 2 Side view of the same dry maxillary. Note the gutta-percha pin at the top of the crest and on the buccal plate.

The EasyGuide® software program (Keystone Dental, Inc., Burlington, MA, USA) provides three anatomical planes, the primary reconstruction axial cut, and two reformatted views, perpendicular and tangential to the arch of the jaw. The latter two, reformatted by the EasyGuide software program, are oriented in any direction the practitioner requests. One is perpendicular to the arch while the other is tangential, but they both go through a planned axis, whatever its orientation. This feature of the planning software is of utmost importance in this experiment because the clinician has to match at least one reformatted plane with the three gutta-percha pins.

After image acquisition, dry crests were sawn along the planes defined by radio-opaque markers to obtain bone sections (Figure 3). For each section, two parameters were recorded: crest height and width, which are important data for preoperative planning. The height of the bone was defined as the lower distance between the top of the crest and the bottom border of the sinus floor. The width was defined as the distance between the palatal and the buccal plates measured on a line perpendicular to the height and passing through the middle of the height line.

On bone sections, all measurements ($n = 14$) were carried out with a Mitutoyo® digimatic sliding caliper (Mitutoyo, Andover, UK) with an accuracy of 0.01 mm. The same data were recorded on images (Figure 4).

Statistical Analysis

Real measurements of the dry maxillaries were statistically compared with those obtained from the CBCT images of the same maxillary using the paired t-test. The level of significance was 5% ($p \leq .05$).

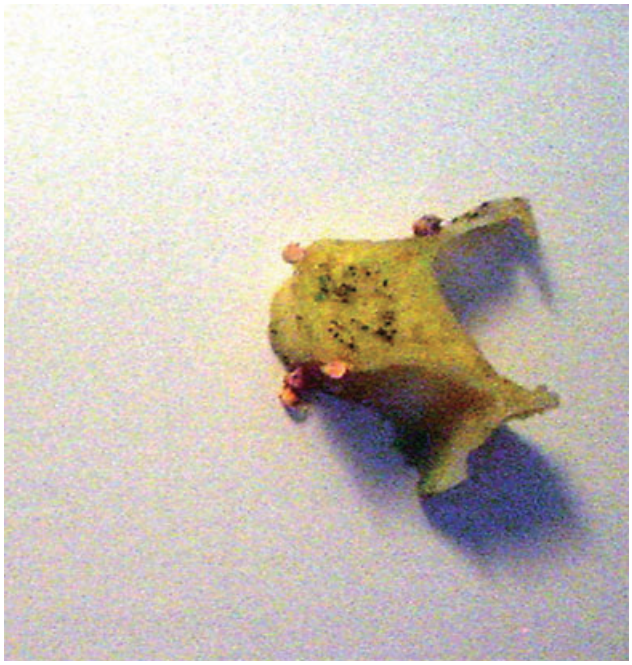

Figure 3 The dry maxillary is sawn using the three gutta-percha pins as reference points to obtain a real measurement of the height and the width of the crest on the plane defined by the three pins.

RESULTS

The data obtained from maxillaries (real measurements) and those obtained from images are presented in Table 1. The differences between real measurements and those obtained on images were not clinically significant.

DISCUSSION

Position papers provided by several groups[4,6] hold that the success of implant treatment relies in part on appropriate preoperative planning taking both the prosthetic project and the amount of bone available into account. Preoperative planning includes both ridge mapping and radiological exams. Radiological exams are recommended to acquire information on both quality and quantity of bone, and to localize anatomical landmarks. Ridge mapping alone is insufficient to accurately predict the amount and the shape of the residual crest for implantation, particularly in the anterior maxilla.[4] In periapical and panoramic radiographs, information on the width of bone is lacking and the height may be misestimated both because of potential distortion caused by positioning errors and variable magnification.[5,9] Thus, the cross-sectional imaging technique is recommended to accurately localize anatomical landmarks[3] such as the mental foramen[5] and the mandibular canal,[10] and to obtain information on the amount of bone on the palatal side of the maxillary sinus as well as the shape and direction of the crest, particularly on areas of aesthetic concern or for the severely resorbed jaw. When complex motions are used, conventional tomography is the most cost-effective method available with the lowest radiation risk and therefore is recommended for the majority of patients. CT is more appropriate for patients who are considered for many implants because conventional tomography provides slices limited in breadth, while CT provides slices of the entire maxilla.

Figure 4 Measurement of the height and the width of the crest was also assessed on the image.

The very sensitive radiological approach is the main drawback of conventional tomography. It requires considerable time to learn because the quality of images depends substantially on the skill of the operator. Image quality depends on the position of the anatomical structure according to the plane of the image layer. A slight modification of the position increases blurring, resulting from the interposition of larger osseous structures such as teeth, filling materials, and soft tissue.[10] Therefore, there is variation both between observers when they are measuring distances on conventional radiographic images and for the same observer.

Helicoidal scanning techniques and the use of cone beams with a multi-array detector have been developed to provide volumetric images through CT. This new technology provides cross-sectional images without superimposition or blurring,[8,11] and decreases the risk of radiation significantly.[7,12]

In CBCT systems, detection has been achieved by a flat-panel-type detector[13] or by an X-ray image intensifier and CCD camera.[8,11,14] The drawback of this latter

TABLE 1 Width and Height Comparison Between Real Measurements and Image Measurements of Anatomical Site on Human Maxillary

		Height (mm)			Width (mm)		
Number maxillary	Anatomical site	Real	Images	Differences	Real	Images	Differences
1	14	14	14.1	0.1	11.5	11.5	0
1	15	12.6	12.7	0.1	12	12.1	0.1
1	16	9.7	10	0.3	12.7	12.4	0.3
1	25	9.35	9.3	0.05	10.5	10.3	0.2
1	26	10.7	10.4	0.3	10.3	10.5	0.2
1	27	11.7	12	0.3	8.6	8.7	0.1
2	15	16.8	16.6	0.2	8.4	8.5	0.1
2	17	12.8	12.2	0.6	11.8	12	0.2
2	25	5.1	5.13	0.03	9.1	9	0.1
2	27	4.4	4.63	0.23	10	10	0
2	28	11	10.57	0.43	11.3	11.2	0.1
3	25	12.3	12.4	0.1	6.4	6.7	0.3
3	26	4.2	4.5	0.3	6	6.25	0.25
3	27	6.4	6.5	0.1	8.6	8.9	0.3

technology is the increase in noise from scatter radiation and a concomitant loss of contrast resolution. This in vitro study demonstrates that for the posterior region of maxilla, the NewTom CBCT technique provides accurate real measurements, confirming previous studies.[15–18] In the present study, all measurements were taken on anatomical sites that were used in the preoperative planning of the implant area. This model reproduces a real patient as accurately as possible with the connection between bone and soft tissue, even if the density of cadaveric bone may not correspond to the density of vital bone. Based on these results, it can be concluded that the technique is reliable for defining bone volume in planning the implant axis even if the image quality seems to be inferior to the conventional CT scan. In contrast, Hashimoto and colleagues[12] demonstrated the superiority of a CBCT machine (3DX Multi Image Micro CT) in displaying hard tissues in the alveolar bone region compared with a multi-detector helical CT machine. In conclusion, CBCT images provide reliable information on bone quantity for preoperative implant planning in the posterior region of the maxillary.

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