Effect of Mandibular Angulation on Pre-Implant Site Measurement Accuracy Using CBCT

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ABSTRACT

Purpose: To evaluate the accuracy of available bone width, height, and length measurements on pre-planned implant sites using CBCT images scanned at different angulations of the mandible. Materials and Methods: Standard cylindrical holes were prepared on six dry human mandibles and filled with warm gutta-percha to create spherical markers for
measurements of available bone width, height, and length. Mandibles were first scanned with a CBCT device in an ideal position with the occlusal plane parallel to the horizontal plane. Then, images of the mandibles were obtained in rotation, tilt, flexion, and extension positions using 5- and 10-degree angulations. Measurements were done on a total of 54 images. Original dimensions of the available bone for planned implant sites were measured with a digital caliper on dry mandibles as the gold standard. The absolute values of the differences between each measurement and the gold standard were obtained for measurement errors. Repeated-measures analysis of variance and Dunnett’s multiple comparisons test were used for comparisons ($P = .05$). Intraobserver and interobserver agreement was calculated using intraclass correlation coefficient (ICC). Results: ICC was excellent for both intraobserver and interobserver reproducibility. No significant difference was found between length and height measurements in ideal position and in rotation, tilt, flexion, and extension movements of mandibles at two different angulations ($P > .05$). Width measurements revealed a significant difference among ideal measurements and measurements at 10-degree flexion, 10-degree extension, 10-degree rotation, and 10-degree tilted mandibular positions ($P < .05$).

Conclusion: The position of the occlusal plane with respect to the floor during the CBCT scan may have a clinically significant effect on dental implant site dimensions. Int J Oral Maxillofac Implants 2021. doi: 10.11607/jomi.8899

Keywords: CBCT, clinical assessment, imaging, dental implant

INTRODUCTION

CBCT (cone beam computed tomography) imaging provided many diagnostic, simulation and treatment planning tools for various applications in dentistry.$^{1,2}$ Among these tools, the measurement tool due to the relative measurement error less than 1% received high recognition and wide range of use particularly for implant planning.$^{3,4}$ Distances between the
planned implant site and closest anatomical landmark, bone thickness, bone length and bone angle are all required measurements for successful implant surgery. However, there are many determinants affecting the measurement accuracy of the reformatted CBCT images. Some of these determinants are the positioning of the patient, technical factors related to the characteristics of the CBCT device (image quality) and radiation exposure (kVp, mA, number of basis images) as well as the factors related to the imaging protocol (FOV size, voxel resolution, scanner performance). Major factors responsible for image distortion and accordingly measurement deviations for CBCT imaging are the position of the occlusal plane relative to the ground and movement of the patient during exposure. Each CBCT device has a particular way of head and/or chin stabilization. Nevertheless; it was reported that head motion was frequently detected during CBCT exposure. Regardless of the stabilization method, it is crucial to minimize the head movement during exposure because studies have proved that image quality is extremely degraded. On the other hand, changes in the position of the head/chin have an important effect on the accuracy of the dimensional measurements used for implant planning. Reformatted cross-sectional images are produced in a plane perpendicular to the scan plane. Accordingly, the distortion in the reformatted images can vary due to the angle of the reformatted image plane and may lead to divergence in the measurements in all three orthogonal planes. It is well known that measurement errors may cause many treatment failures and/or life-threatening complications after implant surgery.

Success of dental implant requires meticulous evaluation of the quality and quantity of the available bone in the recipient site. Many studies have evaluated the available bone height and width for pre-implant evaluation. Bone length is as important as bone height and width since it is regarded as one of the important determinants of available bone and compensates for any crestal defect or the width of an implant. However, it has been rarely
studied. It is very well known that inadequate mesio-distal space would result in either loss of soft and hard tissue adjacent to the implant or formation of cantilever type of forces on the resultant restoration. Only few studies have included the evaluation of available bone length in measurement accuracy \(^8,12\). The effect of head/chin position on the accuracy of linear measurements using either 3D CBCT images or two-dimensional (2D) tomographic slices were evaluated in several studies \(^3,7,13\). While 3D volume images have been generally used to compare the distances between cephalometric landmarks \(^13,14\), other studies comparing the effect of head position on dimensional accuracy have used 2D slices and as already mentioned above, usually included the measure of available bone height and bone width \(^1,3,4\). There is only single study that has evaluated the changes in bone length in deviated positions of the skull \(^12\). Accordingly, it is apparent that the effect of mandibular deviation on the accuracy of all dimensions of available bone has never been thoroughly investigated.

Therefore, the aim of this study was to evaluate the accuracy of linear measurements of available bone on pre-planned implant sites including height, width and length on cone beam computed tomography (CBCT) images in various mandibular angulations. Our null hypothesis was that there would be no significant difference in the accuracy of linear measurements on CBCT images obtained at varied mandibular angulations.

**MATERIALS AND METHODS**

**Preparation of dry mandibles**

Six dentate dry human mandibles without any deformities; pathological lesions and fractures were used in the study. This study was approved by the Ethics Committee of the University (Approval no: 20-5T/45). Four cylindrical holes of approximately 3.0 mm x 3.0 mm in
diameter and depth were prepared using round diamond bur on posterior regions of left sides of the mandibles. Owing to the asymmetry of the dimensions of the right and left sides of each mandible, deviations were utilized only to a single side. Prepared defects were filled with warm gutta-percha to create spherical radiopaque fiduciary markers. Buccal area of first mandibular molar was used for the placement of first and second markers, one adjacent to the alveolar crest and the other one close to the inferior border of the mandible on the same axis. Third marker was placed lingual side of the first marker at the same level. Fourth marker providing the assessment of available bone length was placed on the buccal side of mandibular third molar root at the same level of marker 2 (Fig. 1).

**Imaging**

Dry mandibles were imaged using the Kodak 9000 3D CBCT device (Carestream Health, Inc., Rochester, NY, USA) equipped with CMOS flat panel detector. The cylindrical stitched volume was 85 mm in width, 66 mm in depth and 37 mm in height. Modified exposure parameters to compensate the lack of soft tissue were 80 kV and 6mA with 0.2 mm voxel size. All mandibles were first imaged in an “ideal” position with occlusal plane parallel and mid-sagittal plane perpendicular to the floor. Further, to investigate the effect of mandibular position on available bone measurements eight different images were obtained from each mandible using 5° and 10° difference in various planes. Since it was previously proved that movement range of the head during CBCT scan was between 5 to 10 degrees, no further angulations were included. Each mandible was scanned first in an ideal position and then scanned using the following positions:

a- Mandible was tilted 5° and 10° downward anterior (flexion)
b- Mandible was tilted 5° and 10° upward and back (extension)
c- Mandible was rotated 5° and 10° to the left (rotation)
d- Mandible was tilted 5° and 10° to the right (tilt)
In order to simulate clinical conditions mandibles were placed in the center of a wooden platform screwed on a camera tripod stand’s base (Manfrotto 294, 804RC2, Italy) (Fig. 1). The tripod stand had a dial plate with capability of rotational movement as well as lateral and forward-backward movements in all directions (x, y, z). In order to establish the parallelism of occlusal plane of the mandible to the floor, modeling clay was placed under the left and right mandibular angles and mandible was fixed with a clear tape in order to avoid any movements. Modeling clay ensured that the reference plane (the occlusal plane) was parallel to the floor and exposures with this position were used as the ideal. Moreover, the midsagittal plane of each mandible was aligned with respect to the midsagittal-positioning laser of the CBCT unit during the exposure. In order to confirm the accuracy of the angles, a picture of the mandibles was taken with a camera attached to another tripod before CBCT exposures and analyzed using the photographs and an online protractor.\textsuperscript{17}

**Radiographic measurements**

Total of 54 images were obtained for six mandibles. The reconstruction of the images was automatically done after each exposure by the Kodak 9000 software producing a volume with orthoradial 2D slices in the axial, sagittal and coronal planes.

The images were viewed on a 21-inch LCD monitor (T2224Da, Lenovo, China) with a resolution of 1024x1280 pixels and 32-bit color depth. Radiopaque nature of markers enabled easy detection of the borders of the markers in cross-sectional images. The distances were measured on the slice with the clearest image boundaries of the fiducial marker from the external border of one sphere marker appearing as circle in sectional image to the external border of the other marker. The length and height measurements of available bone were made using the measurement tool of the software program on the cross-sectional images and (Figs. 2A & B) width measurements were made on the axial images where the borders of the radiopaque markers appeared more defined (Fig. 2C). Three linear measurements of available
bone were done between four points determined by radiopaque markers. The distance between markers 1 & 2 (height), distance between markers 1 & 3 (width) and distance between markers 2 & 4 (length) were measured. Measurements were done by two maxillofacial radiologists with 3 to 10 years of experience with CBCT images. The measurements were repeated two times by each observer with an interval of one-day. The observers were free to change the sharpness, contrast and brightness of the images as well as the slice thickness. The mean of the three measurements was calculated and used for statistical analysis.

A digital caliper with reliability of 0.01-mm was used to make the physical measurements on dry mandibles in an identical manner with radiographic measurements (Fig. 3). All measurements were done by a single observer and repeated a week later. The mean of the measurements for each distance was calculated and used as the “gold standard”.

**Statistical analysis**

The mean values of the measurements obtained from the CBCT images and those obtained by direct measurements (the gold standard) were used to calculate the mean error values. In order to calculate the measurement errors, the absolute values of the differences between each measurement and the gold standard were obtained for each linear measurement. Repeated measures analysis of variance (RM-ANOVA) was used to find out if there was a significant difference among the groups (p=0.05). Dunnett’s multiple comparisons test was used for pair-wise comparisons when necessary (p=0.05). Intra- and inter-observer agreement was calculated using intra-class correlation coefficient (ICC) (ICC<0.4 = Poor; 0.4 ≤ ICC ≤ 0.75 = Satisfactory; ICC ≥ 0.75 = Excellent)
RESULTS

Excellent intra- (0.884-0.897) and inter-observer (0.899-0.924) reproducibility was obtained with ICC. No significant difference was found among length and height measurements in ideal position and in rotation, tilt, flexion and extension positions of mandibles with two different angulations (p>0.05) (, 1). On the contrary, width measurements revealed a significant difference between the groups (p<0.05). Pairwise comparisons of width measurements showed a significant difference among ideal and measurements at 10° flexion, 10° extension, 10° rotation as well as 10° tilted mandibular positions (p<0.05).

Table 2 presents the absolute mean differences and standard errors of the mean (SEM) of length, height and width measurements at ideal and different mandibular positions. Ideal position of the mandibles during CBCT scans always presented the minor error for all measurement types, meaning scans with occlusal plane parallel to the floor resulted in measurement values closest to the gold standard. Although not significant, generally, increase in angulation of the mandibular movement resulted in higher deviations for both length and height measurements. In other words, measurement errors increased at most of the mandibular deviations and mostly at 10° angulations.

The absolute mean differences for length, height and width at different mandibular positions and angulations ranged from 0.53 to 2.55, 0.40 to 1.63 and 0.20 to 0.92 respectively. Highest absolute difference among all measurements was obtained for length measurements. Highest mean deviation of length measurements was 2.55 mm (SEM, ±0.52) while it was 1.63 mm (SEM, ±0.20) for height measurements. Width measurements with 10° angulation of all mandibular deviations showed measurement errors between 0.70 mm to 0.92 mm with significant difference from ideal position measurements (p<0.05) (Table 2).
Among all of the deviated positions, rotated position affected the measurement errors more than other three deviations. However, the difference was significant only for width measurements at 10° angulation (p<0.05) (Table 2).
DISCUSSION

This study aimed to determine the accuracy of available bone measurements including bone length, bone height and bone width using dry mandibles in different positions and angulations mimicking patient movements during CBCT scan. Computer-aided implant planning and virtual implant placement depend on anatomic and prosthetic judgments, which require both positions of implant and prosthesis in 3D image. Such planning necessitates radiographic guide during CBCT exposure, which allows for visualization of the prosthetic tooth as well as planned implant location. Since radiopaque markers or fiduciaries resembling the planned tooth and prosthesis are relatively inexpensive and practical, they are widely used in radiographic stents. The use of gutta-percha for pre-surgical implant site assessment is a very common practice and particularly popular due to its easy access and practicability. Even though gutta-percha may produce artifacts on CBCT images, it has been proved that it is negligible for implant planning due to its organic composition with extremely low atomic numbers and therefore, it is preferred in the present study to simulate everyday clinical practice for pre-surgical site representation.\textsuperscript{18}

Mandibular molar region was particularly selected for the placement of the markers, because it is the most frequent area for implant treatment and holds the highest possibility of surgical complications.\textsuperscript{19} In order to obtain healthy osseointegration, correct quantification of all three dimensions of available bone is an obligement to make sure that selected implant site contains proper amount of bone. Nevertheless, most of the studies evaluating dimensional accuracy of available bone have only included the measure of bone height and bone width.\textsuperscript{3,20,21} Present study is one of the rare studies including the measure of all three-bone dimensions at pre-planned implant locations at nine different mandibular position and angulation combinations. Our results showed that the deviations of mandibular occlusal plane from ideal position during CBCT scan caused significant change particularly on the accuracy
of bone width. The width of the available bone was measured as the distance between the markers placed on the outer and the internal cortical plates. When the mandible was inclined, the cross-sectional reformatting was constructed obliquely, not perpendicular to the mandibular base and accordingly, higher values were obtained for diagonally measured distances. Similar results have been reported in previous studies for bone width measurements.\textsuperscript{20,21}

Even though the differences in the measurements of height and length were high for most of the mandibular deviations, change in values did not present statistically significant difference from ideal measurements. As obtained in many previous studies, the highest mean difference between ideal measurements and measurements with mandibular deviations were generally observed at greater (10°) angulations. Although not significant, half of the bone length measurements in deviated positions showed more than 1.5 mm error, whereas only 10° rotation measurement showed more than 1.5 mm error for bone height (Table 2). Thus, it was possible to suggest that bone length measurements were affected more than height measurements by mandibular deviations. Since the distance between the markers defining the bone length measurements were greater than the distance of markers resembling bone height in our study set-up, the volume of bone that was displaced in the image layer in deviated positions were higher for length and accordingly length was more severely affected dimension. This finding is in accordance with previous results.\textsuperscript{3,12}

Accuracy is imperative for implant treatment planning in order to prevent damage to anatomical structures and/or neighboring teeth.\textsuperscript{3} Width measurements were significantly affected by the positional variations of the mandibular occlusal plane during CBCT scanning. Considering the importance of the precision for implant treatment planning, even if there was no statistically significant difference, the differences in available bone length and height measurements found in the present study (exceeding surgical safety zone) may be also
considered important from a clinical point of view. Measurements for potential implant sites are often done to decide on the length and diameter of the implant, on the need for bone and/or sinus augmentation surgeries. Moreover, performances of both static and dynamic guided surgeries depend completely on available bone measurements on CBCT images. Therefore, our length and height measurements showing more than 1.5 mm divergence may have a major effect on surgical planning, success of implant and prosthetic therapies.\textsuperscript{22} Therefore, these results reject our null hypothesis that available bone measurements on CBCT scans obtained at varied mandibular angulations are equivalent.

According to our results, rotated position of the mandibles affected the measurement errors more than all of the other deviations. This result is in accordance with previous studies, which have proved that rotation of the head around the vertical axis has a greater effect on horizontal measurements.\textsuperscript{23} Left side rotation of the head is considered as the adverse direction to the CBCT scanner’s rotation that starts from the subject’s right side. Accordingly, it is advocated that the clarity of the structures decreases on left side of the resultant image, which in turn increases the measurement errors.\textsuperscript{24,25}

It has been previously proved that improper mandibular positioning during CBCT scan produce dimensional variations in multiplanar cross sectional images which are not perpendicular to the horizontal plane.\textsuperscript{26} However, many controversial results exist regarding the accuracy of measurements due to incorrect patient positioning during CBCT scanning.\textsuperscript{26} The discrepancies in results is mainly due to the use of either two-dimensional cross sectional images or 3D reconstructions for measurements. Studies comparing the effect of various head/mandibular positions using 3D volume reconstructions have generally measured linear distances between cephalometric landmarks. In order to measure cephalometric distances, large field of view images are required which needs higher scan times increasing the probability of patient movement plus provides lower resolution images around 0.4-mm voxel
size. In fact, landmark identification is basically very different from measuring linear distances on cross sectional images, which can be done using the original software whereas 3D reconstructions require 3rd party software for distance measurements. In the present study, 2D cross-sectional images were preferred for available bone measurements to create identical conditions with respect to the measurements done on CBCT images prior to implant surgery.

This study simulated some of the probabilities of minimum clinical movements of the mandible during CBCT scan. Our results demonstrated that CBCT images showed high reliability with ICC ranging between 0.88 and 0.94. It can be concluded that alterations in the mandibular occlusal plane during CBCT scan can produce variations in the available bone width, height and length, which may cause failure of implant treatment and possibly damage to the important anatomical structures. However, this study was conducted on dry human mandibles with the absence of soft tissue and therefore, had some limitations as compared to clinical studies. Although CBCT do not provide differentiation of soft tissues, presence of soft tissue may have an adverse influence on the quality of the resultant image. Another drawback is that single CBCT unit was used in the present study with selected kVp, mA and a voxel size. It is possible that different exposure parameters and/or different CBCT systems with different types of sensors producing images with different resolutions may yield different results. Nevertheless, regardless of the CBCT system used, it should be remembered that patient positioning have a profound importance and/or changes in occlusal plane with respect to floor should be avoided during CBCT scans obtained for pre-operative virtual implant planning in order to prevent divergence in available bone measurements.

In conclusion, only width measurements revealed a significant difference with deviations of mandibular occlusal plane from ideal position during CBCT scan. No significant difference was observed for length and height between measurements of ideal and
deviated mandibular positions. However; at least half of the length and height measurements in deviated mandibular positions showed measurement errors exceeding surgical safety zone of 1.5 mm. Among all angular deviations, rotated position of the mandibles affected the measurement errors more than all of the other deviations. Accordingly; it is possible to suggest that within the limitations of this study the position of the mandible during CBCT scan may have a clinically important effect on the accuracy of mandibular implant site dimensions. Therefore, it is recommended to keep the occlusal plane of the mandible as parallel as possible to the floor during CBCT scanning in order to preserve dimensional accuracy and precision.
REFERENCES


17. https://www.ursupplier.com/tools/angle_measurement/


Table 1. Minimum (Min), maximum (Max), mean and standard error of mean (SEM) values of length, height and width measurements at ideal, flexion (Flex), rotation (Rot), Extension (Ext) and tilted mandibular positions with 5° and 10° angulations.

<table>
<thead>
<tr>
<th>Position</th>
<th>Ideal</th>
<th>Flex5°</th>
<th>Flex10°</th>
<th>Ext 5°</th>
<th>Ext10°</th>
<th>Rot 5°</th>
<th>Rot10°</th>
<th>Tilt 5°</th>
<th>Tilt10°</th>
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</table>

* Significantly different from ideal position measurements (p<0.05)
Table 2. Mean measurement errors±SEM (standard error of the mean) of linear measurements at ideal mandibular position and flexion (Flex), rotation (Rot), Extension (Ext) and tilted (Tilt) mandibular positions with 5° and 10° angulations (in mm).

<table>
<thead>
<tr>
<th>Position</th>
<th>Ideal</th>
<th>Flex5°</th>
<th>Flex10°</th>
<th>Ext 5°</th>
<th>Ext10°</th>
<th>Rot 5°</th>
<th>Rot10°</th>
<th>Tilt 5°</th>
<th>Tilt10°</th>
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<td>0.92±0.14</td>
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</table>
FIGURE LEGENDS

Figure 1: Dry mandible with two gutta-percha markers at the mandibular base and one marker at the crest level (red arrows) attached to the wooden platform with modeling clay.

Figure 2: Coronal CBCT image demonstrating a bone length measurement.

Figure 3: Sagittal CBCT image demonstrating a bone height measurement.

Figure 4: Axial CBCT image demonstrating a bone width measurement.

Figure 5: Demonstration of gold standard measurements made on dry mandibles using a digital caliper.
Figure 1
Figure 2

Figure 3
Figure 4

Figure 5
Conflict of Interest and source of funding

The authors declare no potential conflict of interests with respect to this study.