Accuracy and Reliability of Cone Beam Computed Tomographic Measurements of the Bone Labial and Palatal to the Maxillary Anterior Teeth

Hossein Behnia, DMD, MS1/Saeed Reza Motamedian, DDS2/Mohammad Taghi Kiani, DMD, MS3/Golnaz Morad, DDS2/Arash Khojasteh, DMD, MS4

Purpose: The aim of this study was to measure the thickness of bone labial and palatal to maxillary anterior teeth on cone beam computed tomographic (CBCT) images and to compare these measurements with direct clinical measurements to determine the reliability and accuracy of CBCT. Materials and Methods: Eighteen healthy subjects were randomly selected from among candidates for immediate implant placement in the anterior maxilla. After extraction, labial bone thickness was measured at 1, 4, and 8 mm from the bone crest. Palatal bone thickness was also measured at 1 and 4 mm from the bone crest. The same measurements were performed on presurgical CBCT images. The CBCT measurements were compared to the direct measurements, and their accuracy and reliability were assessed by Pearson correlation coefficients and intraclass correlation coefficients, respectively. Results: The mean width of labial bone was 0.50 ± 0.32 mm and 0.76 ± 0.37 mm for direct and CBCT measurements, respectively. Average thickness of the palatal bone was 1.16 ± 0.53 mm and 1.41 ± 0.51 mm for direct and CBCT measurements, respectively. The mean absolute error and mean relative error of CBCT measurements compared to direct measurements were 0.28 ± 0.29 mm and 0.60 ± 0.84 mm, respectively. The Pearson correlation between CBCT and direct measurements was 0.795 (P < .001) and the intraclass correlation coefficient between direct and CBCT measurements was 0.840. The correlation between the measurement series increased significantly when the measured bone was more than 1 mm thick. Conclusion: CBCT measurements of labial bone mostly overestimated bone thickness. CBCT has relatively good accuracy and reliability for measurement of labial bone thickness when the alveolar bone is thicker than 1 mm. However, most subjects have labial bone thinner than 1 mm; therefore, CBCT could result in large errors in many patients.

Key words: alveolar bone, cone beam computed tomography, dental implants, esthetic zone, reproducibility of results

A minimum width of 2 mm of the alveolar labial bone has been assumed to be required for immediate implant placement.1–3 Atraumatic extraction as well as minimum reflection of the periosteum is also recommended for optimum esthetic and functional results.2 Remodeling of the alveolar bone, even after placement of dental implants, continues and may jeopardize the esthetic results.4,5 In this context, the thickness of the labial bone plays a crucial role, whereas simultaneous bone grafting during fresh socket dental implant placement has been recommended by Buser et al.6 Several studies have measured the width of labial bone to assess the prevalence of labial bone thicker than 2 mm.2,4,7–13 These experiments have been performed in various populations and reported different mean thicknesses of labial bone. Direct clinical measurement of bone after the careful extraction of anterior maxillary teeth showed a range of thickness between 0.8 and 1.4 mm.
Radiographic evaluations with cone beam computed tomography (CBCT) have shown mean labial bone thickness measurements between 0.6 and 1.73 mm.\textsuperscript{9,10,12,14,15} However, the reliability of the measurements made on CBCT images was not addressed in the cited articles. Thus, it should be asked whether these measurements on CBCT images are a reliable means to assess buccal bone width prior to deciding upon implant placement immediately after extractions.

To the authors’ best knowledge, no previous study has assessed the reliability of CBCT measurements of labial bone thickness. Therefore, the current study was performed to measure the buccal and palatal bone thickness in the anterior maxilla by CBCT and to compare these with direct clinical measurements. The study was designed to simulate a clinical situation in which the dentist’s decision regarding immediate implant placement would be based on measurements of the thickness of labial and palatal bone overlying the teeth on CBCT images prior to the surgery.

**MATERIALS AND METHODS**

**Patient Selection**
Candidates for immediate implant placement in the anterior maxilla who were referred to the dental school of Shahid Beheshti University of Medical Sciences during 2012 and 2013 were included. The criteria for immediate implant therapy were lack of severe periodontal disease or apical abscess, as well as dental malpositioning. Teeth were removed as a result of caries, endodontic problems, or fracture. Before the study began, the patients gave written informed consent.

**Surgical Procedure and Direct Measurement**
The teeth were extracted atraumatically with periotes and forceps (Salvin Dental Specialties, Inc) to preserve labial bone. In some cases less than 1 mm of periosteum was elevated to determine the relationship between the bone crest and the remnant root, but complete elevation was avoided to preserve peripheral vascularization of the thin labial bone. The thickness of the labial bone at 1 mm, 4 mm, and 8 mm from the alveolar crest in the midmesiodistal portion and the thickness of the midpalatal bone at 1 mm and 4 mm from the alveolar crest was measured with a caliper (Iwansson, Bontempi) (Fig 1). These measurements were considered as the gold standard and were used to assess the reliability of CBCT measurements. Afterward, implants were placed with typical drilling sequences.

**CBCT Measurement**
Presurgical CBCT scans of the patients were gathered. All scans were performed by a single CBCT machine (NewTomVG, QR srl/AFP Imaging Co). The CBCT scans were done at 5.56 mAs and 110 kVp and lasted 18 seconds; a voxel size of 0.3 mm was used. Reconstruction of the images and the measurements were performed by NNT NewTom software (version 3.00, QR srl).

The distances between the inner and outer surfaces of the labial and palatal bone on midmesiodistal axial scans were measured at the same points as the clinical measurements, as previously described\textsuperscript{14} (Fig 2). If the image was scattered or the midmesiodistal slice image of the tooth was not accessible, no CBCT measurement was performed for that tooth.

Measurement of labial and palatal bone thickness on CBCT images was performed twice by a single dentist (SRM) over a 2-week interval. The reproducibility of the measurements was assessed by intraclass correlation coefficient (ICC), and the averages of the two measurement sessions were used for the tooth in question.

**Statistical Analysis**
Descriptive statistics included means and standard deviations for direct and CBCT-mediated measurements. The accuracy of the CBCT measurements was determined with the Pearson correlation coefficient. ICCs were used to determine the level of agreement.
(reliability) between the CBCT and direct measurements. Also, the mean absolute error and the mean relative error of the CBCT measurements were calculated by the following equations:

\[
\text{Absolute error} = \frac{\text{direct measurement} - \text{CBCT measurement}}{	ext{direct measurement}}
\]

\[
\text{Relative error} = \frac{\text{direct measurement} - \text{CBCT measurement}}{	ext{direct measurement}}
\]

All statistical analyses were conducted with IBM SPSS software v. 19.0.

**RESULTS**

This study was performed in 18 healthy subjects (7 women and 11 men; average age, 45 years; range, 28 to 68 years). In all, 39 teeth (13 central incisors, 14 lateral incisors, 9 canines, and 3 first premolars) were included.

The ICC for reproducibility of the CBCT measurements was 0.903, which was considered excellent. The thicknesses of the labial and palatal bone measured directly or on CBCT scans for the maxillary anterior teeth at 1, 4, and 8 mm from the bone crest are shown in Table 1.

The mean thickness of labial bone was 0.50 ± 0.32 mm and 0.76 ± 0.37 mm according to direct and CBCT measurements, respectively. Mean thickness of the palatal bone was 1.16 ± 0.53 mm and 1.41 ± 0.51 mm according to direct and CBCT measurements, respectively. Comparison of the mean values for direct and CBCT measurements revealed that CBCT measurements were underestimated in 18 sites (16%) and overestimated in 85 sites (77%) (Fig 3). To further investigate this difference between the measurements, the mean absolute error (0.28 ± 0.29 mm) and the mean relative error (0.60 ± 0.84 mm) of CBCT measurements compared to direct measurements were calculated. Figures 4 and 5 show that, with increasing thickness of labial or palatal bone, the absolute error decreased slightly and the relative error decreased considerably.

**Table 1**  
**Mean Thickness of Bone Labial and Palatal to Maxillary Anterior Teeth at Different Distances from the Bone Crest**

<table>
<thead>
<tr>
<th>Tooth</th>
<th>Location</th>
<th>Direct measurement</th>
<th>Measurement on CBCT*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean ± SD</td>
<td>n</td>
</tr>
<tr>
<td>Central incisor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buccal 1 mm</td>
<td>11</td>
<td>0.65 ± 0.27</td>
<td>10</td>
</tr>
<tr>
<td>Buccal 4 mm</td>
<td>11</td>
<td>0.48 ± 0.20</td>
<td>10</td>
</tr>
<tr>
<td>Buccal 8 mm</td>
<td>8</td>
<td>0.39 ± 0.22</td>
<td>7</td>
</tr>
<tr>
<td>Palatal 1 mm</td>
<td>11</td>
<td>0.90 ± 0.41</td>
<td>8</td>
</tr>
<tr>
<td>Palatal 4 mm</td>
<td>11</td>
<td>1.47 ± 0.51</td>
<td>10</td>
</tr>
<tr>
<td>Lateral incisor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buccal 1 mm</td>
<td>14</td>
<td>0.52 ± 0.31</td>
<td>9</td>
</tr>
<tr>
<td>Buccal 4 mm</td>
<td>13</td>
<td>0.52 ± 0.38</td>
<td>8</td>
</tr>
<tr>
<td>Buccal 8 mm</td>
<td>10</td>
<td>0.28 ± 0.37</td>
<td>5</td>
</tr>
<tr>
<td>Palatal 1 mm</td>
<td>14</td>
<td>0.88 ± 0.34</td>
<td>7</td>
</tr>
<tr>
<td>Palatal 4 mm</td>
<td>13</td>
<td>1.35 ± 0.70</td>
<td>6</td>
</tr>
<tr>
<td>Canine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buccal 1 mm</td>
<td>8</td>
<td>0.63 ± 0.37</td>
<td>6</td>
</tr>
<tr>
<td>Buccal 4 mm</td>
<td>7</td>
<td>0.66 ± 0.31</td>
<td>6</td>
</tr>
<tr>
<td>Buccal 8 mm</td>
<td>5</td>
<td>0.36 ± 0.21</td>
<td>3</td>
</tr>
<tr>
<td>Palatal 1 mm</td>
<td>8</td>
<td>0.95 ± 0.40</td>
<td>6</td>
</tr>
<tr>
<td>Palatal 4 mm</td>
<td>6</td>
<td>1.47 ± 0.45</td>
<td>5</td>
</tr>
<tr>
<td>Premolar</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buccal 1 mm</td>
<td>3</td>
<td>0.87 ± 0.06</td>
<td>1</td>
</tr>
<tr>
<td>Buccal 4 mm</td>
<td>3</td>
<td>0.43 ± 0.06</td>
<td>1</td>
</tr>
<tr>
<td>Buccal 8 mm</td>
<td>3</td>
<td>0.17 ± 0.15</td>
<td>1</td>
</tr>
<tr>
<td>Palatal 1 mm</td>
<td>3</td>
<td>1.17 ± 0.32</td>
<td>1</td>
</tr>
<tr>
<td>Palatal 4 mm</td>
<td>3</td>
<td>1.40 ± 0.61</td>
<td>1</td>
</tr>
</tbody>
</table>

Measurements on the CBCTs involved fewer teeth because in some cases the CBCT scans were scattered or the midmesiodistal slice image of the tooth was not accessible.

SD = standard deviation.
Figure 6 demonstrates the distribution of alveolar bone width as well as the occurrence of labial and palatal bone thickness ≥ 2 mm. The majority of buccal sites had thickness < 1 mm, while a thickness between 1 and 2 mm was more common at palatal walls. No buccal bone walls were thicker than 2 mm.

The Pearson correlation between CBCT and direct measurements was 0.795 ($P < .001$), showing good accuracy. Single and average ICCs between direct and CBCT measurement were 0.724 and 0.840, respectively. Figure 7 shows that the direct and CBCT measurements had excellent agreement, which increased from central incisor to canine. The measurements of the palatal wall were more consistent than their labial counterpart (Table 2). Table 3 shows that the correlation between the two measurement series increased significantly when the bone was thicker than 1 mm.
DISCUSSION

Alveolar bone dimensions can influence the esthetic outcome of immediate implant placement in the anterior maxilla. Thus, it is important to measure these dimensions during treatment planning. The aim of this study was to determine the thickness of labial and palatal bone and to estimate the accuracy and reliability of CBCT images in measuring such small distances.

Thickness of Alveolar Bone in the Anterior Maxilla

In the current study, previously described methods to measure alveolar bone thickness both directly and on CBCT images were used. Januário et al assessed labial bone thickness of the anterior maxillary teeth in 250 CBCT images and reported small measurements (mean values of 0.6 mm, 0.7 mm, and 0.6 mm for maxillary central incisors, lateral incisors, and canines, respectively). Similarly, a recent experiment reported a mean thickness of 0.83 mm for the labial alveolar bone of maxillary anterior teeth at 1 mm apical to the bone crest. Conversely, evaluation of CBCT images of 66 randomly selected patients of Italian ethnicity showed relatively greater measurements (right and left central incisors 1.41 mm and 1.45 mm, respectively, right and left lateral incisors 1.73 mm and 1.59 mm, respectively, and right and left canines 1.47 mm and 1.60 mm, respectively; all measurements were done 3 mm from the bone crest). In the present study, the average labial bone thickness values at the maxillary central incisors, lateral incisors, and canines on CBCT were 0.71 mm, 0.82 mm, and 0.77 mm, respectively (Table 1).

In the current study, direct measurement of labial bone resulted in relatively lower values. The mean thickness of labial and palatal bone measured directly was 0.51 ± 0.35 mm and 1.25 ± 0.66 mm, respectively. Botticelli et al measured the labial bone thickness at 21 extraction sockets at 1 mm from the bone crest using a caliper. Both maxillary anterior teeth and premolars were included in that study, and mean labial and palatal bone widths of 1.4 ± 0.04 mm and 1.6 ± 0.6 mm were reported, respectively. A more recent study using the same methodology on 93 extraction sockets reported mean thicknesses of 0.8 mm on the buccal and 1.2 mm on the palatal in the anterior maxilla.

A clinically relevant finding was that no occurrence of labial bone width more than 2 mm was seen. The prevalence of bone width ≥ 2 mm based on CBCT analysis was shown to be between 26% and 1% for maxillary anterior teeth. Direct measurement of labial bone showed that, in anterior sites, 87.2% of labial bone walls had a width of < 1 mm, and only 2.6% of the walls were ≥ 2 mm wide. Other studies measured the thickness of facial bone postextraction and reported that, in most cases, facial bone was thinner than 1 mm at 1 mm from the bone crest. The present results showed that the palatal walls of only five teeth featured alveolar bone ≥ 2 mm wide; the majority of labial sites were ≥ 1 mm thick (Fig 3).

Reliability of CBCT Linear Measurements for Short Distances

A limited number of studies have compared the reliability of CBCT measurements for short maxillofacial distances and none have compared these landmark measurements to direct clinical measurements. Several studies investigated the accuracy of CBCT and compared it to direct measurements made on dry skulls; they reported relative errors of 0.6% to 19%. Patcas et al showed that the bone on the labial of mandibular anterior teeth can be measured on CBCT with 0.4-mm voxel size to an accuracy within 0.54 ± 0.42 mm, compared to measurements on a cadaver head. However, the reliability of CBCT measurements in these experiments was investigated for relatively long maxillofacial distances (ranging from 4 to 124 mm) between orthodontic landmarks, and the measurements were compared to direct measurements on dry skulls as the gold standard. In addition, studies in cadavers lack soft tissue, and alcohol fixation may alter tissue properties.

Table 2: ICCs for Comparisons of Direct and CBCT Measurements of Bone Labial and Buccal to Maxillary Anterior Teeth

<table>
<thead>
<tr>
<th>Location</th>
<th>Single measures</th>
<th>Average measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central incisor</td>
<td>0.710</td>
<td>0.830</td>
</tr>
<tr>
<td>Lateral incisor</td>
<td>0.693</td>
<td>0.818</td>
</tr>
<tr>
<td>Canine</td>
<td>0.858</td>
<td>0.923</td>
</tr>
<tr>
<td>Premolar</td>
<td>0.505</td>
<td>0.671</td>
</tr>
<tr>
<td>Buccal wall</td>
<td>0.532</td>
<td>0.695</td>
</tr>
<tr>
<td>Palatal wall</td>
<td>0.610</td>
<td>0.758</td>
</tr>
</tbody>
</table>

Table 3: ICCs for Direct and CBCT Measurements Based on Bone Thickness Classification

<table>
<thead>
<tr>
<th>Width</th>
<th>Single measures</th>
<th>Average measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct measurement ≤ 0.5 mm</td>
<td>0.234</td>
<td>0.380</td>
</tr>
<tr>
<td>Direct measurement ≤ 1 mm</td>
<td>0.425</td>
<td>0.597</td>
</tr>
<tr>
<td>Direct measurement &gt; 1 mm</td>
<td>0.885</td>
<td>0.939</td>
</tr>
</tbody>
</table>
| Total                | 0.724           | 0.840           
The present study is the first to describe the accuracy of labial alveolar bone measurements performed on CBCT images. This comparison of a low-resolution CBCT protocol and direct clinical measurements as the standard was performed, and CBCT measurements showed a relatively good accuracy and reliability for thickness more than 1 mm; the mean absolute error was 0.28 ± 0.29 mm. Kobayashi et al., who used mandibles predrilled with reference holes and CBCT with a voxel size of 0.125 mm, reported a mean absolute error of 0.22 ± 0.15 mm between CBCT and direct measurements. Another study reported a mean absolute error of 0.26 ± 0.18 mm between direct measurements on a dry skull and measurements on CBCT with a voxel size of 0.3 mm. The landmarks in the cited study were predefined by placement of gutta-percha points. Dammstr et al., marked orthodontic landmarks with spherical glass markers and measured the distance between these landmarks on CBCT scans. Comparing CBCT measurements with direct measurements on dry skull, they obtained ICCs of 0.99, and their absolute errors were 0.05 ± 0.04 mm and 0.07 ± 0.05 mm for voxel sizes of 0.2 and 0.4 mm, respectively.

The larger error assessed in the current study might be primarily a result of errors in detection of the bone crest in CBCT images, rather than true linear measurement errors on the CBCTs. However, the aim of the study was to simulate a clinical situation, and radiopaque indicators were not used to detect landmarks. Another reason for the poorer reliability might be a result of lower CBCT image resolution caused by the voxel size of 0.3 mm, versus the smaller voxel size used by Kobayashi et al.

In the current study, a conventional voxel size of 0.3 mm was applied to reduce patient exposure to radiation. The effect of voxel size on image quality was demonstrated by Wenzel et al.

The current study showed that CBCT tended to overestimate bone thickness. Gerlach et al. compared CBCT measurements of cortical bone width overlying mandibular teeth of fresh frozen skulls to histologic measurements and observed that CBCT significantly overestimates measurements. In contrast, most previous findings suggested that CBCT usually underestimates linear measurements between craniofacial landmarks. Gerlach et al. suggested that exaggeration of the thin cortical bone on CBCT sections might be a result of partial bone volume averaging and blurring of thin bone layers.

A noteworthy finding was that the correlation between CBCT and direct measurements increases when bone is thicker than 1 mm. These findings show that CBCT has excellent reliability and accuracy for corroboration of more than 2 mm of buccal bone prior to immediate implant placement. However, it should be noted that most subjects have less than 1 mm of labial bone, which results in larger errors. Similarly, in the study of Razavi et al., poorer correlations were documented when bone was thinner than 0.8 mm. Another study also showed that CBCT cannot detect less than 0.6 mm of bone thickness. In the current study, however, a thickness of 0.2 mm was detectable in CBCT images, although relatively greater error was observed.

The results show that the CBCT measurements overestimated the bone thickness in 77% of measured sites, whereas previous studies demonstrated underestimation in 60.7% and 94.4% of measurements. A probable reason for this difference is that, in the current study, CBCT measurements were compared to clinical measurements, whereas previous studies used a dry skull as a reference.

One of the limitations of the current study was the possible bias of a single observer, resulting in greater consistency in radiologic landmark identification compared to various interpretations by several observers. However, a meta-analysis showed that the number of observers does not play a significant role in the reproducibility of radiologic cephalometric landmark identification. In the current study, the reproducibility of CBCT measurements at a 2-week interval was 0.903. Similarly, measurement of labial bone on CBCT images was previously demonstrated to be reproducible at an ICC of 0.90 for measurements of about 1 mm. Another limitation of this study was that, compared to animal studies, direct measurement of labial and palatal bone was less accurate and any periosteal elevation might have influenced the measurements.

CONCLUSIONS

Cone beam computed tomographic (CBCT) measurement of labial and palatal bone thickness often overestimates bone thickness, compared to direct measurement with calipers. CBCT scans seem to have good accuracy and reliability when measuring labial and palatal bone thicker than 1 mm. However, as most subjects have labial bone that is thinner than 1 mm, CBCT measurements of labial bone may result in large errors in most patients.

ACKNOWLEDGMENTS

The authors declare no conflicts of interest.
REFERENCES