Importance of the axial reference plane in computed tomography for dental implant surgery: A cadaveric study

Abstract

Objectives

The aims of the study were to assess the accuracy of dental computed tomography (CT) scans and to compare the discrepancies obtained when either the occlusal plane or the basal plane was used as the axial reference plane.

Materials and methods

Thirty-nine mandibles from adult cadavers were examined. Eighteen tomographic slices were performed for each mandible, using the occlusal and the basal planes as axial reference planes. The radiographic measurements obtained using the two reference planes were compared with bone measurements taken using a digital calibrator.

Results

Discrepancies, which varied between 0.03 mm and 1.47 mm, were found between measurements taken from CT scans and measurements taken directly from the bone. When the distribution of discrepancies was considered in relation to the axial reference plane used, it was found that when the basal plane was used, a higher percentage of discrepancies of over 0.5 mm occurred (99.44%) than when the occlusal plane was used (44.44%), with the difference being statistically significant ($p = 0.001$).

Conclusion

The discrepancies between CT radiographic measurements and direct bone measurements should be taken into consideration in order to achieve satisfactory dental implant treatments. With regard to positioning the patient when CT scans are taken, use of the occlusal plane as axial reference will produce the most accurate measurements.

Keywords

Axial reference plane, occlusal plane, basal plane, computed tomography, dental implantology.
Introduction

Edentulous patients seeking dental treatment to restore function and esthetics have traditionally received removable complete or partial dentures. However, the use of removable dentures may give the patient a sense of insecurity, reduced masticatory function and taste capacity, as well as low self-esteem.\(^1\) For these reasons, approaches to treatment have turned toward dental implants, which produce marked improvements in patients’ quality of life and high treatment success rates.\(^2\),\(^3\)

An adequate radiographic technique that will provide a sufficiently accurate assessment of the bone dimensions is of great help when planning the surgical intervention. Intra-oral and panoramic radiographs give information in two dimensions, visualizing bone morphology in a buccolingual direction, but lack the third dimension. Both techniques are only useful for a primary preoperative evaluation to obtain preliminary information about the available bone height.\(^4\)

Three-dimensional information is obtained using computed tomography (CT).

In edentulous mandibles, the location and course of the mandibular canal remain relatively unchanged in the cranial and caudal borders of the mandible, although some atrophy at the lingual and buccal external borders may occur.\(^5\) Recently, some anatomical structures in the jaw-bone, which are difficult to detect using conventional radiography, have been explored using CT.\(^6\)–\(^9\) Investigations of mandibular accessory foramina and canals have drawn attention to anatomical variations of perimandibular neurovascularization.\(^10\)–\(^13\)

Although there is a wide range of dental CT equipment marketed as providing exact bone data at a 1:1 scale, several studies have shown discrepancies between radiographic CT measurements and clinical measurements taken directly from the bone.\(^6\)–\(^9\),\(^14\)–\(^18\) Furthermore, depending on the positioning of the patient when the CT measurements are taken, these discrepancies between radiographic measurement and measurements taken from real bone can increase even further.\(^18\) In 2008, Cucchiarelli et al. compared the discrepancies between radiographic measurements with CT and measurements taken directly from 15 edentulous maxillae, using two different axial reference planes.\(^19\) The study showed distortions with regard to the real bone measurements, and these discrepancies were different for each of the two axial reference planes used.

The aims of the present ex vivo study were to assess the accuracy of dental CT scans and to compare the discrepancies obtained when either the occlusal plane or the basal plane was used as the axial reference plane.

Materials and methods

Mandibles

A total of 39 normal and dry mandibles from adult cadavers aged 35–83 (mean age of 50) were examined following state regulations, the study protocol having been approved by the Murcia (Spain) City Hall Health Service. Thirty of these mandibles were edentulous and the other nine retained teeth. In order to homogenize the study, multiple exodontias were performed on the nine mandibles that retained teeth.

Marking the occlusal plane

The occlusal plane was marked on the nine mandibles that retained teeth before the exodontias were performed. This was done by marking a line parallel to the teeth from the incisal edge of the central incisor to the vestibular cusps of the second molar (Fig. 1a). Once the occlusal plane had been marked, the teeth were extracted.

For the 30 edentulous mandibles, the occlusal plane was established in the anterior region by measuring a height of 1 cm (the usual height of the mandibular incisal crowns) and in the posterior region by dividing the retromolar trigone into three parts: upper, middle and lower. Thereafter, a meeting point between the upper third and the middle part was chosen; this point usually measured 1 cm in height (Fig. 1b).\(^20\)

Once the occlusal planes of the mandibles had been established, a Moyco wax piece (Thompson Dental Manufacturing, Montgomeryville, Pa., U.S.) was molded to follow the previously established plane. After placing the wax simulation of the occlusal plane (Fig. 1c), this was divided into 18 parts using 2 mm lead strips. These strips were placed 6 mm apart so that they corresponded to the 18 tomographic slices performed for each mandible (Fig. 1d).

Lastly, Fox planes were attached to the wax on each of the 39 mandibles (to be used as a guide for delimiting the occlusal plane radiographically) and each assembly was placed into a polymethyl methacrylate (PMMA) box for radiographic study.
Marking the occlusal plane:
(a) marking mandibles with teeth intact before multiple exodontias were performed;
(b) marking edentulous mandibles;
(c) placing the wax piece to simulate the occlusal plane;
(d) wax piece divided into 18 parts with lead strips corresponding to the 18 tomographic slices taken of each mandible.

Basal plane
In order to establish a good axial reference from the basal plane, all of the mandibles were positioned in PMMA boxes to support the lower edge against the container’s anterior wall (Fig. 2a).

Dental CT
The CT equipment used was a Toshiba Multi CT scan Aquilion 16 TSX-101A/6A (Toshiba America Medical Systems, Tustin, Calif., U.S.). Thirty-six sagittal tomographic slices were performed for each mandible, 18 taking the occlusal plane as the axial reference plane (Fig. 2b) and 18 using the basal plane (Fig. 2c). The exposure parameters were set at 57 kV, 56 s and 1.0–3.2 mA, and a rectangular collimator was used. The radiographic images were processed using SIMPLANT software (Materialise Dental, Madrid, Spain). All of the measurements were scored independently by two oral surgeons. When measuring the sagittal tomographic slices, the observers were
Axial plane in computed tomography

Figs. 3a–c

Measurements taken from the mandibles: (a) radiographic measurement of a sagittal tomographic slice using the occlusal plane as the axial reference plane; (b) radiographic measurement of a sagittal tomographic slice using the basal plane as the axial reference plane; (c) bone measurement taken using a digital calibrator.

blinded as to which axial reference plane, occlusal (Fig. 3a) or basal (Fig. 3b), had been used. Lastly, the observers’ mean scores were calculated.

Direct mandibular measurements

These measurements were taken using a digital calibrator (AMIG T304B.W-1220, AMIG, Amorebieta-Etxano, Spain). The interedges (apical-coronal distance in mm) were measured perpendicularly from the base of the mandibular body to the alveolar ridge, along each of the lines corresponding to the tomographic slices (Fig. 3c).

Statistical analysis

The data were analyzed using SPSS statistical software (Version 12.0; SPSS, Chicago, Ill., U.S.). Descriptive statistics were obtained for each variable. The associations between the different qualitative variables were studied using Pearson’s chi-squared test. Student’s t-test for two independent samples was applied to quantitative variables, in each case determining whether variances were homogeneous. Statistical significance was set at $p \leq 0.05$.

Results

In comparing measurements taken from the 18 tomographic slices of each mandible with measurements taken directly from the bone when the occlusal plane was used as the axial reference plane, discrepancies were found in all of the tomographic slices assessed. These discrepancies were positive in nine (50%) of the slices, while in the remaining nine (50%), the measurements taken from the CT scans were lower than the measurements taken from the bone. In six of the 18 slices analyzed (33.33%), the discrepancies observed showed statistically significant differences ($p \leq 0.05$; Table 1).

When the basal plane was used as the axial reference plane, discrepancies were also found between measurements taken from tomographic slices and clinical measurements of the mandibles in all 18 slices analyzed. These discrepancies were negative in all cases. In 17 of the slices (94.44%), the discrepancies showed statistically significant differences ($p \leq 0.05$; Table 2).

In this sense, with regard to positioning the patient when the CT scans were taken, use of the occlusal plane as axial reference produced the most accurate measurements (Fig. 4).

When the distribution of discrepancies in millimeters found in each of the 18 tomographic slices was compared in relation to the axial reference plane, a higher percentage (99.44%) of discrepancies greater than 0.5 mm were produced when the basal plane was used than when the occlusal plane was used (44.44%), with the difference being statistically significant ($p = 0.001$; Table 3).

Discussion

Ever since the first dental implants were introduced by Brånemark et al. in 1969, dental practitioners and researchers have sought methods that might improve the accuracy of surgical implant placement. CT has been widely used for preop-
Table 1

Discrepancies between radiographic measurements (mm) and measurements taken directly from the bone (mm) using the occlusal plane as the axial reference plane (Student’s t-test).

<table>
<thead>
<tr>
<th>Sagittal tomographic slices</th>
<th>Radiographic measurements (n = 39) Mean ± SD†</th>
<th>Bone measurements (n = 39) Mean ± SD</th>
<th>Discrepancies Mean ± SD</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut 1</td>
<td>25.04 ± 4.03</td>
<td>24.96 ± 3.93</td>
<td>0.16 ± 1.33</td>
<td>0.250</td>
</tr>
<tr>
<td>Cut 2</td>
<td>25.03 ± 4.11</td>
<td>25.16 ± 3.98</td>
<td>-0.13 ± 1.33</td>
<td>0.085</td>
</tr>
<tr>
<td>Cut 3</td>
<td>25.74 ± 4.24</td>
<td>25.98 ± 4.19</td>
<td>-0.24 ± 1.37</td>
<td>0.106</td>
</tr>
<tr>
<td>Cut 4</td>
<td>26.82 ± 4.17</td>
<td>27.31 ± 4.05</td>
<td>-0.48 ± 1.45</td>
<td>0.498</td>
</tr>
<tr>
<td>Cut 5</td>
<td>28.41 ± 4.35</td>
<td>29.17 ± 4.35</td>
<td>-0.76 ± 1.75</td>
<td>0.389</td>
</tr>
<tr>
<td>Cut 6</td>
<td>30.64 ± 4.39</td>
<td>30.61 ± 4.31</td>
<td>0.03 ± 1.39</td>
<td>0.611</td>
</tr>
<tr>
<td>Cut 7</td>
<td>31.31 ± 4.31</td>
<td>30.29 ± 4.36</td>
<td>1.02 ± 1.48</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Cut 8</td>
<td>31.34 ± 4.57</td>
<td>30.09 ± 4.43</td>
<td>1.24 ± 1.76</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Cut 9</td>
<td>31.59 ± 4.77</td>
<td>30.11 ± 4.74</td>
<td>1.47 ± 1.81</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Cut 10</td>
<td>31.55 ± 4.84</td>
<td>30.24 ± 4.62</td>
<td>1.31 ± 1.71</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Cut 11</td>
<td>31.32 ± 4.64</td>
<td>30.17 ± 4.45</td>
<td>1.15 ± 1.61</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Cut 12</td>
<td>30.87 ± 4.53</td>
<td>29.83 ± 4.55</td>
<td>1.03 ± 1.43</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Cut 13</td>
<td>29.78 ± 4.63</td>
<td>29.51 ± 4.65</td>
<td>0.27 ± 1.77</td>
<td>0.330</td>
</tr>
<tr>
<td>Cut 14</td>
<td>28.13 ± 4.82</td>
<td>28.29 ± 4.91</td>
<td>-0.31 ± 1.87</td>
<td>0.524</td>
</tr>
<tr>
<td>Cut 15</td>
<td>26.61 ± 4.75</td>
<td>27.02 ± 4.75</td>
<td>-0.41 ± 1.75</td>
<td>0.345</td>
</tr>
<tr>
<td>Cut 16</td>
<td>25.64 ± 4.49</td>
<td>25.94 ± 4.71</td>
<td>-0.29 ± 1.45</td>
<td>0.144</td>
</tr>
<tr>
<td>Cut 17</td>
<td>25.21 ± 4.56</td>
<td>25.37 ± 4.78</td>
<td>-0.17 ± 1.31</td>
<td>0.251</td>
</tr>
<tr>
<td>Cut 18</td>
<td>25.11 ± 4.38</td>
<td>25.64 ± 4.64</td>
<td>-0.52 ± 1.48</td>
<td>0.500</td>
</tr>
</tbody>
</table>

† SD = standard deviation.

Fig. 4

Bar graph comparing discrepancies between radiographic measurements (mm) and measurements taken directly from the mandibles (mm) using both axial reference planes studied.
Table 2

<table>
<thead>
<tr>
<th>Sagittal tomographic slices</th>
<th>Radiographic measurements ( (n = 39) ) Mean ± SD</th>
<th>Bone measurements ( (n = 39) ) Mean ± SD</th>
<th>Discrepancies Mean ± SD</th>
<th>( p )-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut 1</td>
<td>24.53 ± 3.88</td>
<td>24.96 ± 3.93</td>
<td>-0.42 ± 1.11</td>
<td>0.064</td>
</tr>
<tr>
<td>Cut 2</td>
<td>24.61 ± 4.02</td>
<td>25.16 ± 3.98</td>
<td>-0.55 ± 1.11</td>
<td>0.001</td>
</tr>
<tr>
<td>Cut 3</td>
<td>25.13 ± 4.15</td>
<td>25.98 ± 4.19</td>
<td>-0.84 ± 1.07</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Cut 4</td>
<td>26.07 ± 4.08</td>
<td>27.31 ± 4.05</td>
<td>-1.23 ± 1.21</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Cut 5</td>
<td>27.71 ± 4.22</td>
<td>29.17 ± 4.35</td>
<td>-1.46 ± 1.26</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Cut 6</td>
<td>29.67 ± 4.30</td>
<td>30.61 ± 4.31</td>
<td>-0.92 ± 1.15</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Cut 7</td>
<td>29.53 ± 4.21</td>
<td>30.29 ± 4.36</td>
<td>-0.75 ± 1.31</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Cut 8</td>
<td>29.38 ± 4.35</td>
<td>30.09 ± 4.43</td>
<td>-0.71 ± 1.16</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Cut 9</td>
<td>29.34 ± 4.47</td>
<td>30.11 ± 4.74</td>
<td>-0.77 ± 1.53</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Cut 10</td>
<td>29.41 ± 4.55</td>
<td>30.24 ± 4.62</td>
<td>-0.82 ± 1.15</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Cut 11</td>
<td>29.25 ± 4.36</td>
<td>30.17 ± 4.45</td>
<td>-0.92 ± 1.18</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Cut 12</td>
<td>29.26 ± 4.37</td>
<td>29.83 ± 4.55</td>
<td>-0.56 ± 1.36</td>
<td>0.001</td>
</tr>
<tr>
<td>Cut 13</td>
<td>28.67 ± 4.62</td>
<td>29.51 ± 4.65</td>
<td>-0.83 ± 1.13</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Cut 14</td>
<td>27.26 ± 4.83</td>
<td>28.29 ± 4.91</td>
<td>-1.03 ± 1.37</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Cut 15</td>
<td>26.14 ± 4.89</td>
<td>27.02 ± 4.75</td>
<td>-0.87 ± 1.26</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Cut 16</td>
<td>25.14 ± 4.94</td>
<td>25.94 ± 4.71</td>
<td>-0.79 ± 1.46</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Cut 17</td>
<td>24.71 ± 4.83</td>
<td>25.37 ± 4.78</td>
<td>-0.66 ± 1.25</td>
<td>0.004</td>
</tr>
<tr>
<td>Cut 18</td>
<td>24.73 ± 4.84</td>
<td>25.64 ± 4.64</td>
<td>-0.91 ± 0.41</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

\( SD = \text{standard deviation.} \)

Table 3

<table>
<thead>
<tr>
<th>Discrepancies</th>
<th>Occlusal plane ( (n = 18) ) ( n ) (%)</th>
<th>Basal plane ( (n = 18) ) ( n ) (%)</th>
<th>( p )-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 0.5 mm</td>
<td>10 (55.56)</td>
<td>1 (5.56)</td>
<td>0.001</td>
</tr>
<tr>
<td>&gt; 0.5 mm</td>
<td>8 (44.44)</td>
<td>17 (94.44)</td>
<td></td>
</tr>
</tbody>
</table>

Discrepancies between radiographic measurements (mm) and measurements taken directly from the bone (mm) using the basal plane as the axial reference plane (Student’s t-test).

Table 3

Distribution of discrepancies in millimeters observed in each of the 18 sagittal tomographic slices in relation to the axial reference plane used (Pearson’s chi-squared test).

Axial plane in computed tomography

It provides good images of the thickness of vestibular cortical bone and interalveolar distances, as well as of important anatomical features in jaws. When used for imaging the mandible, the main advantage of CT scans over periapical or panoramic radiographs is that they provide a relatively accurate assessment of the alveolar crestal bone height and width and its spatial relationship with the mandibular canal. However, although there is a wide range of dental CT equipment marketed as providing accurate bone data at a 1:1 scale, several studies have shown discrepancies between the radiographic measurements taken using CT and clinical measurements taken directly from the bone. In 1996, Covino et al.
used ten rectangular acrylic blocks (prepared with titanium–molybdenum alloy) as markers spaced from 1 to 10 mm, respectively. A plastic sphere was prepared with ten sets of titanium markers spaced at variable intervals of 1–10 mm. Each object was scanned three times at slice thicknesses of 3.0 mm and slice thicknesses of 1.5 mm with 0.5 mm overlap, positioned in the CT scanner in two different positions in relation to the scanning beam (perpendicular and parallel). The authors concluded that when CT was carried out with slices every 3.0 mm, if the procedure was not performed correctly, significant errors would occur, but if the slices were less than 1.5 mm, even if the CT procedure were performed erroneously to some extent, the results would not show much variation and would be more precise. In 2004, Hanazawa et al. compared data obtained by means of a modified CT system and a conventional CT device with real measurements taken directly from cadaver mandibles, finding discrepancies in 90% of the measurements taken with the modified CT system compared with the direct measurements and in 87.5% of those taken with the conventional CT device, the discrepancies being approximately 1 mm.

These radiographic discrepancies can lead to iatrogenic lesions during implant treatment, which are of particular concern in posterior mandibular regions, where they can produce lesions of the mandibular canal. In this regard, Klinge et al., who studied sensitivity and accuracy in locating the mandibular canal using cadaverous mandibles, observed that when the accuracy in determining mandibular canal position was evaluated, comparing the extent of error with the true value, the error was up to 1 mm in 94% of the CT measurements, but 39% with tomography, 17% with panoramic radiography and 53% using intra-oral radiography. Similar discrepancies between mandibular canal positions determined radiographically using CT and measurements taken directly from the bone have been observed by other authors. 

Similarly, numerous authors have observed small variations between the precision of three-dimensional preoperative imaging and the final surgical positions of the dental implants, with variations ranging between 0.7 mm and 1.0 mm due to the discrepancies between CT measurements and the real dimensions. In this way, the results of the present study, in which discrepancies varied between 0.03 mm and 1.47 mm, coincide with the discrepancies observed by these authors.

Acquiring a good CT scan is of primary importance for visualizing the different bony structures, and the quality and accuracy of the scan are influenced by various factors. The skill of the operator has a major influence. Adequate positioning of the patient will minimize error, and the choice of the appropriate equipment settings is important for achieving good contrast. Discrepancies between radiographic and real measurements can increase according to patient positioning for CT scanning. However, although many authors have observed discrepancies between radiographic measurements using CT and real bone measurements, these authors used a single axial reference plane, which in many cases was not specified. Currently, there are very few articles that examine the discrepancies obtained with various axial reference planes. Cucchiarelli et al.’s comparison of the discrepancies between radiographic measurements with CT and measurements taken directly from 15 edentulous maxillae showed distortions with regard to the real bone measurements. It was found that the use of the horizontal plane showed 19.20% magnification, as opposed to the use of the occlusal plane, which showed 16.5% magnification. In this regard, Abrahams made a general study of mandibles using CT and concluded that the best axial reference plane is the occlusal plane. Although the present study found discrepancies when both the occlusal plane and the basal plane were taken as the axial reference plane, the discrepancies were greater when the basal plane was used.

Conclusion
The present study found that there are slight discrepancies between radiographic measurements taken using CT and real bone measurement. These must be taken into consideration in order to perform satisfactory implant treatments. With regard to patient positioning for the CT procedure, use of the occlusal plane as axial reference will produce the most accurate measurements.

Competing interests
We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that may have influenced its outcome.
Acknowledgments

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