RESEARCH ARTICLE

Influence of cone beam CT volume orientation on alveolar bone measurements in patients with different facial profiles

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Objectives: To evaluate the influence of cone beam CT (CBCT) volume orientation on alveolar bone measurements for dental implant planning using CBCT in patients with different facial profiles.

Methods: 74 CBCT volumes were selected from a database and classified according to the facial profile of the patient. Height and width measurements of the alveolar bone were carried out with the volume of the mandible in two different orientations: occlusal plane and mandibular base parallel to the horizontal plane. The data were subjected to the mixed model methodology for repeated measures, through the PROC MIXED procedure. Multiple comparisons were performed by Tukey Kramer test (α = 0.05).

Results: Alveolar bone width was significantly greater when the CBCT volume was oriented with the mandibular base parallel to the horizontal plane, for all facial profiles (p ≤ 0.05). Alveolar bone height was significantly higher (p ≤ 0.05) for dolichofacial individuals when compared to that of mesofacial and brachyfacial individuals, who did not differ significantly between each other (p > 0.05), regardless of the CBCT volume orientations used in this study.

Conclusions: CBCT-based alveolar bone width is increased when the image volume is oriented with the mandibular base parallel to the horizontal plane and dolichofacial individuals present greater alveolar bone height.


Cite this article as: Costa ED, Peyneau PD, Ambrosano GMB, Oliveira ML. Influence of cone beam CT volume orientation on alveolar bone measurements in patients with different facial profiles. Dentomaxillofac Radiol 2019; 48: 20180330.

Keywords: cone-beam CT; dental implants; mandible; patient positioning.

Introduction

Most of the cone beam CT (CBCT) units are equipped with an apparatus (e.g. head and/or chin rest) to fix the patient’s head in an appropriate position.1–3 This is beneficial to reduce the likelihood of motion artefacts and to assess specific diagnostic tasks involving anatomical structures that could be influenced by muscle forces and/or the gravity, such as the dental occlusion, and the temporomandibular, intervertebral and airway spaces.4 In some situations, the patient may deviate from the optimal position,5,6 but considering the principles of CBCT image formation and neglecting some image deterioration from artefacts over the reconstructed volume,4 this should not significantly affect dimensional accuracy of stable bony structures if the patient is able to remain still during scanning.7

CBCT-based quantitative analysis of dental implant sites is essential for the dental practitioner to prevent surgical complications,8,9 and is mainly based on the determination of anatomical landmarks from which the minimum distance is obtained. Alveolar bone height can be considered the shortest distance, in depth, between the alveolar crest and an important anatomical structure (e.g. mandibular canal and maxillary sinus), and alveolar bone width can be considered the distance between the buccal/labial and palatal/lingual cortical
plates. These measurements are commonly obtained from serial cross-sectional images along the jaws, which are differently reformatted according to the orientation of the CBCT volume.

Previous studies have revealed that the orientation of the patient’s head affects linear measurements due to consequent changes in the orientation of the CBCT volume and resulting cross-sections, which can compromise treatment planning. In an endeavour to overcome this issue, most CBCT software applications allow the surgeon to reorient the volume after acquisition. It should be emphasized that the facial profile and the presence of asymmetries and anatomical differences are among the factors that may also influence the measurements. Regarding the facial profile, individuals can be divided into three groups: mesofacial, brachyfacial, and dolichofacial.

An indefinite number of CBCT-based alveolar bone measurements can be obtained from the region of interest depending on the angle that the cross-sectional reformations intercept the jaws. Thus, the aim of this study was to evaluate the influence of the CBCT volume orientation on alveolar bone dimensions for dental implant treatment planning in patients with different facial profiles. The null hypothesis was that the CBCT volume orientation does not influence the measurements of alveolar bone height and width of patients with different facial profiles.

Methods and materials

This study was approved by the local Research Ethics Committee (CAAE 49664415.7.0000.5418).

Characterization of the sample

The sample consisted of 74 CBCT volumes (39 males and 35 females) from a database of patients with permanent dentition. This sample size resulted in 227 degrees of freedom and 109 error degrees of freedom, such that this sample size is large enough for the variability observed in the data (coefficient of variation of 11.72%).

Only volumes with satisfactory sharpness and contrast for a good visualization and identification of bony structures, with a field of view large enough to cover the whole skull, and of patients who had, at least, one mandibular first molar absent were included. As exclusion criteria, CBCT volumes of patients who had a history of surgical treatment, fractures, periodontal disease, the presence of cysts in the region to be evaluated, or congenital abnormalities in the maxillofacial region were not used. Thus, a total of 114 implant sites were selected.

All CBCT volumes were obtained with the i-CAT unit (Imaging Sciences International, Hatfield, PA) with the acquisition protocol of 8 mA, 120 kVp, field of view “Extended height” (23 × 17 cm), voxel size of 0.4 mm, and acquisition time of 29.6 s.

Classification of facial profile

To classify the facial profile of the patients, CBCT volumes were saved in DICOM format and exported to the CS 3D Imaging Software 3.4.3 (Carestream Health Inc., Rochester, NY). The facial profile was classified based on the midsagittal CBCT reconstruction. Patients were divided, according to the facial profile, into mesofacial, brachyfacial, and dolichofacial through the VERT index of Ricketts et al. (1960). The sample consisted of 22 mesofacial, 23 brachyfacial and 29 dolichofacial patients, with a males/females ratio of 1.20, 1.30 and 1.23, and a mean age (standard deviation) of 49.6 (10.2), 45.7 (11.0) and 48.0 (10.5) years, respectively. The overall mean age among the facial profiles was 47.8 years with a coefficient of variation of 4%.

Alveolar bone measurements

In the cross-sectional images, measurements of alveolar bone height and width in the region of the mandibular first molar were obtained using the software Xoran 3.1.62 (Xoran Technologies), totalling 228 measurements (114 implant sites X two measurements). Bone height was measured as the distance between the alveolar crest and the superior cortex of the mandibular canal, and bone width was measured as the distance between the outermost points of the buccal and lingual cortical plates, surfacing the topmost point of the superior cortex of the mandibular canal and perpendicular to the bone height (Figure 1).

Such measurements were performed with the volume of the mandible rotated into two orientations, such that the occlusal plane (occlusal orientation) and the base of the mandible (mandibular base orientation) were parallel to the horizontal plane (Figure 1). To improve the visualization of the mandible only for volume reorientation, images were adjusted for maximum intensity projection (MIP) and a thickness of 100 mm. In this method, only the voxels with maximum brightness are highlighted, facilitating the visualization of high-contrast bone structures. Then, in the axial image of the middle third of the teeth roots, a curved planar reformation (panorama-like image) was obtained by drawing a U-shaped line in the centre of the alveolar bone, following the jaw anatomy, from the right to the left posterior limit of the mandibular ramus.

Two radiologists with experience in the evaluation of CBCT imaging performed, independently, the classification of facial profile and the measurements. No disagreement was found for facial profile classification, and the measurements of alveolar bone height and width from both evaluators were averaged. The evaluation was dynamic, through multiplanar reformatting, in a darkened environment. Images could be adjusted for better contrast, brightness and zoom, according
to the need of each observer. In each session, only 10 images were assessed to avoid measurement error due to visual fatigue of the evaluator. After 30 days, 25% of the sample was reassessed.

Data analysis

Intraclass correlation coefficient (ICC) was calculated to determine the intra- and interexaminer agreement (ICC <0.4 = Poor; 0.4 ≤ ICC<0.75 = Satisfactory; ICC ≥0.75 = Excellent). The descriptive and exploratory data analyses were conducted, followed by the application of the mixed model methodology for repeated measures through the PROC MIXED procedure of the SAS software v. 9.2 (SAS Institute Inc., Cary, NC). Multiple comparisons were performed by the Tukey–Kramer test, considering a significance level of 5% (α = 0.05).

Results

The ICC revealed an excellent intra- (0.895–0.967) and interexaminer (0.880–0.942) reproducibility (Table 1).

The alveolar bone width was significantly greater in the mandibular base orientation in relation to that in the occlusal orientation (p ≤ 0.05), and the volume orientation did not affect alveolar bone height (p > 0.05). No significant difference was observed in the measurements of alveolar bone width among all facial profiles (p >

Table 1  ICC and CI of intra- and interexaminer agreement for the assessment of bone height and width with the mandible rotated into two orientations

| Orientation | Measure | Examiner 1 | | | Examiner 2 | | | Examiner 1 x Examiner 2 | | |
|-------------|---------|------------|---|---|------------|---|---|---------------------------|---|
| Ocular      | Width   | 0.895      | 0.790–0.948 | 0.967 | 0.934–0.983 | 0.902 | 0.805–0.951 |
| Ocular      | Height  | 0.910      | 0.819–0.955 | 0.958 | 0.824–0.984 | 0.942 | 0.884–0.971 |
| Mandibular  | Width   | 0.945      | 0.891–0.973 | 0.929 | 0.858–0.965 | 0.922 | 0.884–0.961 |
| Mandibular  | Height  | 0.942      | 0.882–0.971 | 0.920 | 0.822–0.962 | 0.880 | 0.760–0.940 |

CI, confidence interval; ICC, intraclass correlation coefficient.
and the height of the alveolar bone in dolicho-facial individuals was significantly greater than that for mesofacial and brachyfacial individuals, regardless of CBCT volume orientation \((p \leq 0.05)\) (Table 2).

### Discussion

The success of rehabilitation therapy with implants depends on, in addition to the surgeon's skill and experience, the accuracy of the estimate of height and width of the remaining alveolar bone.\(^5,12\) Considering that imaging exams provide information on the alveolar morphology and bone dimension, and the identification of important anatomical structures, they are essential to guide the surgeon.\(^10,21\) The American Academy of Oral and Maxillofacial Radiology recommends CBCT as the imaging modality of choice to assess implant sites because it provides volumetric images with relatively high spatial resolution\(^9,11\) and dimensional accuracy.\(^1,12,22\)

When designing the present methodology, bearing in mind that dolicho-facial individuals present greater gonial angle\(^23–25\) and mandibular retrognathia, the authors found it very appropriate to compare groups with different facial profiles.

Previous studies on implant evaluation\(^9,11,12\) demonstrated that the spatial orientation of the CBCT volume can influence some alveolar bone measurements obtained from CBCT cross-sections along the jaws. This may be related to the fact that different spatial orientations of the CBCT volume result in cross-sectional images that do not correspond to exactly the same anatomical region. Our results bring novel information that, in all facial profiles, the volume orientation of the mandible has clinical implications, as the alveolar bone presented greater width in the mandibular base orientation when compared to that in the occlusal orientation. This highlights a relative difference between volume orientations, since the resulting cross-sectional images when the volume is orientated with the mandibular base parallel to the horizontal plane are slightly shifted posteriorly towards a thicker region of the mandibular body (Figure 1C and D). From a theoretical perspective, it is evident that there is only one correct shortest distance \((i.e.\) the distance one aims to measure) yet indefinitely many (incorrect) longer distances. As obvious from Figure 2, the incorrect distances are by trigonometric functions related to the angle of inclination of the mandible to the assessment direction. This fundamental fact means that the chances to overestimate bone support dimensions are higher. In other words, it is

### Table 2  Mean values and SD of bone width and height (in millimetre), and absolute and relative difference between CBCT volume orientations according to the facial profile

<table>
<thead>
<tr>
<th>Facial Profile</th>
<th>CBCT volume orientation</th>
<th>Difference between orientations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Occlusal</td>
<td>Mandibular base</td>
</tr>
<tr>
<td>Width (SD)</td>
<td>Mesofacial</td>
<td>8.9 (2.1)</td>
</tr>
<tr>
<td>Brachyfacial</td>
<td>9.4 (1.8)</td>
<td>9.7 (1.8)</td>
</tr>
<tr>
<td>Dolicho-facial</td>
<td>9.0 (3.1)</td>
<td>9.2 (2.6)</td>
</tr>
<tr>
<td>Height (SD)</td>
<td>Mesofacial</td>
<td>12.7 (2.4)</td>
</tr>
<tr>
<td>Brachyfacial</td>
<td>13.2 (3.5)</td>
<td>13.3 (3.4)</td>
</tr>
<tr>
<td>Dolicho-facial</td>
<td>15.0 (2.6)</td>
<td>14.7 (2.7)</td>
</tr>
</tbody>
</table>

CBCT, cone beam CT; SD, standard deviation.\(^a\)

\(^a\)Significantly greater than occlusal orientation for the same facial profile.

\(^b\)Significantly greater than that of mesofacial and brachyfacial for the same mandibular orientation.
by far more likely to overestimate bony dimensions with such assessments, than to (by chance) hit the correct (only one) shortest distance. This is clinically very relevant when planning implant placement or other surgical approaches on dimensional assessments based on three-dimensional imaging, and should generally result in cautious planning using wider safety margins.

Interestingly, in our study, the CBCT volume orientations used did not influence the measurements of the alveolar bone height for all facial profiles. The authors believe that this might be attributed to the fact that our sample was mostly composed of curved mandibular canals in the region of interest, i.e. the first molar region, and this curvature kept the measurements of the alveolar bone height very similar. This in agreement with previous studies that demonstrated no interference on CBCT-based alveolar bone vertical measurements of the molar region when the patient’s head/mandible, and the corresponding volume, was superiorly rotated at 10° and 20°.9,12 The average angle between both orientations in the present study was 15°.

In the present study, even observing significant differences for alveolar bone width according to the CBCT volume orientation, we cannot expect different accuracy outcomes.7 For dental implant treatment planning, the most appropriate measurements would be those obtained from cross-sections under the same orientation of the implant insertion axis planned by the surgeon. When unsatisfactory head orientation for implant planning is identified after image acquisition, the professional should follow consistent criteria to reorient the CBCT volume to safely measure alveolar bone height and width and avoid operative complications related to improper planning.

Measurements of alveolar bone height were higher for dolichofacial individuals when compared to those of mesofacial and brachyfacial individuals, regardless of the volume orientation. In this study, all patients from different facial profiles had permanent dentition, and similar mean age and males/female ratio. Because this is a retrospective study, the authors were not able to collect information on the elapsed time after tooth extraction. However, the alveolar socket was healed in all cases, which indicates no recent tooth extraction, with consequent reduction in susceptibility of alveolar bone dimensional changes to time.20 Further studies including the period after tooth extraction, and multiple systemic and clinical conditions that may affect bone metabolism, e.g. smoking, prosthetic rehabilitation, diabetes and osteoporosis, are recommended.

Limited information is available in the scientific literature on the differences between CBCT orientations, which partially restricts the present discussion. Based on our findings, we highlight that standardization of CBCT volume orientation is of paramount importance, as well as the implementation of a protocol in clinical routine to quantify the height and width of implant sites in all facial profiles, especially in the posterior region of the mandible due to the presence of the mandibular canal. Additionally, considering the important need for wider safety margins during implant planning, the occlusal orientation is recommended for having produced reduced alveolar bone width.

Conclusion

Orienting the CBCT volume with the mandibular base, rather than the occlusal plane, parallel to the horizontal plane led to increased alveolar bone width in all facial profiles, whereas alveolar bone height was greater for dolichofacial individuals, irrespective of the orientation of the CBCT volume. The use of a standardized CBCT image orientation is strongly recommended for implant planning.

Acknowledgment

The authors thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001 for the financial support and the Espaço da Escrita (Writing Center) at the University of Campinas (UNICAMP) for the language services.

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