Comparison between multislice and cone-beam computerized tomography in the volumetric assessment of cleft palate

Marco Antonio Albuquerque, DDS, PhD, Bruno Felipe Gaia, DDS, and Marcelo Gusmão Paraíso Cavalcanti, DDS, MS, PhD, São Paulo, Brazil

The aim of this study was to determine the applicability of multislice and cone-beam computerized tomography (CT) in the assessment of bone defects in patients with oral clefts. Bone defects were produced in 9 dry skulls to mimic oral clefts. All defects were modeled with wax. The skulls were submitted to multislice and cone-beam CT. Subsequently, physical measurements were obtained by the Archimedes principle of water displacement of wax models. The results demonstrated that multislice and cone-beam CT showed a high efficiency rate and were considered to be effective for volumetric assessment of bone defects. It was also observed that both CT modalities showed excellent results with high reliability in the study of the volume of bone defects, with no difference in performance between them. The clinical applicability of our research has shown these CT modalities to be immediate and direct, and they is important for the diagnosis and therapeutic process of patients with oral cleft. (Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;112:249-257)

Among congenital malformations, facial, lip, and palate anomalies are considered to be the most frequent, representing the second most observed genetic defect in the population and constituting a serious dental-medical-social problem with a significant impact on esthetics, function, and the affected patients' quality of life. Alveolar bone graft is an essential procedure in the overall management of patients with cleft bone defect.2-7 It provides stability of the upper dental arch, gives bone support for the teeth adjacent to the cleft area, supports the lip and the nose, restores facial asymmetry, closes the residual oronasal fistula, and provides bone support for dental implants in prosthetic rehabilitation.7-11

Different imaging methods have been used to define the real extension of alveolar and palatal defects and the amount of bone graft necessary to restore oral clefts.6,12,13 The increasing use of volumetric imaging examinations in dentistry has enabled a better understanding of the morphologic structures aiding diagnosis and treatment of various processes that affect this region. Computerized tomography (CT) allows precise assessments of the shape, quality (cortical and cancellous), height, and thickness of the bone by using multiplanar reconstructions. According to Scarfe et al.,14 cone-beam CT (CBCT) provides real-time creation of images in several planes simultaneously (multiplanar reconstructions) and parasagittal sections through imaging volume, with broad applications in clinical practice, mainly for planning of dental implants and diagnosis of dental alveolar fractures, pathologies, and developmental anomalies of the maxillofacial region. Recently the use of 3-dimensional (3D) reconstructed images associated with a navigation system in independent workstations improved preoperative assessment and evaluated the results of the alveolar graft procedure along time by using linear and volumetric measurements of the cleft.9,15,16

The aim of the present study was to determine the applicability of multislice CT (MSCT) and CBCT to obtain the volume of bone defects in dry skulls and to compare both imaging modalities.

MATERIALS AND METHODS

The present study was submitted to and approved by the Committee of Ethics and Research of our institution, under protocol 120/2008.

Nine dry skulls were used to make bone defects in the region of the alveolar ridge and hard palate mimicking unilaterally transforamen clefts. Bone defects were initially designed in the skulls with permanent marker pen, serving as a guide to perform the cuts. Using a pneumatic saw (Micro 100 reciprocating pneumatic handpiece; Zimmer, Hall, Linvatec Corp., Largo, FL, USA) pressurized by a cylinder of compressed air, bone defects were made differing in size, shape, and position between left and right (Fig. 1). The site of the simulated cleft was selected by simulating the common
area of the surgical procedure, and the size was made by following the same procedure. No specific reason was attended for the site and the size of bone defect. All bone defects produced were modeled with wax following the contralateral shape of alveolar ridge and hard palate (Fig. 2). This wax was used as a model for obtaining the actual volume of bone defects (described later by Archimedes principle in the gold-standard analysis).

The skulls were submitted to MSCT (Brilliance CT 6-slice; Phillips Medical System, Andover, MA, USA) (slice thickness 0.8 mm, table increment 0.87 mm, interval of reconstruction 0.435 mm, matrix 1,024 × 1,024, 135 kVp, 250 mA, and field of view (FOV) 16 cm) and CBCT (iCAT Cone-Beam 3-D Dental Imaging System; Imaging Sciences International, Hatfield, PA, USA) (voxel size 0.3 mm, 110 kVp, 15 mA, FOV, 20 cm (30.5 cm), and 40 s for acquisition of raw data). Regarding the iCAT parameters, we preferred to use 0.3 mm voxel size, because it gave us a good resolution. Regarding the radiation dose, we think that it does not need a smaller voxel size for this procedure. Regarding the FOV, we could just get the entire volume by using FOV 12 cm of height.

The skulls were dipped in a container with water in MSCT and in a bulk bag with water in CBCT to mimic the soft tissues (Fig. 3). After image acquisition, the data were stored in DICOM (Digital Imag-
ing Communication in Medicine) format to avoid data loss. This procedure allows further generation of volumetric images for processing, visualization, manipulation, and analysis. Three-dimensional images were generated in Vitrea software 3.8.1 (Vital Images, Plymouth, MN, USA) installed in a Dell 650 Precision independent workstation running the Windows XP operating system.

Before the analysis, the imaging criteria used to define the limits of the bone defects were determined according to a validated study.\textsuperscript{17} The design of the bone defect was done by mirroring (following the bone contour) the morphologic structures of the normal contralateral side (Fig. 4). The images where defects were identified were then outlined with the mouse by using a tool called “Free” to mark the region of interest. The computer automatically provides the area of each design slice, and the volume of the defect was obtained by multiplying the sum of the areas by the range of the image reconstruction (volume of bone defect = sum of areas outlined \times range of the image reconstruction), which is obtained automatically by applying the commands “Surface” and “Measure” to acquire the corresponding area and volume of the bone defect, following the methodology used in previous publications.\textsuperscript{17-19} After the complete selection of the area of interest (in all axial images), the 3D reconstruction was used for final visualization of the anatomic structures (Fig. 5).

We compared the volumetric data obtained by outlining the bone defects obtained in the 2 different CT scanners. This analysis was conducted by 2 oral and maxillofacial radiologists with extensive experience in interpreting CT, independently and on separate occasions making their own decisions on the limits of bone defects. A previous training session was performed until each examiner felt comfortable with the use of electronic measurement tools. Examiner 1 performed the steps twice and examiner 2 only once, to test the accuracy of the measurements (intra- and interobserver). The purpose of this comparison was to validate this methodology in determining the volume of bone defects and cleft palate edge.

The data were compared with the gold standard (GS), which was defined by the real volume of the wax model, calculated by using the Archimedes prin-
ciple of water displacement. Using a precision scale (Adventurer; Ohaus, Pine Brook, NJ, USA), several steps were performed to get the actual volume of wax models. Initially a hook system was hung with a weight for the wax not to float during its immersion in the container with water. The mass of the hook system was initially measured, with the precision scale, with the counterweight without the wax in the air (System Mass on the Air). Subsequently, the hook system with the counterweight was submerged in a tub of Becker solution (200 mL) containing 150 mL water (this volume of water was kept constant during

Fig. 5. Three-dimensional computerized tomography bone protocols demonstrate the model of the bone defect in (A) front view and (B) inferior-superior view with the area and volume of the bone defect.

Fig. 6. The system used to carry out the gold standard assessment using Archimedes protocols. A, Mass of the immersed system; B, system mass + wax mass immersed.
the implementation of all measures) to calculate the mass of the immersed system (Fig. 6, A). The wax model was attached to the hook system and hung on the precision scale to calculate the mass of this system (hook system \( H_{11001} \) wax model of each skull) measured in air (system mass \( / H_{11001} \) wax mass in the air).

This system was finally completely submerged in water and its mass measured (System mass \( / H_{11001} \) wax mass immersed; Fig. 6, B).

The volume of each wax was found using the following formula:

\[
\frac{(\text{system mass} + \text{wax mass in the air})}{\text{system mass} + \text{wax mass immersed}} \]

\[\times p \text{ H}_2\text{O} \text{ distilled at } 25^\circ\text{C} = \text{volume of wax model};\]

where \( p \text{ H}_2\text{O} \text{ distilled} = \text{specific weight of distilled water at } 25^\circ\text{C} \text{ is equal to } 0.9970, \text{i.e., } \sim 1. \text{ The mass of the air system and the mass of the system immersed were constant, being, respectively, } 30.59 \text{ mg and } 26.93 \text{ mg.}\)

This analysis was performed twice for each wax model to find their actual volumes that were used as the GS for our research. The GS results were used to validate the accuracy of MSCT and CBCT in the assessment of the cleft volume and to compare any difference between these findings. To obtain these results, we performed a test comparing the means through an analysis of variance evaluating the existing differences and their significance.

**RESULTS**

For this study, we adopted a reliability index of 99%. To evaluate the applicability of MSCT and CBCT in the measurement of bone defects in the region of the cleft palate and alveolar ridge, an analysis was made of the measurements obtained by the 2 examiners on 2 different occasions using the skulls with bone defects. The results follow:

**Intraexaminer analysis in MSCT**

Analyzing the volumes calculated by examiner 1 using multislice CT at 2 different times, it was observed that these measures were statistically equal on average: \( P = .988 (P > .01; \text{ Table I}) \). It was also observed that the measures had values equal to or very close to the GS of our analysis with a reliability of 99% (Table II). This result showed the applicability of the CT to measure the volume of defects (Tables I and II).

**Interexaminer analysis in MSCT**

An analysis was also performed of the averages obtained by examiners 1 and 2 during the measurements performed in MSCT using the dry skulls compared with the GS for our research. Analyzing the volumes calculated by the 2 examiners at the same time, it was confirmed that the measures, on average, were very similar (Table I) and statistically equal: \( P = .997 (P > .01; \text{ Table III}) \). The average of both examiners’ results was equal to the GS with a reliability of 99%. This demonstrates the reproducibility of the assessment of bone defects in cleft palate and alveolar ridge regions using MSCT.

**Intraexaminers analysis in CBCT**

In this section, an analysis was performed of the averages obtained by observer 1 during the 2 measurements in CBCT and compared with the GS of our research (Tables IV and V). It was observed that the volumes on average obtained by the same researcher at 2 different times using CBCT were statistically equal:  

<table>
<thead>
<tr>
<th>Table I. Average of the 2 samples prepared by examiner 1 and the single samples by examiner 2 without the use of wax and the gold standard using multislice computerized tomography</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>n</strong></td>
</tr>
<tr>
<td>Examiner 1</td>
</tr>
<tr>
<td>Examiner 1’</td>
</tr>
<tr>
<td>Examiner 2</td>
</tr>
<tr>
<td>Gold standard</td>
</tr>
<tr>
<td>Total</td>
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<thead>
<tr>
<th>Table II. Analysis of variance of the 2 samples prepared by examiner 1 and the gold standard using multislice computerized tomography</th>
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</thead>
<tbody>
<tr>
<td><strong>Sum of squares</strong></td>
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<tr>
<td>Between groups</td>
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<tr>
<td>Within groups</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table III. Analysis of variance of the collections prepared by the 2 examiners and the gold standard using multislice computerized tomography</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sum of squares</strong></td>
</tr>
<tr>
<td>Between groups</td>
</tr>
<tr>
<td>Within groups</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>
Table IV. Average of the 2 samples prepared by examiner 1 and the single samples by examiner 2 without the use of wax and the gold standard using cone-beam computerized tomography

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Average</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Examiner 1</td>
<td>9</td>
<td>2.03</td>
<td>0.623</td>
</tr>
<tr>
<td>Examiner 1'</td>
<td>9</td>
<td>2.05</td>
<td>0.647</td>
</tr>
<tr>
<td>Examiner 2</td>
<td>9</td>
<td>2.02</td>
<td>0.737</td>
</tr>
<tr>
<td>Gold standard</td>
<td>9</td>
<td>2.08</td>
<td>0.847</td>
</tr>
</tbody>
</table>

Table V. Analysis of variance of the 2 samples prepared by examiner 1 and the gold standard using cone-beam computerized tomography

<table>
<thead>
<tr>
<th></th>
<th>Sum of squares</th>
<th>Df</th>
<th>Mean square</th>
<th>F</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between groups</td>
<td>0.010</td>
<td>2</td>
<td>0.005</td>
<td>0.011</td>
<td>.989</td>
</tr>
<tr>
<td>Within groups</td>
<td>11.192</td>
<td>24</td>
<td>0.466</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>11.202</td>
<td>26</td>
<td>—</td>
<td></td>
<td></td>
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</tbody>
</table>

Table VI. Analysis of variance of the collections realized by the 2 examiners and the gold standard using cone-beam computerized tomography

<table>
<thead>
<tr>
<th></th>
<th>Sum of squares</th>
<th>Df</th>
<th>Mean square</th>
<th>F</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between groups</td>
<td>0.029</td>
<td>2</td>
<td>0.015</td>
<td>0.026</td>
<td>0.974</td>
</tr>
<tr>
<td>Within groups</td>
<td>13.193</td>
<td>24</td>
<td>0.550</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>13.222</td>
<td>26</td>
<td>—</td>
<td></td>
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</tbody>
</table>

$P = .989 (P > .01)$ and statistically similar to the GS results. This demonstrates the effectiveness of CBCT in the assessment of bone volume in a region with fissure defects in the alveolar ridge and hard palate.

Interexaminer analysis in CBCT

In this section, an analysis was performed of the averages obtained by observers 1 and 2 during the measurements performed in CBCT, and the results were compared with the GS of our research (Tables IV and VI). Performing the same test to assess the volumes in CBCT with 2 different examiners, the results were similar to those found with the MSCT. It was observed that on average the amounts taken by evaluators 1 and 2 were statistically equal among themselves ($P = .974 [P > .01]$) and equal compared with the GS of our analysis. This demonstrates the great reproducibility of CBCT in the assessment of volume defects in oral clefts.

Correlation of results obtained by MSCT and CBCT in the assessment of cleft palate volume

The correlation was also found of the results obtained by the 2 different CT scanners to assess the existence of discrepancies between the results. Performing the test for analysis of the average volumes obtained by CBCT and MSCT scanners, it was observed that they were statistically equal ($P = .937 [P > .01]$), and the results were equal compared with the GS results (Tables VII and VIII). We can then consider that, on average, the CBCT-calculated volumes were equal to MSCT and to the GS, showing no statistically significant difference between the 2 types of CT scanners in the assessment of bone defects in oral clefts.

DISCUSSION

The study of craniofacial development anomalies has received great emphasis in dentistry through the improvement of diagnostic, restorative, and rehabilitative techniques performed by the association of a multidisciplinary team. In this context, oral clefts comprise a malformation in which dentists play a fundamental role in healing and rehabilitation of affected patients.3,15 Although there are well defined protocols for the treatment of oral clefts from the prenatal period into adulthood, there is a lack of studies regarding the development of a methodology capable of determining the volumetric size of the bone defect in volumetric imaging examinations. This analysis would facilitate the treatment planning of secondary bone graft to close the oral cleft.11,20

Different imaging modalities have been used for the purpose of assessing the extent of the oral cleft, as well as to follow up on treatments based on bone grafts.7,12,13 When these examinations are performed before the bone graft surgery, they allow an estimate of the size, position, and structures involved by the cleft.
After the surgery, imaging examinations assist the outcome of the bone graft, monitoring the eruption of teeth adjacent to the graft and evaluating the amount of available bone found for the insertion of the implants during the rehabilitation process.9,21

The use of CT using 3D protocols provided an excellent visualization of the bone architecture, and this is considered to be a valuable tool in the evaluation of craniofacial deformities in patients with congenital malformations such as cleft palate and alveolar ridge.2,4,9,16 Although the applicability of CT in the evaluation of bone grafts in cleft palate region has been frequently reported in literature, its application in the preoperative volumetric evaluation of these defects has yet been little studied. Tai et al.8 conducted an initial single-slice CT study (using 2 mm slice thickness and 2 mm reconstruction interval) with a total of 14 children with cleft palate and ridge, where they established a methodology for measuring the bone defect and the volume of bone grafts processed in the region. The images of the graft were then outlined with the mouse by using specific software to calculate the graft area in each axial and coronal image. The computer processed the area of each design and obtained the total graft volume by multiplying the sum of the areas by the range of reconstruction. In our work, we obtained the cleft’s total volume with the largest number of cuts possible. For this purpose, a large number of images were analyzed by reducing the partial volume effect arising from overlapping structures found in thick sections. We used MSCT slice thickness of 0.8 mm with a 0.435 mm reconstruction interval and CBCT with 0.3 mm voxel size. The influence of slice thickness on MSCT and accuracy of volumetric measurements of the cleft bone defects could be confirmed when compared with results obtained by Oberoi et al.7 and Feichtinger et al.,9 who used a 0.4 mm and a 1.5-mm axial slice thickness, respectively. Both of those papers proposed to identify the level of graft resorption 1 year later. Oberoi et al.,7 who used thinner slices, found resorption of only 16% of the grafted bone, whereas Feichtinger et al.,16 using thicker slices, found this in 51%. According to Oberoi et al.,7 this lower rate of resorption can be explained as the result of more reliable examinations when thin slices are performed. None of those studies had GS control to evaluate the reliability of the results. Our results found a reliability of 99% compared with the GS. This shows that volumetric assessments of bone defects in the region of oral clefts are quite reliable when high-resolution CT examinations are performed.

The validation of a methodology that can accurately define the volume of bone defects in oral clefts is considered to be a very important tool in the treatment planning of cases that will be submitted to secondary bone graft. This analysis also permits surgeons to perform surgical procedures in less time and to choose an appropriate graft donor site and the amount of bone graft, allowing more predictable results.

The methodology to obtain the volume of defects was based in part on that applied in the work of Tai et al.8 and Johansson et al.20 Johansson et al.20 conducted a study in 2001 with the objective of calculating the volume of defects in plaster blocks through CBCT. Similarly to our work, they used the principle of water displacement to obtain the GS to compare the results. The authors found an accuracy of 84% of the results comparing the volumes obtained from CBCT and GS, demonstrating that this methodology gave a good applicability in the evaluation of volumetric defects.

In the present paper, the analyses were performed with the aim of determining the applicability and reliability of MSCT and CBCT in the validation of the volume defects in the region of oral clefts. The lack of work following the same methodology prevents a comparison and discussion of results that we obtained. The intraobserver analysis showed an excellent statistical significance with a reliability of 99%. This result demonstrated the applicability of the radiographic technique to assess the volume of defects. The high significance of interexaminer analysis demonstrated the reproducibility of MSCT in the assessment of bone defects in oral clefts. The correlation between MSCT and CBCT demonstrated that there is no statistical difference between them that both can be used as a valuable and reliable measurement of bone defects.

Pinsky et al.15 developed a study where they used CBCT in measuring linear and volumetric models of acrylic and small bone defects induced in the mandibles. The objective was to evaluate the applicability of CBCT in the evaluation of small defects that would resemble incipient bone destruction caused by periodontal and periodontal diseases. Those authors used a voxel size of 0.2 mm. They stressed that although there are some limitations in the technique (with a voxel size of 0.2 mm, defects smaller than this size are not detected), clinical results are quite acceptable. The authors found an error rate of 0.4% in acrylic model volumes compared with GS. This was corroborated by our results regarding the accuracy in the volume assessment. Using MSCT, we found an error rate of only 1.4% compared with the GS. When CBCT was used, the error rate compared with the GS was 2.4%. Although not statistically significant, the difference between our study and that by Pinsky et al.15 can be explained by the bone marrow space in dry skulls making it difficult to define the exact boundaries of the defect.

Cremonini et al.13 demonstrated the applicability of MSCT in evaluating the availability of bone volume in the retromolar region to the draping of bone grafting. That study used the same software and the same tool for mea-
suring the volume images that we used. They also used 2 examiners for the volume measurement to analyze the effectiveness and reproducibility of the technique. One advantage in our research is that we used a real GS to compare the data obtained by the examiners to obtain a more reliable comparison of results. Likewise, we used a coefficient of significance of 1% versus 5% used in the work of Cremonini et al. The interobserver correlation found in our study was $P = .997$ versus $P = .894$ found by Cremonini et al. The differences between these results are not statistically significant, applying a factor of significance of either 5% or 1%. This similarity of results corroborates the effectiveness of the CT technique (either MSCT or CBCT) and the methodology to measure bone cleft defects in the region of the palate and alveolar ridge.

Wörthche et al. conducted a study that defined the applicability of CBCT in the evaluation of patients with oral clefts, performing a comparative analysis of the effective equivalent dose in different radiographic techniques used in the evaluation of these patients, to determine whether the risk/benefit ratio justifies the performance of more complex tests for the study of these malformations. In our research, we observed no statistical difference between the results obtained by MSCT and CBCT ($P = .937$). This also corroborated other publications regarding craniofacial measurements using MSCT and CBCT. In those papers, the results of both CT techniques were very similar, demonstrating high accuracy and precision of measurements.

The accurate and reliable diagnosis of the size and extent of bone defects caused by oral clefts is important not only in the treatment planning, but also to establish the donor area and the volume of bone graft used in the therapeutic process for these patients. In the present study, we demonstrate that MSCT and CBCT are reliable techniques in the volumetric assessment of bone defects in alveolar and palatal regions. The clinical applicability of our research is direct and immediate, serving as an important diagnosis/treatment procedure for patients with oral clefts.

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REFERENCES


Reprint requests:
Marcelo Cavalcanti, DDS, PhD
Department of Oral Diagnosis
School of Dentistry
University of São Paulo
Av. Prof Dr. Lineu Prestes
2227-Cidade Universitária
São Paulo—SP
Brazil 05508-900
mgpcaval@usp.br