Validation of a method using cone beam computed tomography for measuring bone block grafts for the alveolar ridge augmentation

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Bone grafting is often a prerequisite prior to implant placement. Studies evaluating the volume changes of block grafts in the incorporation phase mostly use methodologies that are difficult to apply when assessing large sample sizes. The aim of this study is to validate a new method for volume measurement of block grafts using CT scans for application on future research. Human bone blocks were fixed with screws on dry skulls simulating a ridge reconstruction. The physical volume of the blocks was determined by the water displacement technique and was used as the control group. A method previously described in the literature was tested using the Dicom Works© software. The new method proposed was performed using a tool of the Dental Slice© software. The volume of each block was automatically calculated by the software. The accuracy of each method was assessed using a paired Student’s t-test. There were no statistically significant differences between the methods and the control group. This novel method to three dimensionally measure bone blocks can accurately determine the volume of grafts for maxillary reconstruction. This method can be useful for future studies that aim to evaluate the remodeling of different types of block grafts.

Keywords: cone-beam computed tomography; bone graft; alveolar ridge augmentation


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Introduction

Bone block grafting is often a prerequisite prior to implant placement in extremely atrophic ridges [1-4]. Onlay block grafts can be obtained from autologous, alogenous or xenogenous sources. Regardless of the nature of the graft, the incorporation phase invariably includes remodeling, and as a consequence, volume changes [5-7]. These reductions in size, depending on the amount, can lead to insufficient bone volume for subsequent implant placement [5,8].

The studies available in the literature have shown reductions in the size of grafts ranging from 10% to 50% 3 to 6 months after the surgery [1, 5, 7, 9, 10]. Although these resorption rates are well described, in most of the studies, measurements are made either clinically using calipers or radiographically [11]. These linear measurements may not
provide the necessary accuracy to evaluate the behavior of grafts in the healing phase because the remodeling process occurs in a three-dimensional manner. On the other hand, studies evaluating 3D volume changes mostly use laborious methodologies that are sometimes difficult to use for research groups of large sizes [5, 7, 12, 13].

Cone beam computed tomography (CBCT) is widely used to provide three-dimensional detailed information regarding bone anatomy and helps surgeons plan and evaluate grafting procedures in implant dentistry [14, 15]. Unlike conventional radiographic imaging, CBCT not only allows precise linear measurements but also helps in the actual calculation of volumetric dimensions by using various available software packages.

CBCT scans have been used in cross-sectional studies to make volumetric measurements of the maxillary sinus and around impacted teeth and to assess bone quantity for harvesting [12, 16, 17, 18]. The time-related evaluation of changes after grafting procedures such as sinus grafting, major maxillofacial reconstructions (such as cleft palate grafts) and harvest of onlay blocks from calvaria [5, 7, 9, 19] is also possible using CBCT scans.

The determination of the time when the second stage surgery (implant placement) must be scheduled is still a point of discussion in the literature [20]. More waiting time implies more graft resorption but apparently better incorporation. The assessment of time-related remodeling of bone block grafts is of paramount importance in determining the best incorporation/resorption relationship in order to reassess the site and place the implant. Moreover, a correct evaluation of the volumetric reduction of these grafts can be used to compare different materials and techniques available to the clinician.

Several software packages are available to process and measure images from CBCT, but currently, there is no standardization. The aim of this study is to validate a new method for volume measurement of block grafts using CBCT scans and to compare this method with other methods previously described in the literature.

**Material and methods**

In our experiment, a total of 32 human bone blocks from the tibia were fixed with titanium screws on 8 edentate dry skulls maxillae (4 blocks on each skull), simulating a ridge reconstruction for dental implant placement (Fig 1). The skulls were then scanned using a high-resolution cone beam computed tomograph (i-Cat © Image Sciences International, Hatfield, PA, USA) with 120 kVp and 47 mAs for 40 seconds with a 0.2 mm voxel size (Fig 2).

**Control group**

The physical volume of each bone block was determined separately by the water displacement technique using a 20 mL measuring cylinder with gradations of 0.1 mL. The
cylinder was filled with water at room temperature (23.5°C) to the 15 mL mark [21, 22, 23]. The bone blocks were completely submerged one at a time, and the new water level was recorded. The volume of the displaced water was obtained by subtracting the initial volume of water from the final volume after immersion of the bone block. The measurements were made twice by two independent observers, and the average measured volume was considered the gold standard.

**Methodology measurements proposed in the literature**

The methodology proposed in several previous studies uses a widely known software program named Dicom Works© [5, 7, 10]. The grafts are identified on 2D CT slices and
The measurements were not significantly different between methods (p < 0.05)

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**Table 1. Measurements obtained by the water displacement technique (WD), method described in literature (MDL) and proposed method (PM)**

<table>
<thead>
<tr>
<th>Skull</th>
<th>Blocks</th>
<th>WD (ml)</th>
<th>MDL cm³</th>
<th>Difference</th>
<th>p-value</th>
<th>PM cm³</th>
<th>Difference</th>
<th>p-value</th>
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<td>0.54</td>
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<td>0.85</td>
<td>0.05</td>
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<tr>
<td>3</td>
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<td>0.89</td>
<td>-0.04</td>
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<tr>
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</table>

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**Proposed methodology measurements**

The DICOM file created by the tomograph was converted using software (Dental Slice Converter© Bioparts, SP, Brazil) to create a virtual 3D model and to virtually separate the bone blocks from the skull. The blocks were isolated using selection by the grayscale threshold tool. This tool allows the selection and virtual isolation of objects within the grayscale threshold determined by the user. In the CBCT image, grayscale shades of the skull differ from shades of the bone blocks, and the same is true for the patients’ bone and the grafts. Hence, the bone blocks could be isolated one by one by determining the gray scale thresholds that include only the blocks. Gross errors of selection were corrected manually. When creating different 3D layers, the software allows each block to be color coded to facilitate differentiation (Fig 4 and 5). The volume (mm³) of each block was automatically calculated by the software.

**Statistical analysis**

The accuracy of each method was assessed by comparison with the volume measured by water displacement using a paired Student’s t-test. The level of significance was set at 5% (p < 0.05)
Results

The data obtained from the measurements by means of water displacement (gold standard), the method described in literature and the proposed method are presented in Table 1.

Discussion

The use of onlay bone blocks grafts to reestablish maxillary width and height prior to implant placement is a well described and predictable technique [2, 4]. High success rates, low complication rates and the long-term survival of dental implants in these grafts make it a good alternative for reconstructing extremely atrophic ridges. It has been well documented that all bone grafts undergo some resorption in the incorporation phase, and the resorption rates seem to vary depending on graft origin (autogenous, allogenous, xenogenous or synthetic) as well as graft source (Ilium, tibia, calvaria) [5, 7, 10, 24].

The time necessary to ensure the proper incorporation of bone block grafts prior to implant placement is still a matter of debate [20]. Apparently, more time leads to better incorporation but higher resorption of the graft. However, the available data on the behavior of block grafts are from animal models and cross-sectional studies [6, 8, 25, 26]. Moreover, most of these trials have assessed linear volume changes. As resorption occurs in a three-dimensional manner, linear measurements may not provide an accurate estimate of the behavior of bone block grafts after surgery. Additionally, linear measurements are made using arbitrary points of reference that, may sometimes not represent the entire change. Evaluating these changes can be useful for determining the time-dependent remodeling ratio of the grafts and for comparing different graft materials.

In a human model, the most reliable and accurate way to measure three-dimensional time-related changes in block grafts after surgery appears to be by means of CBCT. The low radiation doses and precise measurements allow assessment of the grafts’ behavior at different times with no harm to patients [14, 15, 17, 27, 28]. Many papers have been published assessing bone grafts in implantology and maxillofacial surgery tomographically, but there is no standardization of the methods [1, 5, 6, 9, 10, 19, 24], most likely due to the several different tomographs and software available to perform and measure the scans.

Uchida et al. [13] proposed a method for measuring volume changes in sinus particulated bone grafts. 2D measurements were performed on each image slice, and the sum of all areas was equivalent to the total volume of the graft. Although this method has good accuracy and has been used in many studies [5, 7, 10], newer software programs make the measurements easier, quicker and more accurate.

The visual determination of the graft edges on each slice of the tomographic image can take a lot of time and can lead to examiner-related error. In this new method, we used the image grayscale to easily isolate the graft from the skull bone digitally. Due to the difference in density, the grafts appear in different shades of gray in the image. Using the Dental Slice Converter© software, we could determine the grayscale shade of the grafts and digitally separate them from the skulls. We were then able to determine the three-dimensional extension of the grafts without having to evaluate individual 2D slices.

Studies evaluating and comparing different bone graft modalities and materials with respect to bone remodeling are lacking in the literature. The development of an easy method to assess the remodeling of bone grafts can facilitate future trials. In addition, the low radiation dose of CBCT safely allows the follow up of the bone grafts at different times. This proposed measurement method has been demonstrated to be as accurate as the method previously described in the literature and very precise compared to physical measurements.

Based on this experiment, this novel method to three dimensionally measure bone blocks with CBCT can accurately determine the volume of grafts for maxillary reconstruction prior to implant placement. This method can be useful for future studies that aim to evaluate the remodeling of different types of block grafts.

Conflicting interests

The authors have declared that no conflict of interests exist.

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Author contributions

D.D. carried out the experiment, performed the statistical analysis, analyzed the results and drafted the manuscript. L.F.D., L.M.V. and E.M.B.T. designed the experiment and analyzed the results. All authors read and approved the final manuscript.

Abbreviations

CBCT: cone-beam computed tomography; CT: computed
tomography; DICOM: digital imaging and communications in medicine.

References


