Reliability of Cone Beam Computed Tomography in Determining Mineralized Tissue in Augmented Sinuses

Carlo Maria Soardi, MD, DDS
Fernando Suárez-López del Amo, DDS
Pablo Galindo-Moreno, DDS, PhD
Andrés Catena, PhD
Davide Zaffe, MBiolSc
Hom-Lay Wang, DDS, MSD, PhD

Purpose: The aim of this study was to analyze cone beam computed tomography (CBCT) densitometries of maxillary sinuses augmented with human bone allograft. In addition, previously obtained microradiographic specimens were used to verify the diagnostic potential of CBCT. Materials and Methods: A two-stage protocol was conducted in 21 consecutive patients, all with a crestal bone height < 2 mm. Mineralized human bone allograft particles were used to augment sinuses using a lateral window approach. A succession of CBCT scans of the maxilla were taken before surgery, immediately after sinus augmentation, and 6, 10, and 18 months after implant placement. Using virtual probes, CBCT images taken at 6, 8, and 10 mm from the crestal surface were processed with medical imaging software and expressed as gray level (GL).

Results: A total of 24 sinus augmentation procedures were performed in 21 patients. The average values of CBCT-GL ranged from 571 to 654, presenting the maximum value at 8 mm immediately after implant placement and the minimum value at 6 mm after 10 months. Furthermore, it was found that the graft mineral content decreased over time, completely disappearing between 10 and 11 months.

Conclusion: CBCT and the medical imaging software employed for imaging visualization are reliable tools to study biomaterial behavior after sinus augmentation procedures. In addition, results from this study demonstrate that a complete resorption of human bone allograft is possible. Due to the limited sample size, further clinical and morphometric studies are needed.

Keywords: bone allograft, cone beam computed tomography, maxillary sinus augmentation, microradiographs

Long-term stability of dental implants is known to be strongly influenced by both bone quantity and quality. Moreover, bone quality has been demonstrated to play a key role regarding implant prognosis. Assessment of bone quality is of paramount importance when planning to restore edentulous patients with dental implants. Therefore, over the years, multiple techniques have been developed attempting to predict the osseous volume and bone quality prior to implant insertion. The advances in diagnosis represent the need to correlate modern noninvasive in vivo diagnostic methods to the in vitro methods already proven and standardized over years of research.

Among the tools currently available for diagnosing, dental imaging has been shown to be a reliable method to assess bone structures in all three dimensions. Initially, computed tomography (CT) was widely used due to its capacity to generate three-dimensional images by reconstructing many axial slices. In addition, CT possesses high resolution and accuracy with minimum distortion and magnification. Later, cone beam computed tomography (CBCT) was introduced, reducing scanning time, radiation exposure, and cost, making this machine more accessible for the patients. CBCT has been proven to be predictive as gray density for the subjective bone quality classification.

On the other hand, microradiography, also called contact radiography of thick sections, represents an analytic technique similar to CT. Microradiography has been proven to be a useful method to obtain information regarding the mineral content of different zones of bone. The study of calcified tissues has been the major application for this technique.
To the best of the authors' knowledge, microradiography analysis has never been used before to compare its results with CBCT images. As a matter of fact, several studies attempted to compare CT scans with histomorphometry values,11,12 but no study has evaluated so far the values obtained from CBCT and section microradiography at the same site in the same patient.

Therefore, the aim of the present study was to analyze CBCT densitometries of maxillary sinuses after augmentation with human bone allograft. In addition, previously obtained microradiographic specimens13,14 were used to verify the diagnostic potential of CBCT in the evaluation of mineral material content.

**MATERIALS AND METHODS**

**Patient Selection**

The selected patients were examined and treated in a private dental office in Italy. All individuals enrolled in this study were partially or totally edentulous patients in need of either unilateral or bilateral maxillary sinus augmentation for the posterior placement of dental implants. The inclusion criteria were: less than 2 mm of crestal bone height measured by CBCT, good general health, nonsmokers, absence of diseases that could affect bone metabolism (eg, hyperparathyroidism, osteomalacia, osteoporosis, etc) or wound healing, absence of specific diseases or problems within the maxillary sinus, and no bisphosphonates or regular medication consumption for more than 3 months.

In Italy, contrary to public and private health centers, procedures performed in a private dental office do not require ethics committee approval. Nevertheless, all patients signed informed consent forms in which all procedures of the study were detailed. The research was conducted in full accordance with ethical principles, including the Declaration of Helsinki of the World Medical Association.15

**Surgery**

Antibiotics, amoxicillin (Ratiopharm) 1 g twice a day, were given to patients 1 day before surgery and for 6 to 7 days after surgery. After local anesthesia was administered (articain hydrochloride, Ultracain, Sanofi-Aventis Deutschland), a full-thickness flap was elevated to expose the lateral wall of the maxillary sinus. Following the technique described by Vercellotti,16 a bony window osteotomy was performed using a piezosurgical device (Mectron); then, the bony window together with the sinus membrane were elevated using the piezosurgical device followed by a sinus curette. For grafting the void created under the sinus membrane, a 80/20 mixture of larger particles of cortical (1 to 2 mm) and small particles of cancellous (0.25 to 1 mm) mineralized human bone allograft (MHBA; Puros, Zimmer Dental) moistened with saline solution was used as grafting material. Particles were gently packed beneath the membrane. Prior to soft tissue closure, an absorbable collagen membrane (BioMend, Zimmer Dental) was placed over the previously created window. Lastly, the flap was repositioned and sutured using Gore-Tex 5/0 sutures (W.L. Gore & Associates). After surgery was completed, patients were given Synflex forte 550 mg (Recordati) as analgesic if needed. In addition, patients were asked to rinse with chlorhexidine mouthrinse (1.2%), twice daily without brushing the surgical area for 2 weeks. Sutures were removed after 12 to 14 days, and monthly follow-ups were performed to ensure adequate healing until implant insertion.

Before implant placement (3.7 or 4.7 mm, external diameter, Tapered Screw Vent, Zimmer Dental), a bone core biopsy specimen from each implant insertion site was collected using a trephine, assuring an unbroken core biopsy specimen longer than 11 mm (modified trepan mill, 3.2 and 4.2 external diameter, 2.2 and 3.2 internal diameter, Stoma) under a saline jet at 600 rpm. All the bone core biopsy specimens were collected at implant placement at 6 months after the sinus augmentation procedure. The assistance of surgical guides was employed to collect the bone cores based upon the individual prosthetic requirements. In addition, the drilling was performed up to 14 mm to allow a proper length of harvested core specimens. Biopsy specimens were treated following the technique described by Soardi et al.14

**CBCT Study**

CBCT scans (ProMax 3D Max CBVT, Planmeca OY) were repeatedly performed for each patient in the maxillary region following this sequence: before surgery, after sinus augmentation, immediately after implant insertion (6 months), and consecutively after 10 and 18 months. The DICOM data obtained were processed with medical software (3Diagnosys 3.0-3DIEMME). This particular software offers the possibility of using a virtual probe in the desired region to extract the bone density values and export them in Excel tables for statistical analysis. The virtual probes used (Fig 1) had a diameter of 6 or 7 mm (2 mm wider than implants placed, to avoid the gray level [GL] distortion by the beam hardening from the metal) and were set in the regions of the sinus augmentation or implant insertion. The voxel GL data surrounding the region of interest and along the entire length of the implant were extracted from each probe used. Hence, it was possible to examine the image Gls corresponding to each selected tissue density and perform a comparison among different samples.

Bone density values around implants were collected, excluding areas affected by artifacts. As the CBCT...
system was not calibrated in Hounsfield units (HU), data obtained were expressed in GL. This calibration factor is not a limit since all the data have been acquired with the same machine. Also, a comparative analysis has been performed among the different acquisitions. In CBCT sections at 6, 8, and 10 mm from the crestal surface, the mean ± standard deviation of GL was calculated.

Microradiography
The specimens preparation and processing are reported in further detail in the recently published CBCT/microradiography correlative study. Briefly, paraformaldehyde-fixed core biopsy specimens were embedded in methyl methacrylate (PMMA) and cut using a diamond saw microtome. One hundred sections, perfectly polished, were x-ray microradiographed on high-resolution film. The amount of bone and graft content, whose radiopacity degree was different (bone was distinctly more radiotransparent), was evaluated on the microradiograph images using an image analyzer and software (AnalySIS, Soft Imaging System).

To correlate the averages of CBCT-GL values to the microradiographic content of bone and graft, the data collected during two previous studies were reanalyzed.13,14

Statistical Analysis
The linear mixed model (SPSS v20) was used to test the time effect as well as depth influence. Briefly, the change of the bone density as a function of time elapsed from the first surgery (within patients, 3 time points: 6, 10, and 18 months) and the influence of depth from baseline bone density (within patients, 3 levels: 6, 8, and 10 mm from the crest) were analyzed. The Schwarz Bayesian criterion (BIC) was used to select the covariance structure (four structures were tested: compound symmetry, AR(1), diagonal, scaled identity). Bonferroni-corrected post hoc tests were used to examine between repeated condition differences. A .05 $P$ value was set up for all statistical decisions.

RESULTS

Surgery
A total of 22 individuals, 9 men and 13 women, aged from 36 to 75 years, were included in this study. A total of 24 maxillary sinus augmentation procedures were performed: bilaterally in 2 patients and unilaterally in 20 patients. Primary wound closure was achieved in all 24 surgeries with no complications or adverse events observed during follow-up. A total of 24 bone core biopsy specimens, corresponding to a total of 24 implants placed, were obtained from the 22 patients. Three out of 24 biopsy specimens were damaged after drilling and hence discarded. A total of 21 biopsy specimens from 19 patients were used for the CBCT/microradiography correlative study.14

CBCT Study
Figure 1 shows a representative CBCT behavior in one of the 22 patients from grafting up to the 18-month follow-up. As observed in the different images, no remarkable changes occurred, and the implant remained completely surrounded by bone after 18 months.

The GL obtained at 6, 8, and 10 mm during implant placement (6 months), 10 months, and 18 months from grafting are summarized in Table 1. Mean GL values ranged from 570 to 654, presenting the maximum value at 8 mm from the crest immediately after implant placement and the minimum value at 6 mm from the crest at 10 months (Table 1).

Figure 2 shows the densitometric CBCT trend of the 24 sites at different time points.

Statistical Analysis
Table 1 shows the statistical analysis of the CBCT with time (6 to 18 months). Compound symmetry covariance structure showed the lowest BIC and was used to test for the effects of the repeated factors. The mixed linear
analysis showed the time effect, \( F(2,207) = 4.748, P = .04 \). Pairwise comparisons between times from surgery yielded differences between 6 months and 18 months \( (P < .02) \).

The data collected during two previous studies\(^1\) on maxillary sinus floor augmentations performed using the same graft were not entirely investigated. The microradiographic specimens of the previously published 28 bone core biopsy specimens (Fig 3),\(^1\) were further analyzed to define the time effect on the bone formation and graft resorption (Fig 4a).

Figure 4a displays the results of densitometric linear regression analysis of microradiographic data and time. There was an upward trend of bone formation and a downward trend of graft disappearing with time (Fig 4a).

Essentially, the microradiographic mineral content of biopsy specimens decreased from 41.8% (15.5% bone + 26.3% graft) at 3 months to 39.84% (39.84% bone + 0% graft) at 12 months, with the disappearance of graft between the 10th and 11th month (Fig 4b).

Figure 5 shows the trend of the theoretical mineral content, calculated using the microradiographic mineral content of the biopsy specimens. The theoretical mineral amount will be 40.3% (37.9% bone and 2.4% graft) after 10 months \( (m_{10}) \) and 38.5% (all bone) after 18 months \( (m_{18}) \).

To estimate the CBCT reliability, the authors correlated CBCT values and microradiographic content of bone and graft remnants at three different levels from the crest (Fig 6) using the 21 core biopsy specimens obtained from the previously published study.\(^1\) Table 2 shows the microradiographic mean amount of bone and graft inside the sections at 6, 8, and 10 mm from the crest.

The microradiographic bone and graft content of the midmost biopsy sections (6 and 8 mm) of each single patient was used to solve the equation

\[
GL = bx + gy
\]

where \( GL = \) CBCT-gray level; \( b = \) microradiographic bone fraction \( (B\%/100) \); \( x = \) bone coefficient; \( g = \) microradiographic graft fraction \( (G\%/100) \); \( y = \) graft coefficient.

The mathematical processing returned the following coefficients (mean ± SD): bone coefficient \( x = 3,800.7 \pm 12,245.2 \), and graft coefficient \( y = -747.4 \pm 11,667.9 \), the first positive and the second negative. Those were two unbelievable coefficients; since both bone and graft contribute to the final radiographic density, then both coefficients should be positive, denoting that CBCT was not able to separate bone from graft content.

Each patient, the mineral coefficient \( z \) could be calculated using the relation \( z = GL/m \), where \( GL = \) CBCT-gray level; \( m = \) microradiographic mineral fraction \( (M\%/100) \).
Fig 4  (a) Trend of bone and graft from 3 to 12 months after grafting. (b) Mineral content of biopsy specimens. gray bar = bone; green bar = graft.

Fig 5  Theoretical amount of mineral content (M%) of 3- to 18-month biopsy specimens.

Fig 6  Representative image of a core biopsy specimen showing the microradiographs of sections performed at the (a) 6-, (b) 8-, and (c) 10-mm levels.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Mean Percent Values of Microradiographic Bone and Graft Inside 6-, 8-, and 10-mm Sections of 21 Core Biopsy Specimens in Previous Study14</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>6 mm</td>
</tr>
<tr>
<td>Bone</td>
<td>26.1</td>
</tr>
<tr>
<td>Graft</td>
<td>19.2</td>
</tr>
</tbody>
</table>

The mathematical processing, using all 6-, 8-, and 10-mm sections of the 21 core biopsy specimens performed 6 months after grafting (at implant positioning), returned the following values (m ± S.D.): z = 1,480.5 ± 603.6. Being GL = zm, it would mean that GL should be 370.1, when M% = 25%; GL should be 740.2, when M% = 50%, and so forth.

Using z = 1,480.5 and m$_{18}$ = 0.385 as previously calculated, the theoretical CBCT densitometric value (GL) after 18 months could be calculated by the equation
GL = zm. Then, the theoretical GL result would be 570 after 18 months, which is a value very close to the recorded average of CBCT-GL values, 18 months after grafting (Table 1).

**DISCUSSION**

Implant stability, both short- and long-term, is largely influenced by bone quality and quantity.\(^1\) Hence, it is important to assess both conditions prior to implant placement to avoid intra- or postoperative complications. CBCT has recently emerged to be one of the most reliable tools since it is a noninvasive technique when compared with microcomputed tomography (\(\mu\)CT) or conventional histomorphometry.\(^5,14\) Also, CBCT offers several advantages over conventional CT scans, such as lower-dose radiation with high resolution and being cheaper.\(^6\) The present study confirmed that CBCT is an accurate method to evaluate the performance of MHBA used for sinus augmentation up to 18 months.

The reliability of CBCT to assess bone density remains to be determined. Nonetheless, a strong positive correlation has been found between radiographic bone densities measured by CBCT and bone volume assessed by \(\mu\)CT.\(^1,7\) Similarly, the positive correlation of conventional multislice computer tomography and CBCT-based gray density values was also identified.\(^7\) Moreover, Monje et al demonstrated the reliability of CBCT using radiographic bone density to determine bone quality evaluated by \(\mu\)CT in the posterior atrophic maxilla.\(^1,8\) Nonetheless, as far as the authors know, this is the first study aimed to analyze the behavior of CBCT densitometries of maxillary sinuses grafted by human bone allograft.

The present study findings demonstrated that using linear regression analysis, there is a positive correlation between the GL and microradiographic bone/graft remnants present at the time of evaluation. The same analysis highlighted the good CBCT predictability: the average of CBCT-GL values almost exactly matched the theoretical GL value calculated from Soardi et al.\(^1,14\)

Many grafting materials have been developed and used for sinus augmentation techniques.\(^1,9\) Nonetheless, autogenous bone is still considered the "gold standard" because of its osteogenic, osteoinductive, and osteoconductive capacity.\(^20\) However, the necessity of a second surgical site, limited availability, and morbidity of the donor site have limited its application. Other grafting materials, including allogeneic bone grafts, with osteoconductive capacity and possibly osteoinductive potential,\(^20\) have been widely used. Data from the present study showed that MHBA had been almost completely replaced by the newly formed bone. This resorption/remodeling pattern of the graft has been attributed to the activity of the macrophage and osteoclast cells.\(^21\) The present results indicated that the mineral content of the biopsy specimens decreased from 41.8% at 3 months to 39.84% at 12 months, with the disappearance of graft between the 10th and 11th month. Therefore, assuming the reliability of CBCT for determining bone densitometry, the human bone allograft is, in fact, an acceptable bone graft material for sinus augmentation. In addition, the average of residual graft found in the present study is in agreement with a previous study.\(^21\) This also agreed with the finding when autogenous bone was used as a graft material in sinus augmentation procedures.\(^22\)

This study demonstrated the reliability of CBCT for evaluating the newly formed bone and also the remaining bone after a medium-term follow-up. However, caution must be exercised when interpreting the results of this study due to the limited sample size and the lack of histomorphometry analysis to correlate the findings. As a result, further studies are needed to confirm these results.

**CONCLUSIONS**

Within the limitations of this study, it can be concluded that CBCT is a reliable tool to assess bone and biomaterial behavior in the follow-up of sinus elevation procedures. In addition, it is evidence of the total resorption of the mineralized human bone allograft employed.

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**REFERENCES**


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