Computerized Tomography–Assisted Calculation of Sinus Augmentation Volume

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Purpose: *This study was intended to calculate the augmentation volume for a sinus lift procedure based on cross-sectional computerized tomography (CT) scans for 2 different augmentation heights.* ***Materials and Methods:*** *Based on area calculations of cross-sectional CT scans, the volume of additional bone needed was calculated for 44 sinus lift procedures. The amount of bone volume needed to raise the sinus floor to heights of both 12 and 17 mm was calculated.* ***Results:*** *To achieve a sinus floor height of 12 mm, it was necessary to increase the height by a mean of 7.2 ± 2.1 mm (range, 3.0 to 10.5 mm), depending on the residual ridge height; to achieve a height of 17 mm, a mean of 12.4 ± 2.0 mm (range, 8.5 to 15.5 mm) was required (P < .01). The calculated augmentation volume for an augmentation height of 12 mm was 1.7 ± 0.9 cm^3; for an augmentation height of 17 mm, the volume required was 3.6 ± 1.5 cm^3. Increasing the height of the sinus lift by 5 mm, ie, from 12 mm to 17 mm augmentation height, increased the augmentation volume by 100%. A significant correlation was found between augmentation height and the calculated sinus lift augmentation volume (r = 0.78, P < .01).* ***Discussion and Conclusion:*** *Detailed preoperative knowledge of sinus lift augmentation volume is helpful as a predictive value in deciding on a donor site for harvesting autogenous bone and on the ratio of bone to bone substitute to use. Calculation of the augmentation size can help determine the surgical approach and thus perioperative treatment and the costs of the surgery for both patients and clinicians.* (Basic Science) Int J Oral Maxillofac Implants 2006;21:907–913

Key words: *augmentation volume, computerized tomography, sinus lift augmentation*

Lack of sufficient bone height in the posterior maxilla frequently precludes standard implant placement in this region. Since the 1980s, many investigators have used internal sinus augmentation (sinus floor elevation) to allow implant placement in the posterior maxillary region in patients who initially present with insufficient bone height.[1–3] After successful internal maxillary sinus augmentation, anchorage of dental implants is possible even in cases in which the posterior maxillary region has undergone severe bone resorption.[3–5] Traditional internal sinus augmentation and implant placement using the lateral window approach are accomplished as either a 1-step or a 2-step surgical procedure.[3–6] In this surgical technique, a hinged opening is made in the facial antral wall and inverted to create a space for the graft material.[1] Various types of grafting material (eg, autogenous bone, xenogenic bone, combinations of these materials) have been used successfully. The graft material is placed between the antral floor and the elevated sinus membrane (including the inverted bone plate).[5–14] Although there have been some modifications of the surgical techniques in recent years,[15,16] the original technique described by Boyne and James is still in use today.[1]

Autogenous bone can be harvested from the iliac crest, the metaphysis of the tibia, and several intraoral mandibular sites such as the symphyseal or retromolar area and the maxillary tuberosity.[17–21] Detailed knowledge of the bone volume needed prior to surgery may be helpful in selecting the optimal donor site. Preoperative knowledge of the required bone volume minimizes the extent of the surgical procedure as well as the potential complications encountered and reduces hospital costs and expenses for the patient.[22–24]

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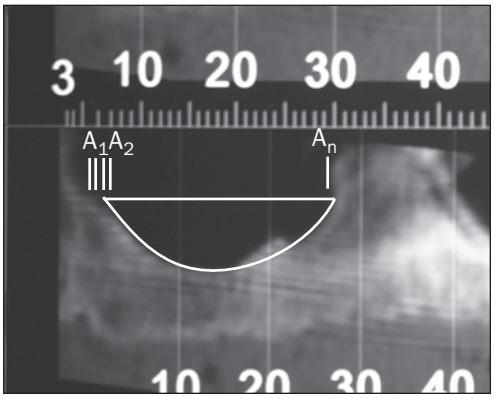

Fig 1 CT panoramic images showing the mesiodistal extension of the planned sinus augmentation and the available cross-sectional scans.

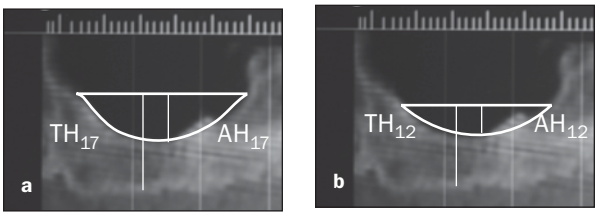

Fig 2 CT scans with superimposed vertical reference lines. The total height (TH) lines indicate the total height needed to accommodate *(a)* a 15-mm-long implant or *(b)* a 10-mm-long implant; The augmentation height (AH) lines indicate the amount by which the current height must be increased (TH = AH + residual ridge height).

A total maxillary sinus volume of approximately 15 cm^3 has been reported in the literature (ie, anatomic and radiographic studies).[25] In a cadaveric study, Uchida and colleagues[25] described a total sinus volume of 14 cm^3. They also measured the sinus floor volume for simulated sinus lift procedures and found that, depending on the procedure and implant length, it was necessary to increase the bone volume of the antral floor by 1 to 7 cm^3.

Few clinical investigations regarding sinus augmentation volume (ie, the amount by which it is necessary to increase the sinus volume) as determined prior to surgery have been carried out.[25,26] Computerized tomography (CT) and software programs may be used to obtain sectional images of the maxillary sinus and the adjacent antral floor.[26–29] Detailed cross-sectional CT scans allow calculation of the augmentation volume for various implant lengths and residual ridge heights. The aim of the present study was to measure the sinus augmentation volume using preoperative cross-sectional CT scans and to calculate the required graft volume for several augmentation heights and implant lengths.

MATERIALS AND METHODS

The present study included 31 patients (18 men and 13 women; mean age, 53.1 ± 7.2 years, range, 36 to 68 years) with unilateral (n = 18) or bilateral (n = 13) edentulous posterior maxillae. Overall, 44 posterior maxillary regions scheduled for sinus lift procedures for implant treatment were studied.

Basic radiographic diagnostic evaluation consisted of a conventional orthopantomogram. In addition, a dental CT was performed from which CT panoramic images and reformatted CT cross-sectional scans were prepared. Axial CT radiographic examinations were carried out using a Somatom Plus S machine (125 kV, 520 m As, matrix 512 × 512; Siemens, Munich, Germany). Axial sections were made parallel to the alveolar ridge of the maxilla at 1-mm intervals. The axial scans were reformatted into panoramic images, and proportional 1-mm cross-sectional views were obtained from the axial scans using the dental CT software program (Siemens).[26–28]

In the CT panoramic images the mesiodistal extension of the planned sinus augmentation was determined using the number ($A_1 - A_n$, Fig 1) of available cross-sectional scans (Fig 1). Vertical reference lines were superimposed on the scans (Fig 2). For a 10-mm-long implant, a reference line of 12 mm was used; this included a 2-mm safety margin. For a 15-mm-long implant, a 17-mm-long reference line was used. The total height (TH) was the height of the residual bone plus the amount by which it would be necessary to augment the sinus to place an implant of the desired length (ie, the augmentation height [AH]). When calculating the augmentation volume, 2 mm of augmentation height were added to compensate for the possibility of graft resorption. To determine the maximum AH, the AH reference line was drawn from the lowest point of the sinus floor; a horizontal line was then drawn across the scan for determination of the required volume for each implant length (Fig 3).

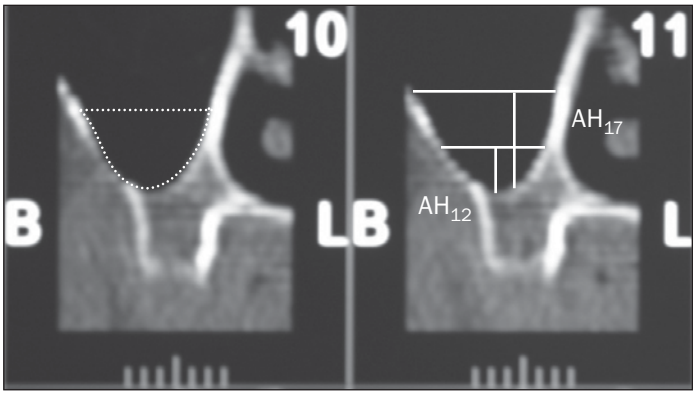

Fig 3 Cross-sectional CT scans with the necessary AHs for 10- or 15-mm-long implants shown.

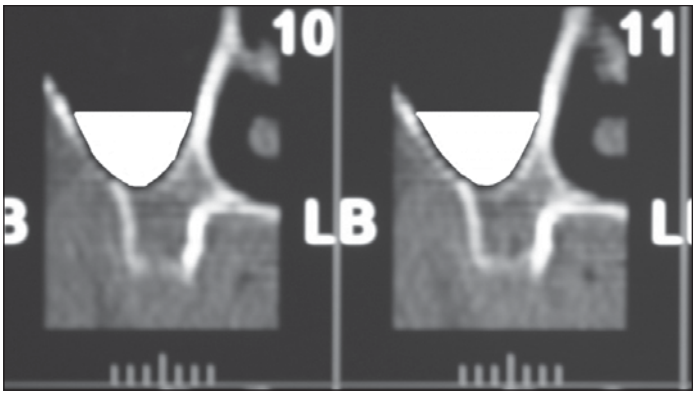

Fig 4 Area calculation on cross-sectional CT scans.

All 1-mm cross-sectional scans were converted to digital images with an HP 1210 scanner (Hewlett-Packard, Palo Alto, CA) and then processed with Photoshop 5.0 LE (Adobe, San Jose, CA; Figs 3 and 4). Using a PC cursor the surface was defined on the respective cross-sectional scan and the pixel number of the surface was determined (Fig 4). Summation of the individual pixels and their defined size (1 pixel = 0.004 mm) produced the surface areas of the individual cross-sectional scans at the given heights. Using the previously determined anterior-posterior distance (Fig 1), the number of cross-sectional scans required was defined. The overall volume (V) was determined using the formula $V = n \times A_n$, where n was the sum of the surface areas of the individual cross sections.

Volume calculation was carried out in this manner for all planned sinus lifts with adequate consideration of residual alveolar ridge height (RRH). The augmentation volumes for augmentation heights of 12 and 17 mm were calculated and compared. The volumes determined were given in absolute numbers, but they were also compared as relative figures for the varying augmentation heights. A simple correlation was calculated for the calculated volumes and the required augmentation heights defined. Means ± SD and simple correlations were compared using the Student *t* test. *P* values of .05 were considered significant.

RESULTS

Using CT data the maximum AH required and the augmentation volume required to achieve THs of 12 and 17 mm were calculated for 44 maxillary posterior areas. The maxillary posterior areas had a mean ± SD RRH of 4.5 ± 2.1 mm (range, 2.0 to 8.5 mm).

The maximum AH required for elevation from the most caudal point of the sinus lift floor to the level of the horizontal reference line was calculated for heights of 12 or 17 mm. For an AH of 12 mm, an elevation of 7.2 ± 2.1 mm (range, 3.0 to 10.5 mm) was required; to obtain an AH of 17 mm, elevation of 12.4 ± 2.0 mm (range, 8.5 to 15.5 mm) was required ($P < .01$).

To achieve a TH of 12 mm, mean augmentation volume of 1.7 ± 0.9 cm^3 (range, 0.3 – 3.0 cm^3) needed to be achieved; for a TH of 17 mm, the mean augmentation volume was 3.6 ± 1.5 cm^3 (range, 0.8 – 5.6 cm^3).

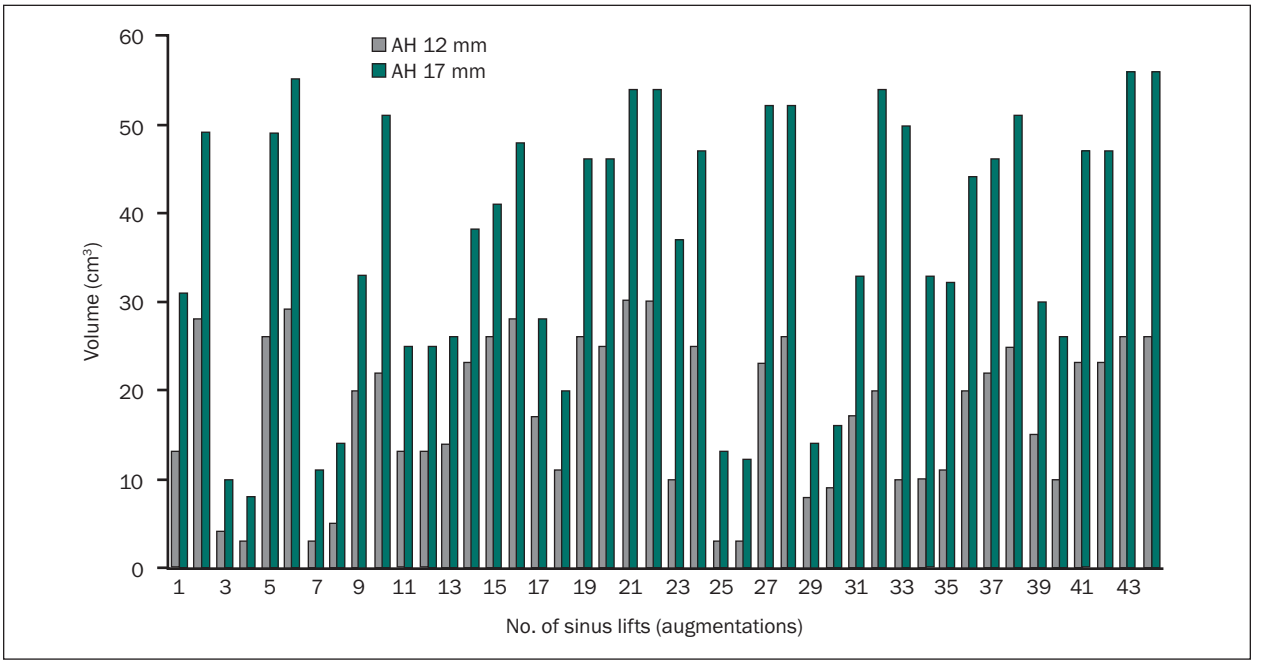

Fig 5 Individual augmentation volumes of all maxillary sinus areas (n = 44) where sinus augmentation was planned relative to intended augmentation height.

In Fig 5 the individual augmentation volumes of all maxillary sinuses are shown in relation to the different AHs (12 or 17 mm).

Figure 6 shows the relationship of augmentation volumes for augmentation heights of 12 mm (V_{AH12}) and 17 mm (V_{AH17}). An increase of elevation of 5 mm, ie, from an augmentation height of 12 mm to a height of 17 mm, was associated with an increase of 100% for the augmentation volume.

A significant correlation was found between the required AH and the calculated sinus lift volume (r = 0.78, $P < .01$). Figure 7 shows the correlation between AH and augmentation volume for all cases (n = 88): The necessary volume in $cm^3 \times 10^{-1}$ was equal to 0.352x – 8.073, where x was the augmentation height in mm $\times 10^{-1}$.

DISCUSSION

Results of numerous clinical studies have shown that autogenous bone alone or in combination with xenogenic bone substitute is the graft material of choice for elevation of the maxillary sinus floor to achieve a sufficient height for implant placement in atrophic posterior maxillary regions.[2–5,10–14] Autogenous bone material may be harvested from intraoral donor sites (the ascending ramus, the retromolar area, the mandibular symphyseal region, and the maxillary tuberosity) or extraoral ones (eg, the ilium, tibia, or cranium).[17–21,30,31] Sailer,[6] Uchida and associates,[25] and Montazem and colleagues[31] described the bone graft volume which can be harvested from the mandibular symphyseal region as ranging from 3 to 6 cm^3. The varying dimension between buccal and lingual cortical bone results in variable bone volume and limits the volume of intraoral symphyseal bone available for transplantation.[31,32] Excessive harvesting of symphyseal bone may lead to damage of the roots of adjacent anterior teeth and cause neurosensory disturbances.[17,19,23,31,32] Based on anatomic investigations and calculations, the bone volume of the ascending ramus and the retromolar area is about 2 to 3 cubic centimeters.[30,33] Use of the retromolar area or the ascending ramus is often limited because of atrophy-related resorption of the mandible and the risk of injury of the inferior alveolar nerve bundle.[30,33] In contrast, extraoral donor sites allow the harvest of larger amounts of bone range of bone.[20,22]

Detailed knowledge of the volume of bone required prior to surgery is helpful to determine the amount of bone to be harvested and thus to select an adequate donor site.[17] Preoperative knowledge of the sinus augmentation size may minimize potential intraoperative complications at donor sites and can also be used to estimate the costs of additional xenogenic graft materials used.[19,23,24] A review of recent studies has suggested that implants to be placed in the poste-

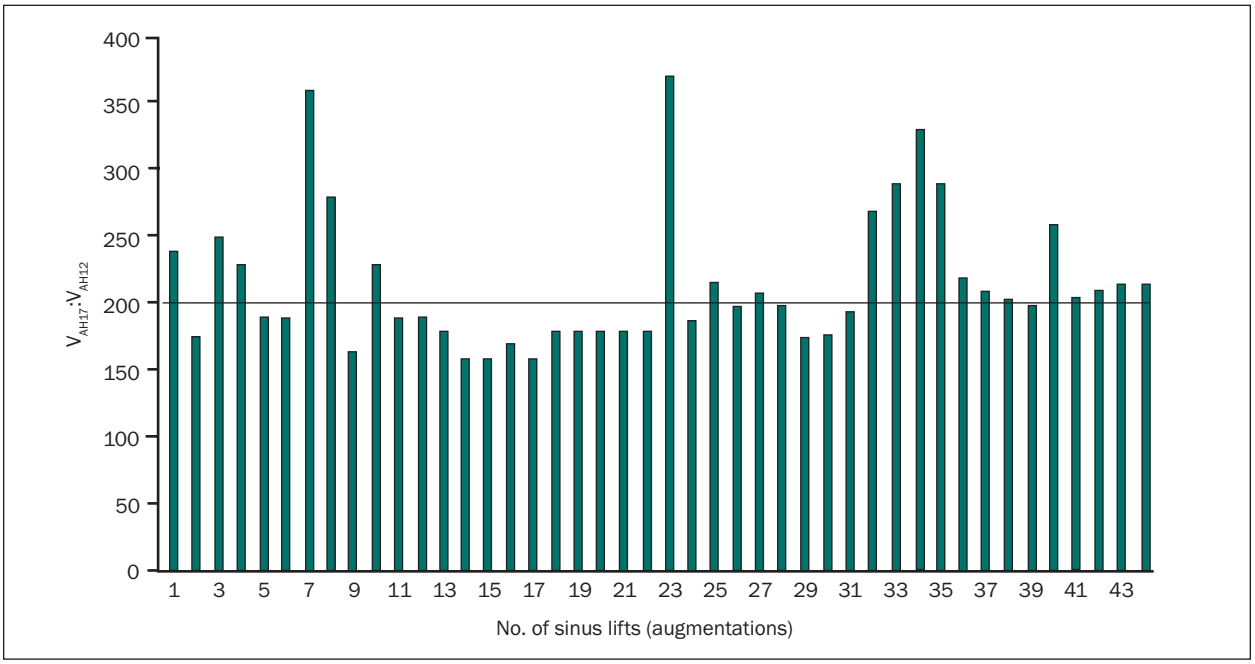

Fig 6 Relationship between augmentation volume for the 2 AHs for each sinus area studied.

rior maxilla should be at least 13 mm in length to achieve long-term success.[3,5] Thus, in the present study calculations were carried out for the placement of a 15-mm implant; in addition, 2 mm were added to the necessary AH to account for graft resorption.[34,35]

The results of the calculations in the present study demonstrate that for cases with reduced residual ridge height elevation of up to 15 mm is associated with an augmentation volume of up to 5 to 6 cm^3. This size is tantamount to the maximum dimension of the mandibular symphyseal donor site and exceeds the maximum amount of bone that can be harvested from the ascending ramus or the retromolar area.[3,17–20,30–33] A sinus augmentation volume of 5 to 6 cm^3 may require the use of an extraoral donor site or a bone substitute.[11,12] Thus, calculation of the augmentation volume may affect donor site selection, which in turn affects the method of anesthesia, peri- and postoperative treatment, and patient cost.

Knowledge of the anticipated augmentation size is especially helpful for the calculation of the amount of bone substitute used.[11] The obtained correlations and mathematical model presented here may be helpful in establishing preoperative estimates of the amount of bone to harvest and the amount of bone substitute to use.

The literature includes a wide range of different recommendations about the ratio of autogenous bone to bone substitute to use.[11–14,34] However, high

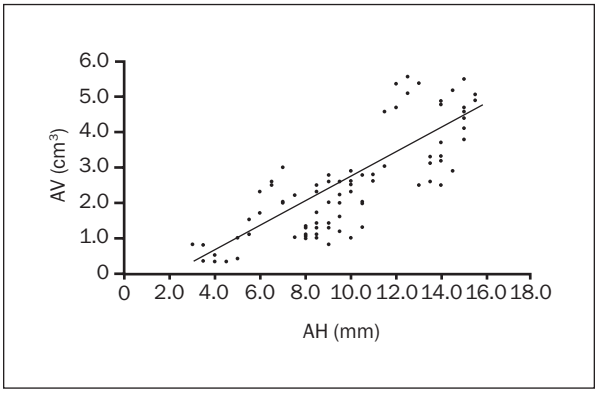

Fig 7 Correlation between AH and volume.

success rates have been presented recently for sinus augmentation with xenogenic bone substitutes alone or with several mixtures of autologous bone and xenogenic substitutes at ratios of 1:3 or 1:4.[3,5,11,14] Therefore preoperative CT calculation of sinus augmentation volume may also determine the amount (and/or ratio) of xenogenic substitute to use and provide predictive information on surgical and material costs for the patients.[11–14,34]

Several investigators have previously reported on donor site, graft bone volume, and implant length in conjunction with bone grafting in the maxillary sinus

floor.[25,26] In an anatomic model as well as in a CT investigation, the calculated bone graft volumes ranged from 2 to 15 cm^3.[25,26] The findings reported for the present study confirm the data described by Uchida and associates,[25] who reported that the augmentation volume required for a 10-mm elevation would be 1.5 ± 0.9 cm^3. In this study, the bone volume required for a 15-mm elevation was smaller, possibly because the preexisting alveolar ridge was included in the calculations made in the present study. In contrast, the study of Uchida and associates[26] only used axial scans, and the residual ridge was not considered. The present study shows that cross-sectional CT scans define the width and height of the residual ridge and allow for an exact calculation of the height and volume of augmentation. Cross-sectional CT scans also provide information on surrounding structures.[27–29] Images of the maxillary posterior areas using cross-sectional CT scans may be useful in selecting the appropriate surgical approach and may also be useful when deciding whether to use the conventional lateral approach or the crestal osteotome technique.[1,15,16,27,28]

However, there are also critical limitations of the use of radiographic calculations such as those presented in the present and former studies. Clinically, the contour of the sinus lift will not always follow the straight lines drawn on CT scans. Because of concavities and convexities in clinical situations, radiographic calculations only provide useful approximations of volume.[34–36]

Interesting findings were obtained in the present study when the relative volumes of sinus lift augmentation for different augmentation heights were compared. It was found that increasing the augmentation height from 12 mm to 17 mm resulted in a significant increase of bone augmentation volume. With an increase of augmentation height of 5 mm, the augmentation volume increased by 100%.

With the present findings showing a maximum sinus augmentation volume of 5 to 6 cm^3 and with previous studies demonstrating that at least 2 to 3 cm^3 of bone can be harvested from intraoral donor sites, intraoral sites should be given preference over extraoral donor sites.[17,18,30,31] Using the bone harvested from intraoral sites, unilateral as well as bilateral sinus floor elevation may be carried out with bone from intraoral sites alone if there is not substantial atrophy.[3,5,11]

Based on the calculations described and using the recommended ratios of bone to bone substitute (1:4), extraoral bone harvesting is only necessary in patients with contraindications for intraoral mandibular harvesting sites, maxillae with severe bilateral atrophy, or maxillae for which both external and internal (onlay) grafting are needed.

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