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Computer-assisted analysis of bone volume for sinus augmentation procedure

Nabil GHOSN

Joe KHOURY

Nada NAAMAN

COMPUTER-ASSISTED ANALYSIS OF BONE VOLUME FOR SINUS AUGMENTATION PROCEDURE

Nabil Ghosn* | Joe Khoury | Nada Naaman*****

Abstract

The objectives of this study were to determine the volume of bone required prior to a sinus graft using two different methods, to compare it to the actual volume used during surgery and to evaluate a segmentation technique in quantifying the volume of a xenograft on the post-operative cone beam computed tomography (CBCT) slices. CBCT data from 11 CBCT scans for 11 patients (6 males, 5 females) requiring 13 lateral augmentation procedures were imported to Simplant Pro 15® (Materialise, Leuven, Belgium) in DICOM format. Residual ridge height (RRH) was measured for each implant site as well as mucosal thickness (MT). MT was classified by grades (1 to 4). Simulation of implant placement for each site was realized and the graft volume was pre-operatively calculated by a semi-automatic segmentation (SAS) technique and another automatic Simplant sinus graft (SSG) technique. All patients underwent a lateral sinus augmentation surgery 3 to 12 weeks after the initial CBCT scan. The volume of the bovine bone grafting material (BBM) particles was quantified during the surgery (Vr) for all patients and on immediate post-operative CBCT scans (CBCT-V) for 7 patients. With a mean augmentation of 9.45 ± 1.72 mm, the calculated volumes were 2.243 ± 0.962 mm3 and 2032 ± 0.843 mm3 for the SAS and SSG methods, respectively. Percent variation between Vr and SAS volume was significant (22.4%) and non-significant (4.5%) between Vr and SSG volume. In cases with MT grade 1 & 2, no difference was found between Vr and SAS volume. No difference was found between Vr (1.918 ± 1.118 mm3) and CBCT-V (1.979 ± 1.108). In conclusion, the results showed that the use of the Simplant® software was effective in determining the required graft volume for the surgery, the volume measurements with the SSG were more accurate than the SAS and the quantification of BBM particles on CBCT data sets was reliable and accurate with the segmentation technique used.

Keywords: Sinus floor augmentation - cone beam computed tomography - graft volume measurement - computer-assisted image interpretation - surgical simulation.

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ANALYSE ASSISTÉE PAR ORDINATEUR DU VOLUME OSSEUX DANS LES PROCÉDURES D'AUGMENTATION DU SINUS MAXILLAIRE

Résumé

L'objectif de cette étude était de déterminer le volume d'os nécessaire pour la greffe sinusienne à l'aide d'un logiciel de simulation implantaire (Simplant®), de comparer ce volume calculé par deux méthodes au volume utilisé durant la chirurgie et d'évaluer une technique de segmentation mesurant le volume d'os bovin sur des coupes de tomodensitométrie à faisceau conique (CBCT) réalisées en post opératoire. Les données de CBCT de 11 patients (6 hommes, 5 femmes) ayant besoin de 13 élévations sinusiennes ont été transmises au logiciel Simplant Pro 15 (Materialise, Louvain, Belgique) en format DICOM. La hauteur de la crête osseuse résiduelle et l'épaisseur de la muqueuse sinusienne (MT) ont été mesurées. MT a été classifiée sous différents grades (1 à 4). Une simulation de la pose des implants a été réalisée au niveau de chaque site et le volume de greffe a été calculé en pré opératoire à l'aide d'une technique de segmentation semi-automatique (SAS) et d'une autre technique de calcul de greffe sinusienne spécifique au logiciel Simplant (SSG). Tous les patients ont subi une élévation sinusienne par voie latérale, 3 à 12 semaines après la prise des CBCT. Le volume d'os bovin a été mesuré en per opératoire (Vr) pour tous les patients et sur les coupes de CBCT en post opératoire (CBCT-V) pour 7 patients. Pour une augmentation en moyenne de 9.45 ± 1.72 mm, les volumes calculés ont été de 2243 ± 0.962 mm3 et de 2032 ± 0.843 mm3 pour les techniques SAS et SSG, respectivement. La variation en proportion était significative entre Vr et le volume de SAS (22.4%) et non significative entre Vr et le volume de SSG (4.5%). Dans les cas présentant une MT de grade 1 et 2, une absence de différence a été notée entre Vr et le volume de SAS. Aucune différence significative n'a été retrouvée entre Vr (1.918 ± 1.118 mm3) et CBCT-V (1.979 ± 1.108). En conclusion, les résultats ont montré l'efficacité du logiciel Simplant pour la détermination du volume de greffe nécessaire pour l'augmentation sinusienne ainsi qu'une meilleure précision de la technique SSG par rapport à la SAS. En plus, la technique de segmentation des particules d'os bovin était efficace pour le calcul du volume de ces derniers au niveau des CBCT post opératoires.

Mots-clés : greffe sinusienne - tomodensitométrie à faisceau conique - simulation de greffe osseuse - mesure volumétrique.

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* DDS, MScD,
Instructor, Dpt of Oral
and Maxillo-Facial Radiology,
Faculty of Dental Medicine,
Saint-Joseph University, Beirut, Lebanon
Nabil.ghosn@usj.edu.lb

** DDS, MScD,
Instructor, Dpt of Periodontology,
Faculty of Dental Medicine,
Saint-Joseph University, Beirut, Lebanon

*** DDS, DUSC, PhD
Dean,
Director of Postgraduate Program,
Dpt of Periodontology,
Faculty of Dental Medicine,
Saint-Joseph University, Beirut, Lebanon

Introduction

The necessity for an adequate bone volume, providing sufficient ridge height and width for functional and esthetic implant therapy, made bone grafting a common and well-documented procedure in dental practice during the last decades [1]. Bone resorption that occurs in the edentulous maxilla frequently involves a sinus augmentation procedure to allow implant placement in the posterior maxillary region in patients who initially present insufficient bone height [2]. The space created between the maxillary alveolar process, the elevated Schneiderian membrane and the rotated lateral sinus wall is filled with graft material [3].

Pre-operative knowledge of the required bone volume may be helpful in selecting the optimal donor site, in minimizing the extent of the surgical procedure, in deciding which ratio of bone to bone substitute to use and in reducing the potential complications encountered, as well as the global expenses for the patient [2, 4].

Since 1993, various software tools that enable pre-implant planning and performing volume measurements have been developed, combining computerized tomography (CT) images with computer design. During pre-operative evaluation, the use of this diagnostic tool would enable us to reach the volume of necessary graft, therefore, a reduced surgery time, cost and patient expectations would be achieved [2]. However, the studies found in the literature such as those published by Uchida et al. [4] or more recently by Krennmair et al. [3] didn't use these software tools to measure the volume of bone graft needed for maxillary sinus lifting. They rather employed sophisticated methods that are difficult to extrapolate to routine use in pre-operative planning.

Few clinical investigations regarding sinus augmentation volume as determined prior to surgery have been carried out [2-5]. These studies used similar methods to calculate the sinus bone graft by using a straight horizontal reference plane, which was the height up to which the sinus was to be lifted and all images were taken with a regular CT scan. None of the studies compared the pre-calculated volume with real per and post-operative measurements, which can leave a doubt on the usefulness of such methods, therefore the purpose of our study was to correlate these predictions with per and post-operative volume measurements.

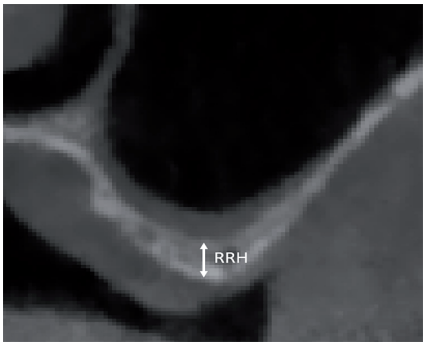

Fig. 1: RRH measurement on a CBCT coronal section.

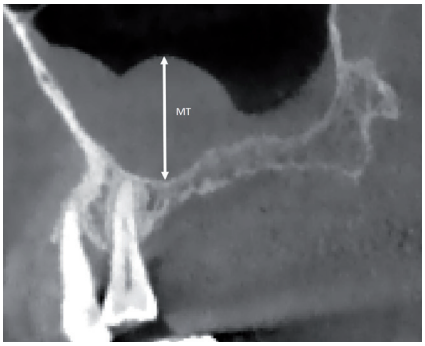

Fig. 2: MT measurement on a CBCT sagittal section.

The primary objective of the current study was to evaluate two methods in determining the volume of graft needed for the sinus augmentation procedure using an imaging software the Simplant Pro®. The secondary objectives were to compare the calculated volumes to the actual volume used during surgery and to determine the reliability and accuracy of a segmentation technique in measuring the volume of the grafted bone substitute on the post-operative CBCT slices.

Materials and methods

Study design

Eleven patients were selected from the dental care center of the Faculty of Dental Medicine, Saint-Joseph University, with unilateral posterior maxillary edentulism or bilateral posterior maxillary edentulism (6 females, 7 males; mean age 57.54±13.69), requiring 13 lateral sinus augmentations. Patients underwent a CBCT scan using the Newtom VGI scanner 3 to 12 weeks prior to surgery between 03/03/2011 and 28/01/2013, followed by a sinus augmentation with natural bovine bone grafting material (Cerabone®, Botiss dental GmbH, Uhlandstr. 20-25, 10623 Berlin - Germany). Sinus augmentation types were 2 bilateral and 9 unilateral.

Inclusion criteria

Having posterior maxillary edentulism and a distance of less than 6 mm from the ridge crest to the maxillary sinus floor on at least one edentulous site. Eight patients were nonsmokers and three reported smoking less than 10 cigarettes per day. Informed consent was obtained from all patients prior to participation in this study.

CBCT Scan Protocol

Patients were scanned with the Newtom VGI CBCT machine. Imaging conditions were: 110 kv tube voltage; 2.2 to 8.30 mA tube current; 15 x 15 cm field of view; and 0.3mm voxel size. Projection data were collected with a device rotating 360 degrees around patients over a total acquisition time of 18 seconds.

Evaluation of images

Scan data were saved in DICOM (Digital Imaging and Communications in Medicine) format and image analysis and measurements were performed using the Simplant Pro 15® (Materialise Dental nv, Leuven, Belgium) which provided axial, coronal and sagittal views through multiplanar reconstructions of 0.15mm slices. Axial

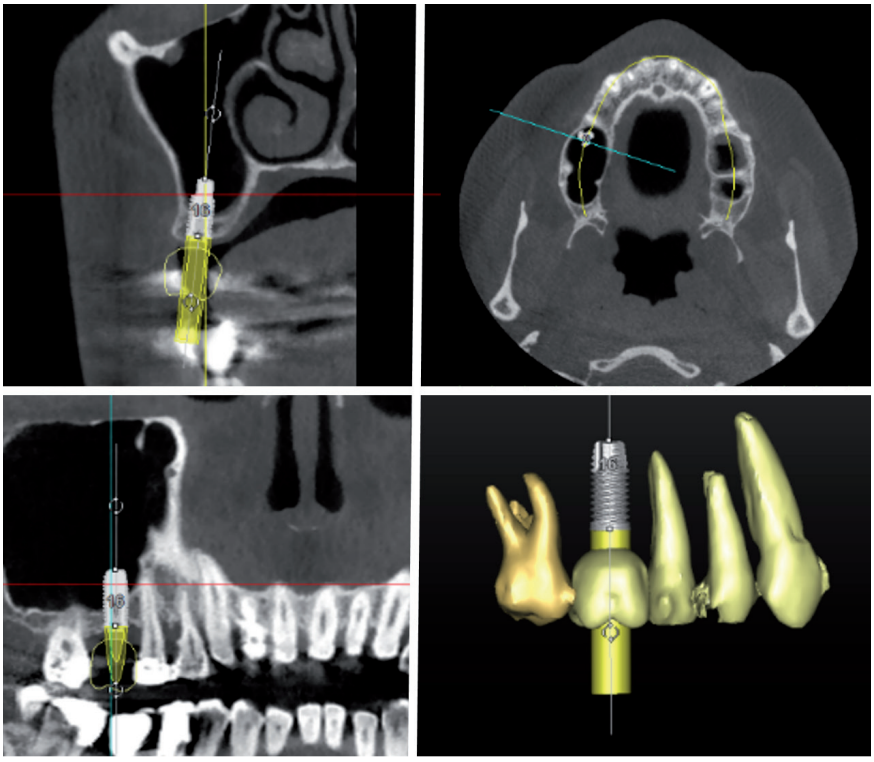

Fig. 3: Virtual implant placement.

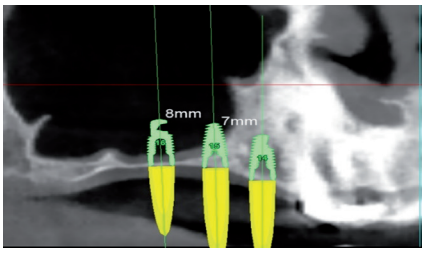

Fig. 4: Green line represents the vertical alignment of 3 virtually planned implants as well as the inter-implant distances.

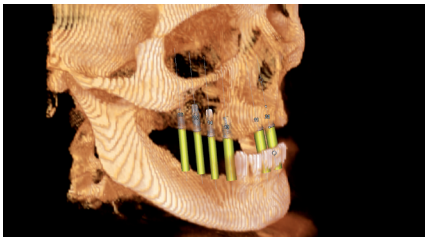

Fig. 5: Insertion of implants in a totally edentulous maxilla.

images were reoriented to occlusal plane when present or to palatal plane as a horizontal reference. A panoramic curve was created and cross-sectional images perpendicular to that curve were reconstructed at a 1 mm interval.

All included CBCT scans were evaluated for residual ridge height (RRH) and sinus floor membrane thickness (MT) corresponding to each sinus in the left and/or right posterior maxilla of each patient:

- RRH was measured in mm. Each sinus was considered independent and evaluated in the coronal section (Fig. 1) corresponding to the center of the edentulous and potential implant site [6]using cone-beam computed tomography (CBCT. All the data were then added up and the average was calculated for each sinus [2].
- MT was classified according to height. Height was divided in accordance to the metric thickening of 0–2, 2-5,5–10 and 10mm and above [6] and classified by grades of 1–4, respectively. MT was measured in mm. The measurement occurred at the most severe thickening (Fig. 2) in the area to be grafted in the coronal or sagittal sections [6-8].

In case of a thickening of grade 3 & 4, patients were examined by an ENT (ear, nose and throat) specialist and underwent appropriate treatment before the sinus augmentation procedure [9].

Virtual implant placement

In order to plan each case, virtual implants were placed as follow:

In case of a Kennedy Cl III edentation (n=1): virtual tooth was placed in the software and its position was guided by the neighboring teeth and the dental arch. The virtual tooth served as a guide for the placement of the implant (Fig. 3).

In case of a Kennedy Cl I or II edentation (n=10): virtual implants were placed directly without virtual teeth and their positions were guided by the bone, the neighboring teeth and the inter-unit distances [8, 10]: distances between the center of premolar roots or implants were set at 7mm and distances between the center of molar roots or implants at 8mm while the minimum implant to implant distance remains > 3mm (Fig. 4).

In case of a totally edentulous patient (n=2) all implants were virtually placed starting with teeth number 11 and 21 at both sides of the incisal foramen (Fig. 5) and the position of implants were guided by the bone and the inter-unit distances.

Calculation of bone graft volume

After placing and choosing the desired implant length (IL), 2 methods were used for comparison in Simplant Pro 15® to calculate the graft volume.

Semi-automatic sinus segmentation (SAS)

This was done by creating a mask in the Simplant® software. A mask is

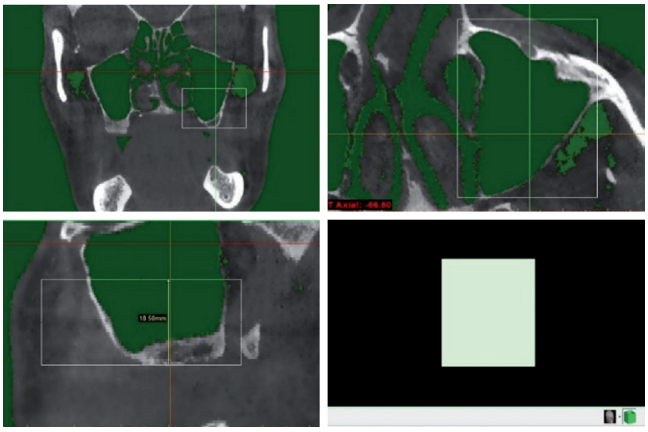

Fig. 6: Mask creation by thresholding.

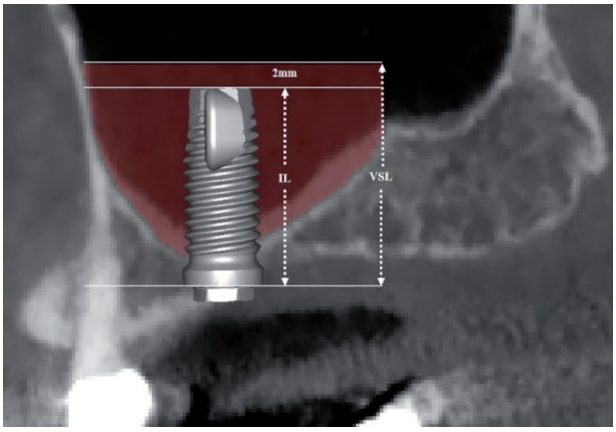

Fig. 7: Vertical simulation level (VSL): Implant Length (IL) + 2mm.

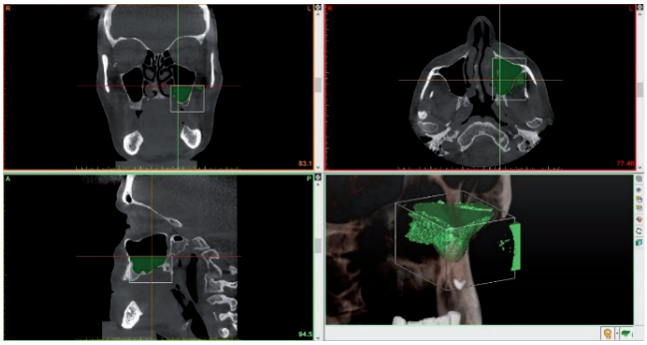

Fig. 8: Mask cropped to the desired length (DL).

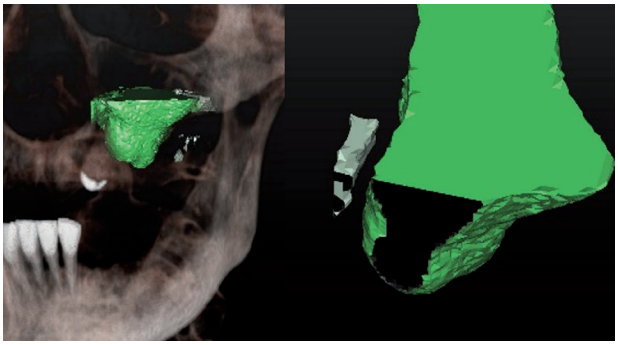

Fig. 9: Editing Mask in 3D.

a selection of pixels with a gray value within a specified range of Hounsfield Units (HU). All pixels with a gray value within this range will be selected and therefore will be included in the mask. The minimum threshold was set to the lowest (-1024: Empty spaces) while the maximum threshold was adjusted manually in a way that the created mask followed the edge of the surrounding bone structures (Fig. 6). The mask was then cropped to the vertical simulation level (VSL) in the sinus (VSL=IL+2mm) at the site of the placed virtual implant (Figure 7). The 2mm were added to account for graft resorption [5]. The desired length was measured from the bone crest at the center of the site where the implant is to be placed to the desired apical point while being parallel to the occlusal or palatal plane (Fig. 8). In case of a difference between the apical levels of two adjacent implants, the level of the most apical implant level was chosen. The cropped mask was edited in 3D mode to remove all the parts that extruded from the sinus (Fig. 9). The anterior and posterior walls of the sinus were used as the horizontal reference for the graft, but in cases where a sinus septum was present, the mask was cropped at the level of the most apical point of the first septum that follows the last implant (Fig. 10). A 3D object was calculated in high quality then its volume was automatically calculated by the software (Fig. 11).

Simplant Sinus Graft (SSG)

Desired implants (width and length) were chosen and their placement was simulated in 3D parallel to teeth roots and to each other in 3D. Bone graft was calculated by the "calculate sinus graft" option in the implant menu. Apical level of desired bone graft above the apex of the implant is chosen by the operator as well as the HU threshold. Default values (4.5mm above implant level and 30mm diameter) were used in all cases. The software automatically calculated the graft volume based on the differences in density between bone and empty spaces. This allowed to mimic a graft that closely follows the edge of the bone, even if there was a thickening of the Schneiderian membrane (Fig. 12). When the sinus graft was calculated, the amount of graft material needed to fill the graft (in mm3) was shown in the 'graft volumes' list. After the creation of the sinus graft for each implant, all grafts were merged into one single graft. The graft was checked manually on each section to make sure that it followed the edge of the sinus. In cases of an extension of the graft outside the crest or into the

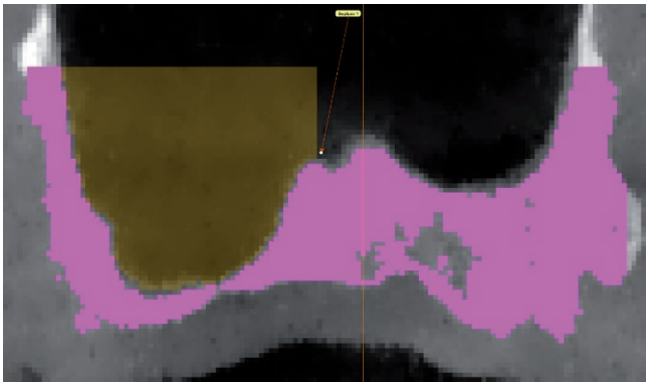

Fig. 10: Antero-posterior graft limit.

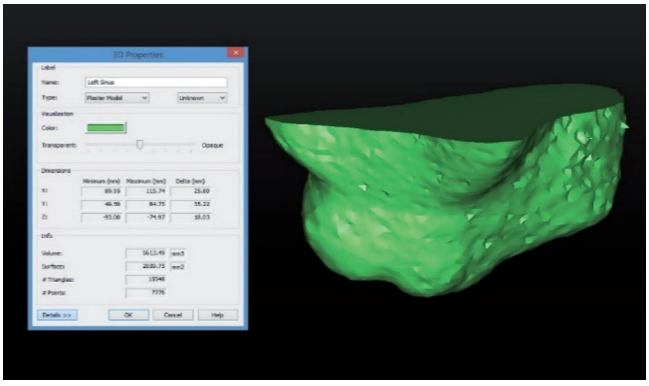

Fig. 11: 3D Object calculated. The dialog shows the volume of the object in mm3.

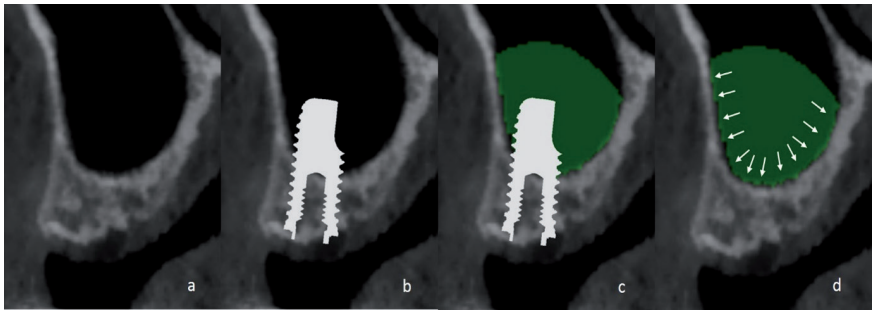

Fig. 12: Simplant "Calculate Sinus Graft" in case of an absence of a membrane thickening: a. cross section showing an absence of a Schneiderian membrane thickening; b. virtual implant placement; c. automatic graft calculation; d. cross section showing the virtual bone graft that follows the edges of the sinus

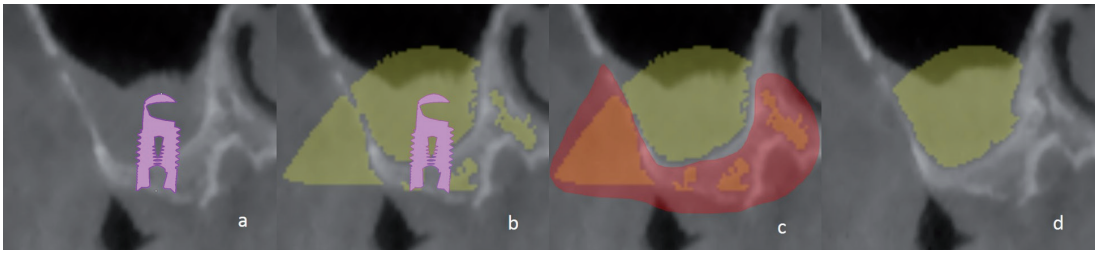

Fig. 13: Removing extruded parts of the graft in case of a thickening of the Schneiderian membrane: a. virtual implant placement; b. the automatic graft selection that included a part of the soft tissue that is outside the limits of the sinus; c. selection of the extruded parts on each cross-section; d. cross section with the graft limit after the removal of the extruded parts.

nasal cavity, the extruded parts of the virtual graft were removed manually in each cross-section (Fig. 13) and in cases where a thickening in the membrane prevented the complete automatic calculation, a manual adjustment of the volume by the addition of the non-selected areas occupied by the thickening of the membrane is made.

Measurements

The following measurements were repeated twice, at least 2 weeks apart, by the same operator for each method, in order to assess the intra-observer reliability of each measurement:

- Semi-automatic segmentation volumes: SAS-V1 and SAS-V2
- Simplant sinus graft volumes: SSG-V1 and SSG-V2

Surgery

All patients underwent surgery 3 to 12 weeks after the initial CBCT scan. Surgeries were performed by two operators. The lateral wall of the sinus was exposed by performing a crestal incision and a mucoperiosteal flap. A bony window was created using a piezoelectric instrumentation (Mectron ®). The distance between bone crest and the apical part of the window was equal to DL (Fig. 14).

When the bony window became removable, the surgeon started to separate the sinus membrane from the inferior edge of the osteotomy region and pushed the membrane upward. The sinus membrane was carefully

separated from the inner and inferior walls. The external wall was either removed and placed back after the graft, or pushed inward and upward to form a new horizontal ceiling for the space created. In the first case, caution was made not to push the membrane to a level that is more apical than the upper part of the prepared window and the external wall was placed back at the end of the surgery without the use of a collagen membrane. In the second case, a collagen barrier was used to cover to the exterior wall of the sinus. However, we had 2 cases of small perforation (n=2) and a resorbable collagen membrane was applied to cover the hole (Jason®, botiss dental GmbH, Uhlandstr. 20-25, 10623 Berlin - Germany). A natural bovine bone (Cerabone®, botiss dental GmbH, Uhlandstr. 20-25, 10623 Berlin - Germany) was mixed with a saline solution then packed gently into the sinus in order to completely fill the cavity with the grafting material and achieve the desired bone height. In some cases (n=3) autogenous bone harvested with a safescraper was added to the grafting material and the volume of the graft with its blood components was measured before placing it in the sinus with a 3cc syringe [11]. When the sinus was filled, a resorbable collagen membrane (Jason®) or the external bony wall was placed back on the outer surface of the window and the flap was sutured with a primary closure. Remaining bone substitutes and autogenous bone were measured with a 3cc syringe.

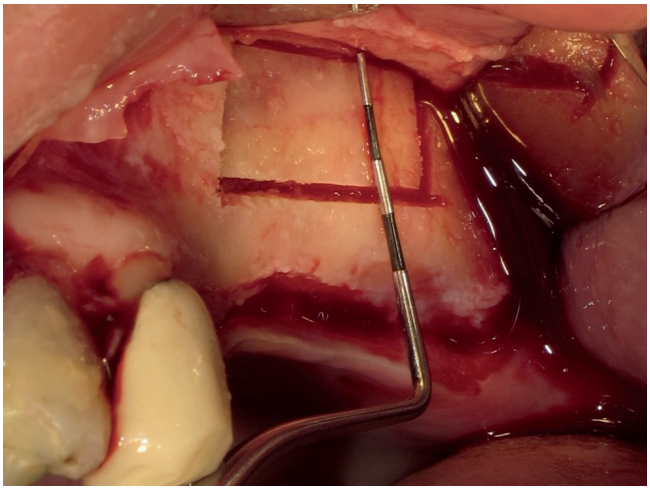

Fig. 14: Preparation of the window with piezosurgical device.

Measurements

-Volume of natural bovine bone (Vbb).
-Volume of harvested autogenous bone (Vab).
-Volume of remaining unused graft particles (Vrp).
-Total real used volume (Vr) = Vbb + Vab – Vrp.

Post-operative CBCT volume calculation

In order to compare the real used volume (Vr) during surgery and the real used volume calculated on the post-operative CBCT scan (CBCT-V), patients were scanned a second time 2 days to 2 weeks after the surgery. CBCT scan data were imported into Simplant Pro 15®. Post-operative volume measurement was done by a segmentation process of the bone graft:

• An initial mask was created with a manual setting of the minimum and maximum HU threshold. HU thresholds were chosen to include all the graft particles. The initial mask (green) contained all the graft particles with parts of the surrounding maxillary bone with the same grey density (Fig. 15).

• A duplicate of the green mask was created and edited by the 'multislice editing' tool in the tools menu. All the grafted particles were selected on each slice (at 0.3mm thickness) and removed from the duplicated mask (Fig. 16). The result was a mask that contained only the surrounding bone structures.

• A third mask was created by the Boolean operation tool. This mask was equal to the green mask (Grafted area + surrounding bone) minus the yellow mask (surrounding bone alone) and contained only the grafted particles (Fig. 17).

• The mask was manually rechecked on each slice to make sure of the selection.

• A 3D object was calculated from the mask in high quality (Fig.17). The volume of this object was shown in mm3 in the properties menu.

Measurements

In order to assess the intra-observer reliability of the measurement, the same operator measured the volume twice, at two different times:

• CBCT-V1 and CBCT-V2

Statistical analysis

Statistical analysis was performed using SPSS for Windows version 18.0. The alpha error was set at 0.05. Reproducibility of measurements for the SAS method, for the SSG method and for post-surgery (CBCT) were evaluated using the Intraclass correlation coefficient (ICC). The average measure was used for statistical analysis. Paired Student t test was used to explore significant difference between the real used Vr and CBCT-V.

Repeated measure analysis of variance (ANOVA) followed by multiple comparisons (Least significant difference) were conducted to explore significant difference between the mean real used volume and the mean volume estimated according to SAS and SSG methods. Other repeated measures ANOVA were used to explore

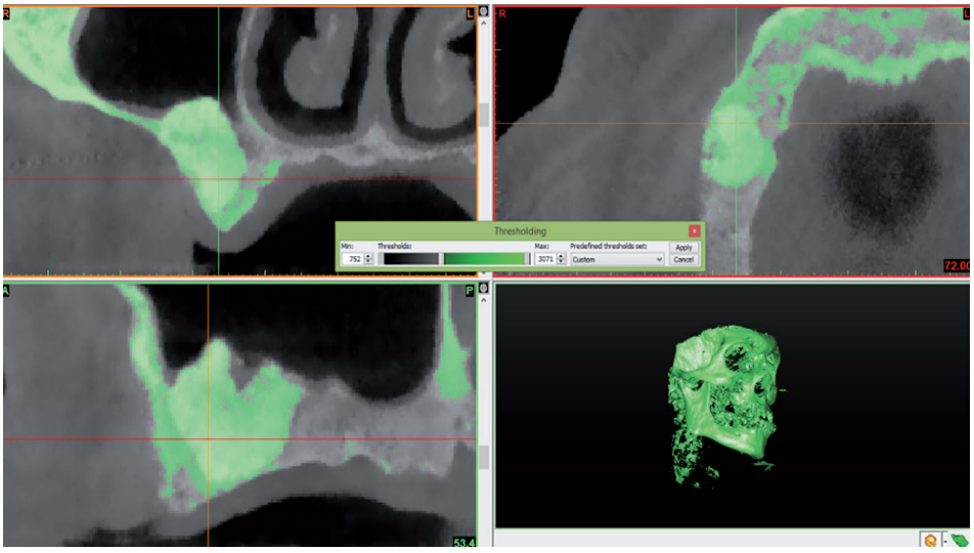

Fig. 15: Initial green mask that included all the graft particles with parts of the surrounding maxillary bone with the same grey density.

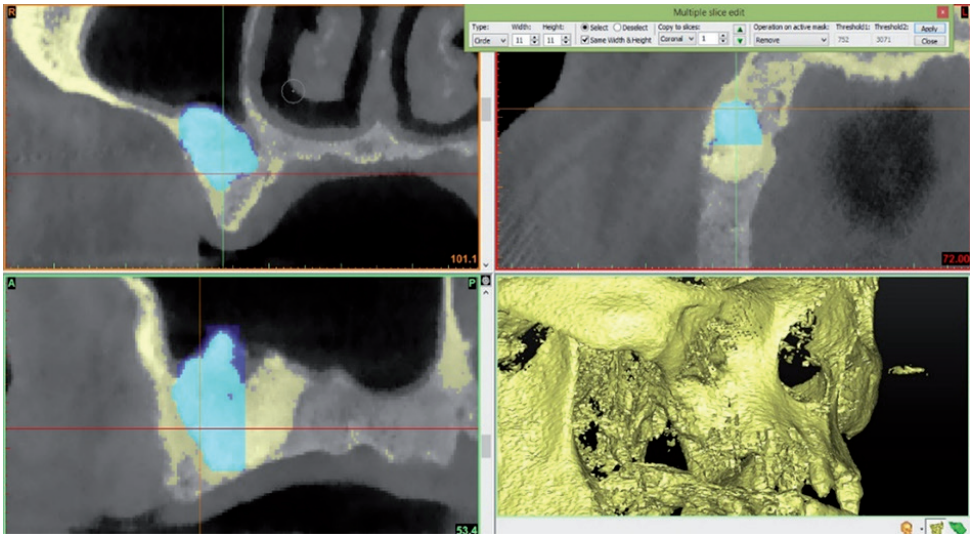

Fig. 16: Selection of grafted particles on the duplicated mask (in yellow).

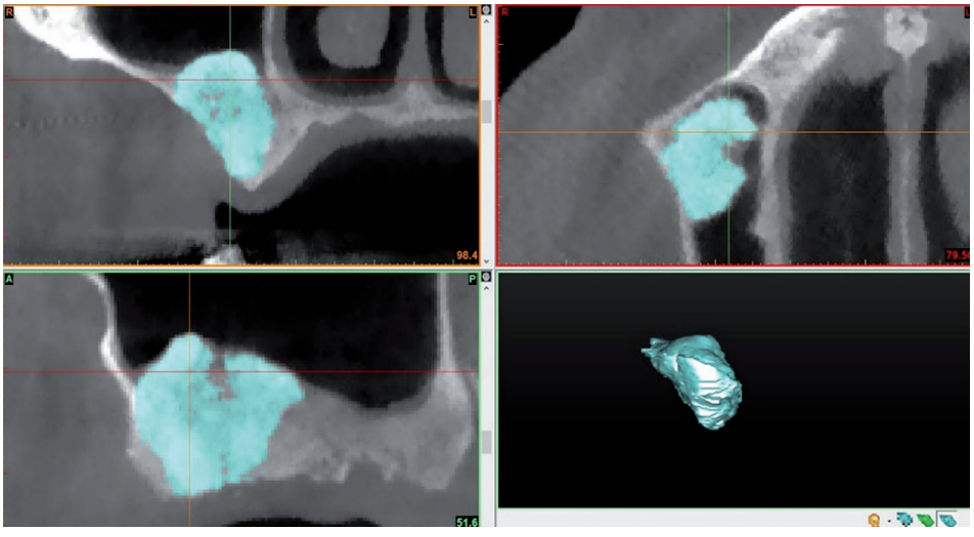

Fig. 17: Blue mask including only the grafted particles with the 3D object in the lower right window.

significant difference between the mean real used volume and the mean volume estimated with the SAS and SSG methods according to mucosal thickness.

Results

Description of the sample

Eleven subjects (6 males and 5 females; mean age 57.5 ± 13.7 years) were included in the study. In the maxilla, the majority of the participants (72.7%) presented a posterior unilateral edentulism (Cl II of Kennedy); 9.1% had a bilateral posterior edentulism (Cl I Kennedy), 9.1% were Class III of Kennedy and 9.1% were totally edentulous. For the 11 patients, 13 sinus sites were analyzed. The implants desired lengths were between 10 and 13mm.

The residual ridge height, the vertical simulation level and the augmentation height for the 13 sites are presented in Table 1.

The mucosal thickness was between 0 and 2 mm in 38.5% of cases, more than 10 mm in 30.8% of the sites and between 2 and 5 mm in 23.1% of cases. The mucosal thickness for the 13 sites is presented in Table 2.

	N	Mean ± SD	Minimum	Maximum
Residual ridge height (mm)	13	3.86 ± 1.29	1.64	5.70
Vertical simulation level (mm)	13	13.31± 1.18	12	15
Augmentation height (VSL-RRH)	13	9.45 ± 1.78	6.30	12.36

Table 1: Characteristics of the grafted sites.

Mucosal thickness	Frequency (percentage)
Grade 1 (0 - 2mm)	5 (38.5%)
Grade 2 (2 - 5mm)	3 (23.1%)
Grade 3 (5 - 10mm)	1 (7.7%)
Grade 4 (> 10 mm)	4 (30.8%)
Total	13 (100.0%)

Table 2: Mucosal thickness among implant sites.

Statistical analysis before and during surgery

Reproducibility of measurements: semi-automatic sinus segmentation method

Table 3 shows the measurements according to the SAS method carried out by the same operator in two different times. This study showed that the mean measurements were not significantly different between the two different time periods (p-value = 0.278; paired Student test). The reproducibility of measurements was very high (ICC = 0.988, 95% CI [0.961, 0.996], p-value <0.001). The average of the two measurements was used for statistical analysis.

Number	SAS-V1 (mm3)	SAS-V2 (mm3)
1	2.8	2.63
2	3.79	3.82
3	1.08	0.98
4	1.16	0.84
5	3.1	2.87
6	2.63	2.52
7	1.45	1.34
8	2.42	2.3
9	2.15	2.09
10	3.96	3.71
11	1.04	1.34
12	1.83	1.71
13	2.17	2.2
Mean ± SD	2.275 ± 0.972	2.210 ± 0.951

Table 3: Reproducibility of measurements: SAS method.

Reproducibility of measurements: Simplant sinus graft method

Table 4 shows the measurements according to the SSG method carried out by the same operator at two different times. The reproducibility of the measurements was very high (ICC = 0.998, 95% CI [0.993, 0.999], p-value <0.001). The mean measurements were not significantly different between the two different times (p-value = 0.263; paired Student test). The average of the two measures was used for statistical analysis.

Comparison between the real used volume and the two methods of volume estimation

The mean and standard deviation of the real used volume and of the volume estimated upon the SSG and SAS methods in 10 sites are presented in Table 5. Three sites were excluded from the analysis for the following reasons:

- In 2 bilateral sinuses in the same patient, the sinus window was prepa-

Number	SSG-V1 (mm³)	SSG-V2 (mm³)
1	2.62	2.67
2	4	3.98
3	1.21	1.18
4	1.46	1.43
5	2.63	2.4
6	1.75	1.72
7	1.15	1.12
8	2.15	2.06
9	2.16	2.09
10	2.64	2.66
11	0.99	1.06
12	1.34	1.34
13	2.48	2.54
Mean ± SD	2.045 ± 0.847 mm³	2.019 ± 0.838 mm³

Table 4: Reproducibility of measurements: Simplant sinus graft method.

	N	Mean ± SD	Minimum	Maximum
SAS (mm³)	10	2.164± 0.863	1.03	3.84
SSG (mm³)	10	1.834± 0.628	1.02	2.65
Real used volume (mm³)	10	1.850± 0.765	0.75	2.70

Table 5: Comparison between the real used volume and the two methods.

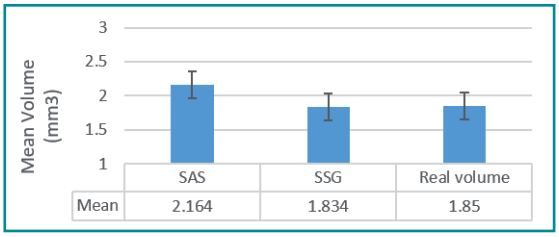

Fig. 18: Comparison between the real used volume and the two assessment methods.

red to a more apical level than the vertical simulation level.

• A simultaneous implant placement was carried out in one sinus.

The statistical analysis showed that the mean estimated volume using the SSG method was not significantly different from the mean real used volume (The mean variation between measurements was 4.5%) (p-value = 0.842). However, the mean volume estimated according to the SAS method was significantly greater than the mean estimated volume according to the SSG method (the mean variation between measurements was 21.4%; p-value = 0.046) and the real used volume (p-value = 0.030) (Fig. 18, Table 6).

This study has shown that when augmenting the sinus by 9.5mm, the mean necessary volume of graft was 1.834 ± 0.628 mm3 according to the SSG method and 2.164 ± 0.863 mm3 according to the SAS method.

Comparison between volumes according to mucosal thickness

The mean and standard deviation of the real used volume and of the volume estimated upon SSG and SAS methods are presented in Table 7, according to mucosal thickness. When the thickness of the mucosa was greater than 10 mm, the mean volume estimated using the SAS method was significantly greater than the mean estimated volume according to SSG method and the real used volume (p-value = 0.049; ANOVA repeated measures). No significant difference was found when the mucosal thickness was less than 2 mm (p-value = 0.199, repeated measures ANOVA) between 2 and 5 mm (p-value = 0.763, ANOVA with repeated measures).

Statistical analysis after surgery

Reproducibility of the post-surgical measurements (CBCT-V)

The bony window was placed back in six cases. In the 7 remaining cases, collagen membrane was used to cover the osteotomy window. The post-surgical volume was measured by the same operator at two different times for 7 grafted sinuses. Four patients (with 4 sinuses) didn't take a post-op CBCT and 2 more post-op CBCTs were excluded because they showed extruded biomaterial outside the sinus limits. Table 8 shows these measures at seven grafted sinuses. Average measurements were not significantly different between time 1 and time 2 (p-value = 0.482; paired Student test). The reproducibility of measurements was very high (ICC = 1.000, 95% CI [0.997, 1.000], p-value <0.001). The average of the two measurements was used for comparison.

Comparison between real used volume and post-surgical volume

Table 9 shows the mean and the standard deviation of the real volume of the graft and the post-surgical CBCT volume. Statistical analysis showed that the mean real used volume was not significantly different from the post-surgical volume (p-value = 0.111; paired Student test) (Fig. 19).

Bone window versus membrane placement to cover the lateral sinus opening

No significant difference was found between mean SAS-V, mean SSG-V and the real used volume when the osteotomy window was replaced (-p-value=0.752) or no (-p-value=0.221) (Table 10).

SAS	Real volume	Variation	SSG	Real volume	Variation
1.03	0.8	28.8%	1.195	0.8	49.4%
2.985	2.7	10.6%	2.515	2.7	-6.9%
2.575	2.1	22.6%	1.735	2.1	-17.4%
1.395	1.2	16.3%	1.135	1.2	-5.4%
2.36	2.2	7.3%	2.105	2.2	-4.3%
2.12	2.5	-15.2%	2.125	2.5	-15.0%
3.835	2.5	53.4%	2.65	2.5	6.0%
1.19	0.75	58.7%	1.025	0.75	36.7%
1.77	1.25	41.6%	1.34	1.25	7.2%
2.375	2.5	-5.0%	2.51	2.5	0.4%
		21.4% SS*			4.5% NS**

*Significant statistical difference
** Non significant statistical difference
Table 6: Percent variation between the real volume and the two methods.

Mucosal thickness		Mean (mm3) ± SD	N	p-value
1	SAS	1.398 ± 0.370	3	0.199
	SSG	1.223 ± 0.105	3	
	Real used volume	1.083 ± 0.247	3	
2	SAS	1.890 ± 0.618	3	0.763
	SSG	1.752 ± 0.630	3	
	Real used volume	1.817 ± 0.936	3	
3	SAS	0.00	1	
	SSG	2.510 ± 0.00	1	
	Real used volume	2.500 ± 0.00	1	
4	SAS	3.132 ±0.643	3	0.049
	SSG	2.300 ± 0.494	3	
	Real used volume	2.433 ± 0.306	3	

Table 7: Comparison between the real used volume and the two methods according to mucosal thickness.

Number	CBCT-V1 (mm3)	CBCT-V2 (mm3)
1	3.870	3.800
2	0.750	0.718
3	1.310	1.300
4	2.180	2.116
5	0.762	0.766
6	2.720	2.740
7	1.880	1.940
Mean ± SD	1.925 ± 1.125 mm3	1.911 ± 1.111 mm3

Table 8: Reproducibility of the post-operative CBCT volume measurement.

	N	Mean ± SD
CBCT-V (mm3)	7	1.979 ± 1.108
Real used volume (mm3)	7	1.918 ± 1.118

Table 9: Comparison between real used volume and post-surgical CBCT volume.

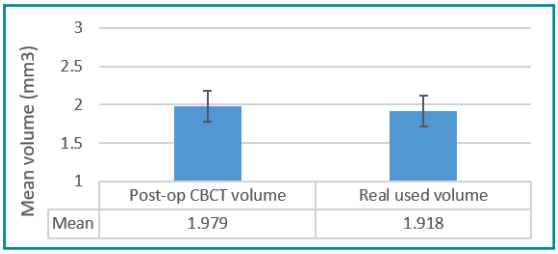

Fig. 19: Comparison between real used volume and post-surgical CBCT volume.

Window replaced		Mean ± SD	N
No	Mean SAS-V	2.3925 ± .99060	6
	Mean SSG-V	1.9283 ± .73295	6
	Real used volume	1.9583 ± .79901	6
Yes	Mean SAS-V	1.8200 ± .57971	4
	Mean SSG-V	1.6912 ± .49294	4
	Real used volume	1.6875 ± .79622	4

Table 10: Comparison between SAS-V, SSG-V and real used volume according to osteotomy window removal.

Discussion

Maxillary sinus augmentation surgery has proven to be a predictable procedure to restore the bone volume in the posterior maxilla and allow implant placement with high predictability [12-14]. Autogenous bone has long been considered the gold standard augmentation material, but due to shortcomings such as the donor site morbidity, the potential resorption and the loss of volume, numerous bone replacement grafts (allografts, xenografts and alloplasts) have been used. To date, xenografts used alone or as a composite with autogenous bone, remains the group with the most clinical research with implant survival outcomes equal or superior to those achieved with autogenous bone alone [12-14]. As the volume of bone graft is not estimated based on objective diagnostic criteria, the extracted amount of bone for grafting is often excessive or deficient [11]. Therefore, the analysis of the required bone volume prior to surgery is helpful in:

- Selecting the optimal donor site and minimizing the extent of the surgical procedure in case of an autogenous bone graft [3, 4, 11].
- Deciding which ratio of bone to bone substitute to use in case of a composite graft [3].
- Knowing the global expenses for the patient [2, 5].

The majority of the implant planning software programs available have the ability to segment DICOM images acquired from a CT scan and/or have a different method for the calculation of a graft volume. In the literature search conducted, we only found four studies for the analysis of sinus graft volume prior to surgery [2-5], from which only two studies [2, 3] used a computer based virtual planning software to calculate this volume. SimPlant Pro 15 (Materialize Dental NV, Technologielaan 15 3001, Leuven, Belgium), the image analysis software used in this study, has a specific function for sinus graft calculation since earlier versions. Although this software has been widely used for implant simulations before surgery since 1993, no studies were conducted to assess the accuracy of the sinus graft calculation method.

There are 2 main differences between the Simplant Sinus Graft (SSG) method and the previously described methods [2-5]:

- The shape of the simulated graft: the previous studies used a straight horizontal plane to delineate the upper graft limit while the delineation was made with a curved plane in the SSG method allowing a closer simulation of the real graft shape.
- Simplicity of the technique: the SSG uses an automatic segmentation technique with minimal user adjustment while the other methods are more sophisticated and require more time and expertise.

Automatic segmentation of an empty sinus cavity (without mucosal thickening) is an easy task in a CBCT image set because the difference in the density values between the empty sinus cavity and the maxillary bone

is quite important. When a mucosal thickening is present, strong edges between the sinus mucosa and the maxillary bone may not be present and the imaging will often produce a "grainy" region that is more detectable by the human eye than by sophisticated computer algorithms. Hence, in this study, the process was always regulated by a human operator and a manual adjustment was always needed in cases with mucosal thickening for both methods: the SSG and the SAS technique.

In this study, the mean RRH was 3.86mm and the mean vertical simulation level was 13.31, resulting in a mean augmentation height of 9.45mm. For this AH, the mean pre-operative calculated volume was 1.83ml and 2.16ml for the SSG and the SAS methods, respectively. These results were in accordance to those reported by Uchida et al. [4] who showed that 1.92 mL of bone volume was needed for a 10mm of sinus augmentation. In contrast, Arias-Irimia et al. (2012) [2] showed that 2.65mL of bone is needed to augment the sinus of 9.56mm and Krennmair et al. [5] 1.7mL for a 7.2mm AH. The delineation of the simulated graft in this study was done in the axial plane and in the coronal plane in case of a presence of sinus septa posterior to the last implant, unlike previous studies. This was done to reduce the risk of an overestimation of the graft volume in the posterior sites where the sinus is not going to be actually filled.

The segmentation technique used by Buyukkurt et al. [3] was comparable to the SAS method. However, they showed that 1.67mL of bone volume is required for a 10mm AH (compared to 2.16mL). This difference might be due to the fact that their study population included dentate patients not requiring sinus augmentation, which might be the cause of a decreased graft volume.

Although the measurement of the sinus graft volume based on image analysis of 3D CT scan data has been attempted [2-5], the relationship between the measured graft volume and actual graft bone volume used in bone grafting has not been clarified. The main strength of the current study lies in comparing both methods to the volume of the bone graft used during surgery.

In this study, the grafted particles volume was measured twice. The first measurement was a direct measurement of the remaining particles with a 3cc syringe [11] after the completion of the surgery. The second one was realized on the post-operative CBCT scans for 7 patients using a semi-automatic segmentation technique in the Simplant Pro software [15]. The post-operative CBCT-calculated volume was realized to determine the reliability of the software in the graft volume calculation so we could identify whether the error comes from the simulation technique or from the computerized volume measurement in case of a difference between the simulation and both measurements. However, statistical analysis showed that the actual volume was not significantly different from the post-op CBCT calculated volume (Table 8). Thus, the volume measurement error was excluded.

When compared to the actual volume (mean 1.85cc), the SSG method (mean 1.834cc) proved to be more accurate than the SAS method (mean 2.34cc). This might be due to the difference in the shape of the simulated graft or to the difficulty in the SAS method in cases where a mucosal thickening is present. Mucosal thickening has proven to affect the volume measurement in the SAS method in cases where it is above 10mm (grade 4) while no statistically significant difference between the SAS and the actual volume was present in grades 1 and 2. However, conclusions cannot be drawn with this small sample size (13 sinuses).

The current study showed the preoperative method of calculation of the sinus graft volume using surgical planning software. The bony window was prepared to the same vertical level of the simulation for a standardization purpose. However, in practical use, the operator will be able to achieve the desired graft vertical height without having to prepare the bony window to the same vertical level when using this amount of bone. It is also important that the individual who estimates the amount of grafting bone required understands the surgical procedure to ensure an accurate estimate [11]. The bucco-lingual width of the sinus cavity and the reflection of the sinus membrane from the medial wall of the sinus are other factors that could affect the volume of the grafted bone substitutes. An incomplete reflection of the membrane from the medial wall will result in an incomplete filling of the sinus cavity [16] and, therefore, a smaller amount of bone substitute will be used. However, in the current study, care was taken to completely reflect the sinus membrane from the medial wall. Even though no difference between the volume of the simulated graft and the actual graft was detected, a difference might be found in the shape of this volume and in the RRH. Can the same planned implant dimension be placed in the grafted bone? Thus, future research is required to compare the difference in shape between the simulated graft and the real one and to study the ability of placing the required implants.

Recent studies have shown that the maxillary sinus floor augmentation could affect the sinus membrane thickness. A swelling of 5 to 10 times of its size could occur in early healing (1 week) after internal sinus augmentation [17] that will eventually disappear after 1 month of healing. After 4 to 6 months of healing, Pommer et al. (2012) [18] showed an increase in membrane thickness in 72% of the operated sinus via lateral technique. This increase might indicate morphologic alterations of the maxillary sinus membrane that could impair its physiologic mucociliary activity [18]. In the current study, post-operative CBCT scans were evaluated in 9 grafted sinuses. All the cases that presented an initial MT of grade 1 and 2 (6 cases) showed a noticeable increase in MT. The remaining

3 cases (with initial MT of grade 4) showed a decrease in MT in comparison with the initial CBCT. All the cases of MT grade 3 and 4 underwent an ENT treatment before the sinus augmentation surgery which might explain the important decrease in MT in comparison with the initial CBCT scan.

Implant survival in grafted sinuses may be confounded by factors other than the graft material used [14]. Survival rates for implants placed in grafted sinuses were studied according to grafting material, timing of implant placement, type of implant surface, quantity and quality of residual bone but not according to the sinus volume or graft volume [19]. A variety of significant factors, such as residual bone height, the incidence of Schneiderian membrane perforation, the size of the lateral window and the total volume of the sinus, may also influence the proportion of vital bone [20]. Successful graft consolidation relies on the progressive apposition of newly formed VB, followed by functional remodeling and progressive replacement of the grafting material by vital tissue [21]. This process requires the presence of a stable scaffold, adequate angiogenesis (blood supply) and the migration of osteogenic cells. These events could be slowed down in situations where the dimensions of the maxillary sinus cavity or the lateral window are excessive [16, 20]. Therefore, delayed or insufficient bone maturation may occur in cases where the sinus cavity presents larger dimensions, or where limited alveolar bone remains after tooth loss and larger sinuses may be prone to less favorable bone formation, such as in critical size defects [16, 20] Moreover, the high osteogenic potential of autogenous bone may be essential when the sinus floor augmentation is performed in larger sinuses [16]. Because the influence of these factors on sinus augmentation outcomes is still unclear [22], it is important that future research will focus on the evaluation of the effect of the graft volume with different bone to bone ratios on the healing patterns (the newly formed vital bone), the healing time and the implant survival rate. This may turn the graft volume into a decisive factor for the selection of the optimal bone replacement graft.

Conclusion

Within the limitations of the current study, the following conclusions can be drawn:

- The use of the implant planning software is effective in the pre-surgical analysis of bone volume prior to the sinus augmentation procedure.
- The SAS and the SSG techniques can be used in cases with an absence of a sinus membrane thickening.
- In cases with severe MT, the SSG method proved to be more accurate than the SAS in determining the graft volume.
- The semi-automatic segmentation technique is effective in measuring the BBM particles on the post-operative CBCT data set.

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