Nongrafted Sinus Floor Elevation with a Space-Maintaining Titanium Mesh: Case-Series Study on Four Patients

Mohammed Atef, MSc;* Maha Mohammed Hakam, PhD;† Mohamed Ibrahim ElFaramawey, PhD;‡ Adel Abou-ElFetouh, PhD;§ Mohamed Ekram, PhD¶

ABSTRACT

Purpose: Numerous materials and techniques have been introduced to augment the maxillary sinus floor for future dental implant placement. Schneiderian membrane tenting above simultaneously placed implants proved to be a successful technique. The present study investigated the use of a titanium micromesh for lateral-window sinus floor elevation without bone grafting.

Material and Methods: Four patients indicated for two-stage sinus lifting were included. Through a lateral window, a titanium micromesh was tailored and placed into the sinus to maintain the elevated membrane in place. Immediate and 6-month postoperative cone beam computed tomography (CBCT) was performed to measure the gained bone height. During implant placement, bone core biopsies were retrieved for histomorphometry.

Results: The average residual ridge height among the eight sinuses was 3.6 mm ± 1.6 mm. Six months postoperatively, it reached 9.63 mm ± 1.47 mm. Histomorphometry revealed that the average bone volume of the native bone was 30.3% ± 9.1%, while that of the newly formed bone was 55.3% ± 11.4%.

Conclusion: Within the limitations of this study due to the small sample size, the use of the titanium micromesh as a space-maintaining device after schneiderian membrane elevation is a reliable technique to elevate the floor of the sinus without grafting.

KEY WORDS: bone formation, histomorphometry, maxillary sinus, membrane elevation, titanium mesh

INTRODUCTION

Sinus pneumatization and insufficient bone quality are among the factors that hinder posterior maxillary rehabilitation using dental implants. Numerous sinus augmentation techniques have evolved to overcome the bone volume deficiency.[1,2]

The lateral-window approach is the classic technique for maxillary sinus floor augmentation. It can be done either in a single stage with simultaneous implant placement or in two stages with delayed implant placement, depending on the available quantity and quality of residual bone in the atrophic ridge.[3,4]

Autogenous bone is considered the best material for sinus floor augmentation in terms of histological behavior. However, donor site morbidity and graft volume loss are among the main disadvantages of autogenous bone, which directed most efforts toward using bone substitutes and new grafting techniques.[5,6]

Thereafter evolved the idea of maxillary sinus membrane lifting without the use of any bone grafts; this was first introduced by Lundgren and colleagues.[7] During the past decade, several studies followed that reported careful elevation of the schneiderian membrane followed by simultaneous installation of the root form

*Assistant lecturer, †Professor, ‡Lecturer, §Lecturer, Oral and Maxillofacial Surgery Department, Faculty of Oral and Dental Medicine, Cairo University, Cairo, Egypt; ¶Professor, Oral Radiology Department, Faculty of Oral and Dental Medicine, Cairo University, Cairo, Egypt

Reprint requests: Mr. Mohammed Atef, 23 Kolyet El-Banat buildings, apartment (34), Nasr City, Cairo 11759, Egypt; e-mail: zokasur@staff.cu.edu.eg, zokasur@live.com

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implants to act as tent poles below the membrane.[8–14] Longer-term studies using the same technique showed implant survival rates of 97%, 98.7%, and 100% for the conventional delayed-loaded implants after follow-up periods of 10, 1 to 6, and 5 years consecutively. Such implant survival rates compared favorably with those of implants placed in nongrafted sites. In addition, the marginal bone loss around the placed implants in these studies was in the acceptable range of 1 to 2 mm after 5 years.[15–17]

The full mechanism of new bone formation in such nongrafted sinuses is still not fully understood. It has been demonstrated that cells isolated and cultured from the maxillary sinus lining possess an osteogenic potential both in vitro and in vivo; such cells were even capable of forming bone tissue in ectopic conditions.[18,19] On the other hand, Scala and colleagues[20,21] argued that bone formation in the nongrafted sinuses was similar to that in extraction sockets and that the bony sinus walls and septa were responsible for the osteogenic process. They showed that the nonsupported sinus membrane collapsed into the created cavity and limited the amount of bone gain and bone-to-implant contact to about half the implants' lengths projecting into the sinus cavity.

However, the residual alveolar crest is not always of enough height or quality to allow for primary stability for the implant installation. Accordingly, attempts were made at introducing space-making devices below the elevated maxillary sinus membrane when no implants could be simultaneously placed. In an experimental study, Cricchio and colleagues[22] made use of a polylactide device to maintain the space in the created sinus cavity, and they found good bone formation despite the lack of stabilization. In contrast, Schweikert and colleagues[23] inserted a titanium plate fixed to the lateral sinus wall to maintain the elevated schneiderian membrane in place. Histological evaluation revealed that only 40.2% of the initially created void below the plate was maintained after 6 months.

In a recent pilot clinical study, Johansson and colleagues[24] placed implants in three patients 6 to 9 months after the maxillary sinus membrane was elevated through a lateral approach and the created void maintained by a hydroxyapatite (HA) device. Implants successfully osseointegrated and were functional 1 year postoperative despite only two of the three cases showing histological evidence of new bone formation. Hence, the purpose of the present study was to evaluate the osteogenic potential of the maxillary sinus in a two-stage sinus membrane elevation using titanium mesh to maintain the created space after membrane elevation without the use of any graft or space-filling material.

PATIENTS AND METHODS

Patients were selected from the outpatient clinic, Oral and Maxillofacial Surgery Department, Faculty of Oral and Dental Medicine, Cairo University. The present study was approved by the ethics committee of the Faculty of Oral and Dental Medicine, Cairo University. Each patient was interviewed in order to obtain a comprehensive history, including full medical and dental history. A preoperative digital panoramic radiograph with 1:1 magnification was taken for each patient as a primary survey. Maxillary sinuses had to be free from any local pathosis, previous sinus surgery, or major bony septa as evident on the panoramic radiograph. The distance between the crest of the ridge and the floor of the sinus in areas planned for future implantation had to be less than 5 mm. For the selected patients, preoperative cone beam computed tomography (CBCT) scans were performed while the patients were wearing a radiographic/surgical stent to accurately measure the bone height at the area planned for future implantation and locate the exact mesiodistal dimension of the lateral-window osteotomy during surgery (Figure 1).

Surgical Procedures

Operative procedures were performed in two stages.

First-Stage Surgery. With the patient under general anesthesia, a three-line mucoperiosteal pyramidal flap was reflected to expose the lateral wall of the maxilla. A diamond round bur was used to delineate the outline of the rectangular osteotomy, guided by the radiographic-surgical stent (Figure 2). The created window was totally decorticated in five sinuses, while in the other three it was elevated into the sinus cavity to form a new roof. The membrane was then carefully elevated from the lateral wall and floor of the maxillary sinus. The width of the osteotomy was approximately measured; then, a foil template was trimmed to fit into the created space (Figure 3). A 0.1-mm dynamic titanium micromesh (Leibinger, Stryker Co., Geneva, Switzerland) was then cut and bent, guided by the template, and fixed to the lateral wall of the sinus with a minimum of two 1.5-mm

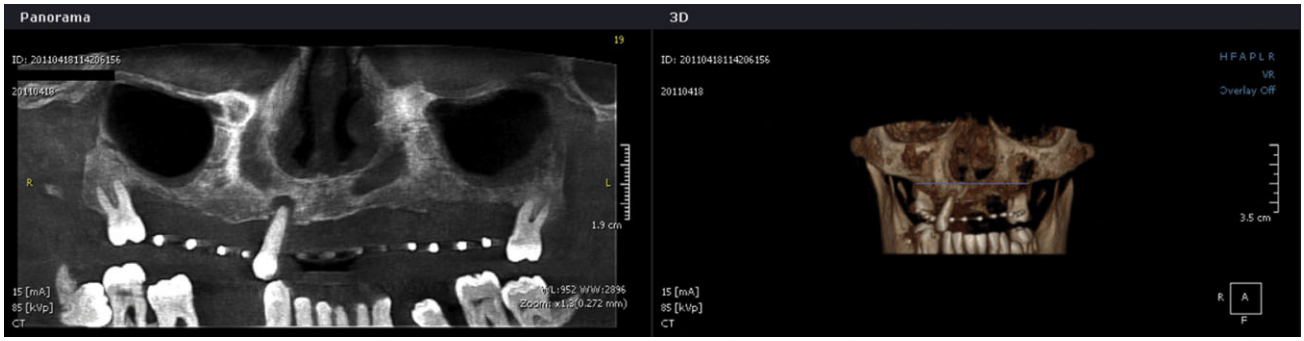

Figure 1 Reformatted panoramic view and reconstructed three-dimensional image from preoperative CBCT showing the radiopaque landmarks of the radiographic/surgical stent.

microscrews (Figure 4). Finally, the soft tissue flap was readapted and sutured.

Postoperative medications were prescribed as follows: amoxicillin/clavulanic acid tablet 1 g every 12 hours for 10 days, diclofenac potassium tablet 50 mg every 8 hours for 4 days, and then, as needed, systemic and local decongestants in the form of pseudoephedrine hydrochloride (HCL) 60 mg and oxymetazoline HCL 0.25% nasal drops every 8 hours for 1 week, and chlorhexidine gluconate 0.1% mouthwash three times daily for 14 days. Postoperative instructions were explained to the patients as follows: ice packs for 10 minutes every 30 minutes for 24 hours, strict oral hygiene measures in the form of regular use of toothbrush and antiseptic mouthwash starting the day after surgery, avoiding any positive or negative pressure on the nasal cavity (e.g., nose-blowing, drinking using straw, spitting, and breathing down) for the first 24 hours after the surgery.

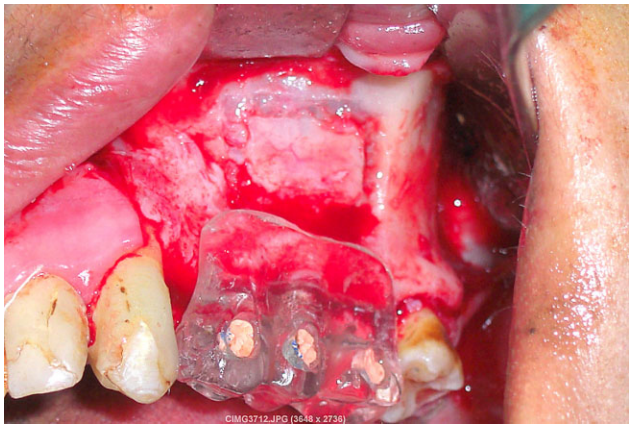

Figure 2 Rectangular osteotomy guided by the radiographic/surgical stent.

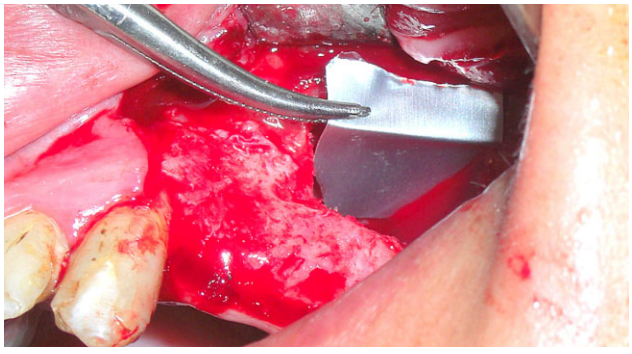

Figure 3 Foil template try-in.

Second-Stage Surgery. Dental implants were placed according to the surgical stent in a standard fashion (Figure 5). The implants were left submerged for 6 months before loading with fixed prostheses.

Clinical Follow-Up

Patients were evaluated at 3 days and weekly thereafter for the first month and then once monthly for signs of infection or dehiscence.

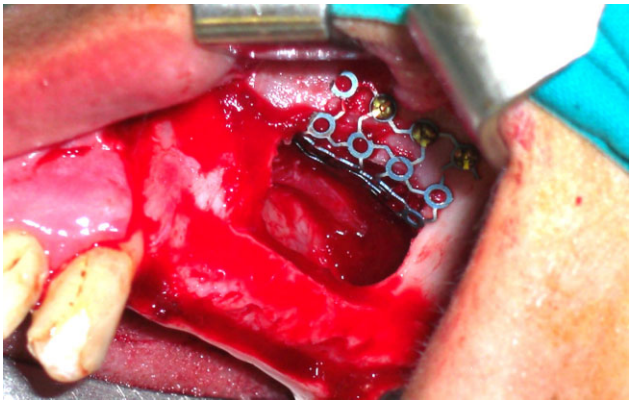

Figure 4 The titanium mesh fixed to the lateral wall of the sinus with microscrews.

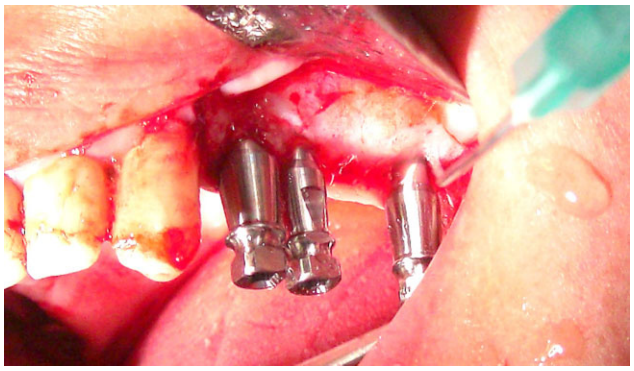

Figure 5 Implants installed in the alveolar ridge with the fixture mount transfer connected to it.

Radiographic Assessment

This was achieved by CBCT scan immediately and 6 months postoperatively to evaluate bone regeneration along the sinus floor; these, together with the preoperative CBCT, make a total of three scans for each patient. On the immediate postoperative CBCT, the residual bone height was measured. Other measurements were taken from the crest of the ridge on both the reformatted panoramic and the cross-sectional views to four reference points corresponding to the center of four mesh holes through which an arch curve was drawn on the axial maximum intensity projection (MIP) view (Figure 6). A mean was taken for each point; then, the mean of the four measurements was calculated for data analysis. Similar measurements, at the same four reference points, were taken from the 6 months CBCT from the crest of the ridge to the newly formed sinus floor.

Histological Assessment

At the time of implant placement, core biopsies were retrieved, guided by the same radiographic-surgical stent used in the first-stage surgery (Figure 7). The specimens were immediately fixed in 10% buffered formalin for 1 week, then decalcified and processed according to a standardized protocol Ethylenediaminetetraacetic acid (EDTA)-formic acid combination. Then, specimens were embedded longitudinally into paraffin blocks and oriented in a standardized way for labeling and differentiating the newly formed bone end from the native bone end. Blocks were cut into longitudinal 5 µm-thick sections using a manual rotary microtome (RM 2135 microtome, Leica, Heidelberger Straße, Nussloch, Germany) and stained with Mayer's hematoxylin and eosin stain (H&E) for histological analysis.

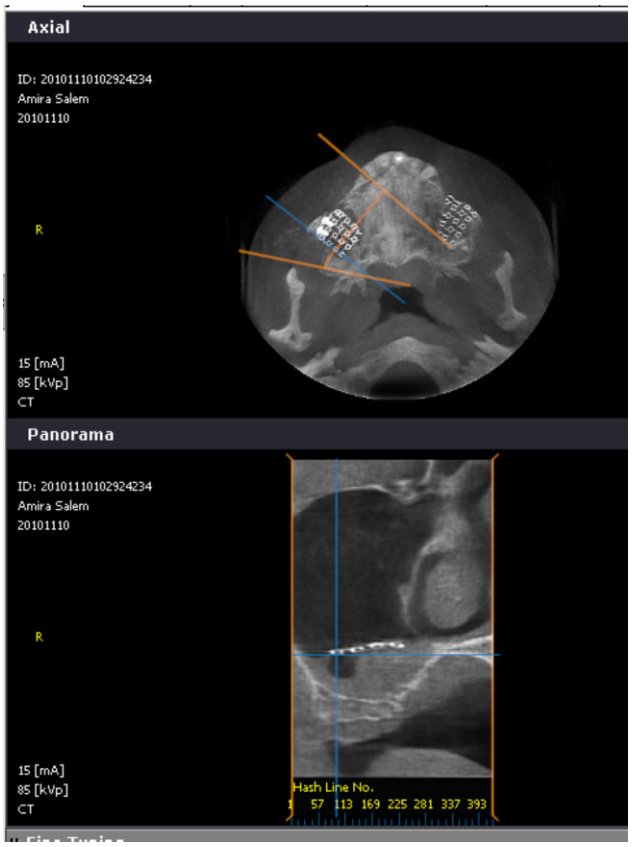

Figure 6 Reformatted MIP axial and panoramic view from the 6 months postoperative CBCT showing selected reference points, delineated by a line drawn passing through the center of the mesh holes.

Histomorphometric Analysis

All the stained sections were examined with an Olympus CX20 (Olympus, Shinjuku-ku, Tokyo, Japan) microscope attached to a camera and computer. For each of the native and newly formed bone specimens, the most representative five fields per specimen were captured using magnification (×100). Images of the slides were

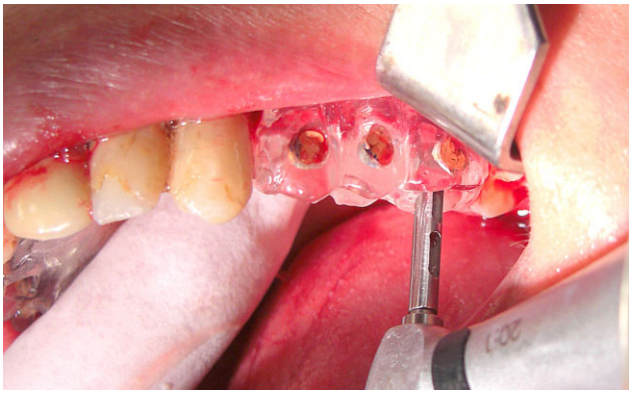

Figure 7 Retrieving the core biopsy guided by the stent.

taken and saved as figure files; the image analysis was done with an image analyzer computer system using the ImageJ software (v. 1.45e, National Institutes of Health, Bethesda, MD, USA).

The bone volume (bone area fraction) was measured for each image. For each sinus, the mean bone volumes of the native and newly formed bone were calculated for data analysis.

Statistical Analysis

Statistical analysis was performed using SPSS (v. 15, SPSS Inc., Chicago, IL, USA). Data were represented as mean ± standard deviation. A paired-sample *t*-test was used to compare each pair of the studied variables within the studied group of patients. The test result was considered statistically significant if the p value was equal to or less than 0.05.

RESULTS

The study comprised three men and one woman, with a total number of eight operated sinuses. Ages ranged from 18 to 54 years with a mean age of 37.75 years.

Clinical Findings

The membrane elevation and mesh fixation procedure went without any sinus membrane tears. At the second-stage surgery procedure, a total number of 16 implants were installed, with primary stability in all the operated sinuses. The postoperative follow-up course went uneventful for both first- and second-stage surgeries, without complications regarding infection, dehiscence, bleeding, and significant hematoma.

Radiographic Results

The immediate CBCT showed opacification below and around the mesh appearing in both the cross-sectional and panoramic cuts, which indicates the presence of a blood clot inside the created space (Figure 8). The 6 months postoperative CBCT showed considerable amounts of radiopacities indicating new bone formation (Figure 9). In some cuts the bone did not fill the whole volume below the mesh, creating voids. The line of demarcation between the newly formed bone and the native bone could be identified in almost all the examined cuts (Figure 10).

Bone Height. The immediate CBCT showed residual bone height ranging from 1.71 to 5.65 mm with a mean of 3.59 ± 1.64 mm; the immediate postoperative height beneath the mesh measured 11.3 to 15 mm with a mean of 13.14 mm, while the bone height after 6 months ranged from 7.11 to 12.08 mm with a mean of 9.63 ± 1.47 mm. The paired-sample *t*-test showed a significant increase in the bone height after 6 months ($p = 0.01$) (Figures 11 and 12) (Table 1).

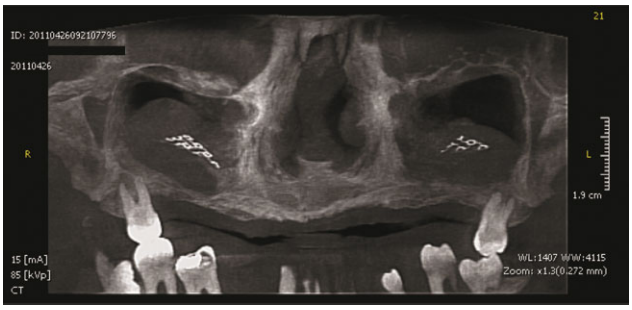

Figure 8 Reformatted panoramic view from immediate CBCT after the operation showing intrasinus hematoma surrounding the titanium mesh.

Histological Results

Clinical interpretation of the retrieved core biopsies showed that the color of the newly formed bone was coral pink, compared with the white color of the native bone (Figure 13). The length of the cores was almost of the same length estimated from the 6 months postoperative CBCT.

Histological interpretation for the native bone revealed the presence of mature trabecular bone with clearly seen lamellae surrounding moderately vascularized wide fatty marrow spaces; small amounts of inflammatory cells infiltration were seen in the marrow cavities. Moderate amounts of osteoblasts and small amounts of osteoclasts were present (Figure 14). The newly formed bone was mostly composed of interconnecting rods of

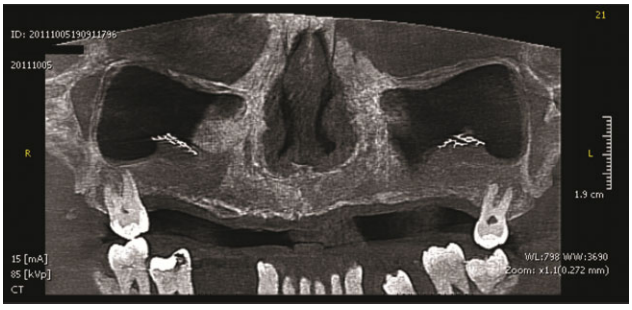

Figure 9 Reformatted panoramic view from the 6 months postoperative CBCT for the same patient as in Figure 8 showing new bone formation within the tented area.

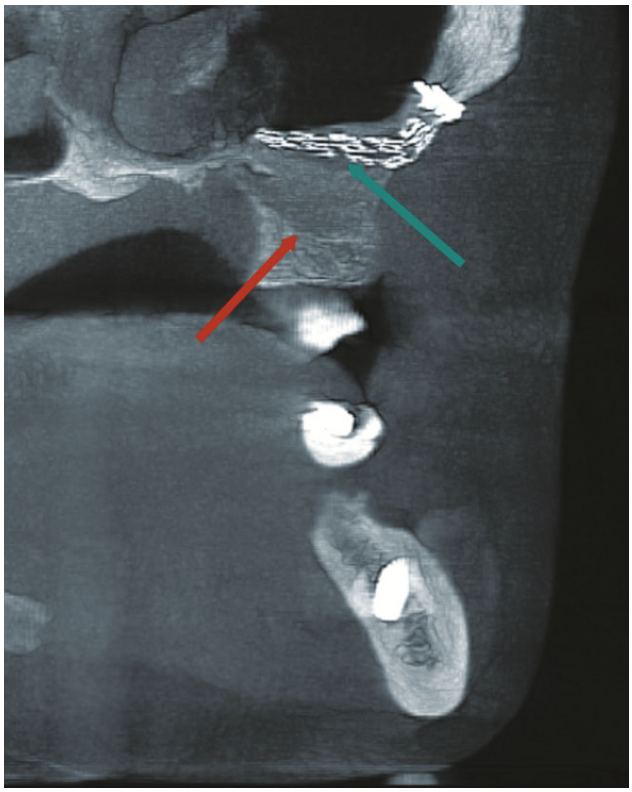

Figure 10 Reformatted cross-sectional view from the 6 months postoperative CBCT showing incomplete bone filling under the mesh (*green arrow*), and a line of demarcation between the native and the newly formed bone (*red arrow*).

woven bone showing haphazardly oriented collagen fibers interspersed in a background of extracellular matrix rich in newly formed blood vessels (angiogenesis) and newly formed collagen fibrils. Osteocytes were irregularly arranged within the bony matrix. Osteoblastic rimming could be seen delineating the marrow spaces. Small to moderate amounts of trabecular bone with clearly seen lamellae surrounding narrow marrow spaces were observed, with few inflammatory cells (Figure 15).

Histomorphometric Analysis

The bone volume of the native bone ranged from 18.31% to 41.85% with a mean value of 30.26% ± 9.13%, while the bone volume of the newly formed bone ranged from 32.30% to 69.93% with a mean value of 55.34% ± 11.36%. The paired-sample *t*-test showed significantly higher bone volume in the newly formed bone compared with the native bone ($p = 0.01$) (Table 2).

DISCUSSION

The present study confirmed the reliability of the osteogenic potential of nongrafted membrane-elevated sinuses. All the operated sinuses showed new bone regeneration without any filling material inside the sinus. However, we actually cannot compare the technique in the present study to the single-stage nongrafted sinus floor elevation techniques (tenting) because the reported thrombogenic effect of the surface-treated titanium might play an effective role in bone formation in the latter technique.[25,26] This could not be compared with the small area of the machined-surface titanium micromesh.

In the present study, the lateral window was quite large to ensure that the mesh covered all the area planned for implant insertion, contrary to the recommendation of Traxler and colleagues[27] to do a small-sized osteotomy to maintain the endosseous arterial anastomosis. However, the gained amount of bone was enough in terms of height and width for implant installation, with a length ranging from 10 to 14 mm and diameters of 3.7 and 4.8 mm.

Few other authors attempted a two-stage lateral-window sinus lift procedure without bone grafting. Cricchio and colleagues[28] designed a bioresorbable device in an experimental study. They considered the gained amount of bone to be disappointing, and reported membrane tears during device application. They also pointed to the large space occupied by the

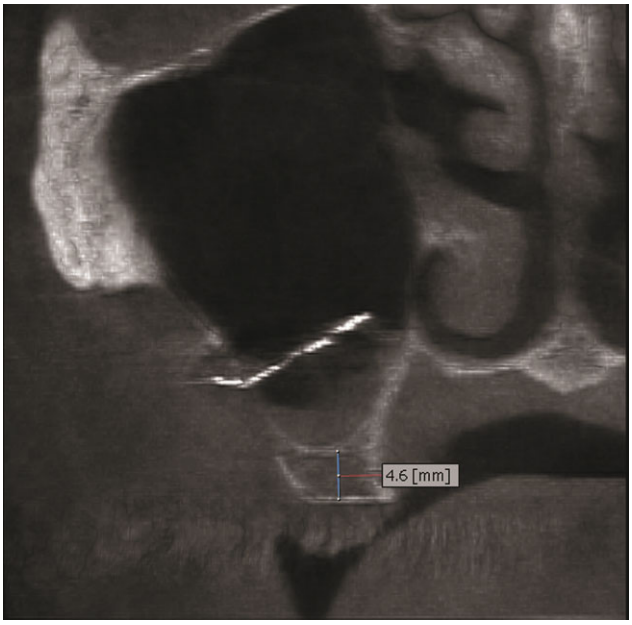

Figure 11 Reformatted cross-sectional view from the immediate postoperative CBCT of case (1), showing the distance between the crest of the ridge and the floor of the sinus.

TABLE 1 Mean Height of the Native Bone, Titanium Mesh from the Crest of the Ridge, and the Bone 6 Months Postoperative for Each Sinus (mm)

Patient (No.), Sex, Age (Years), Sinus Side	Preoperative – from Crest of the Ridge to the Sinus Floor (mm)	Immediate Postoperative – from Crest of the Ridge to the Titanium Mesh (mm)	Six Months Postoperative – from Crest of the Ridge to the New Sinus Floor (mm)
(1) F, 34			
R	4.4	14.5	10.37
L	5.65	15	10.26
(2) M, 54			
R	5.3	14.8	12.08
L	4.9	11.3	8.89
(3) M, 45			
R	2.65	11.5	7.11
L	2.35	12.2	10.33
(4) M, 18			
R	1.75	13.9	9.34
L	1.71	11.9	8.72

R, right; L, left; F, female; M, male.

device as a hindering factor to the reported osteogenic potential of the schneiderian membrane. Finally, they assumed that the material of the device might interfere with the changes occurring inside the sinus during the healing period. In another study by the same group, different shapes of polylactide space-making devices were used.[16] These devices, with their modified biomechanical properties, allowed for more bone formation and improved biological response. However, they suggested that these devices, lacking enough stabilization, might have negatively affected the osteogenic process. The dynamic titanium micromesh almost solved the previously mentioned problems. It showed excellent biocompatibility, offered simplicity during its shaping and application, and successfully maintained the created space without any noticeable changes in its position, as proven by the CBCT. Moreover, the holes of the mesh allowed direct contact between the blood clot in the created space and the schneiderian membrane with its reported osteogenic potential. Finally, the small volume the mesh occupied saved most of the gained height for placing the longest possible implant.

The question of the need to cover the osteotomy window with a membrane is still debatable. Many

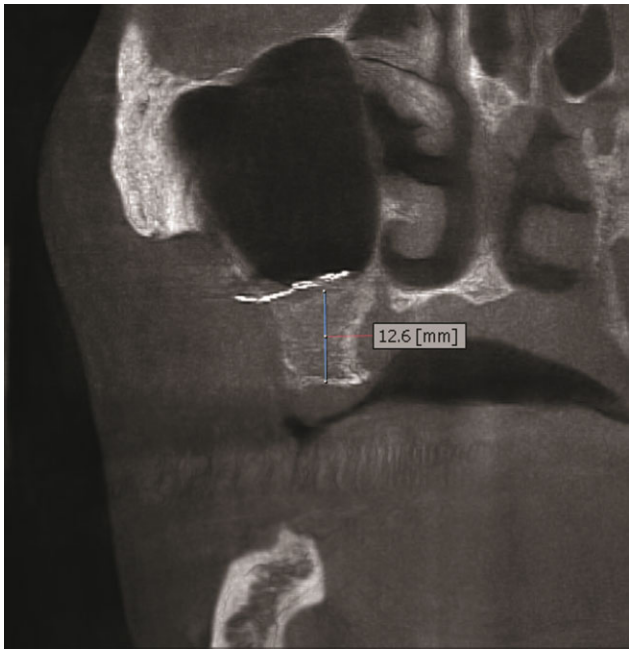

Figure 12 Reformatted cross-sectional view from the 6 months postoperative CBCT of case (1), showing the distance between the crest of the ridge and the new floor of the sinus at the same point as in Figure 11.

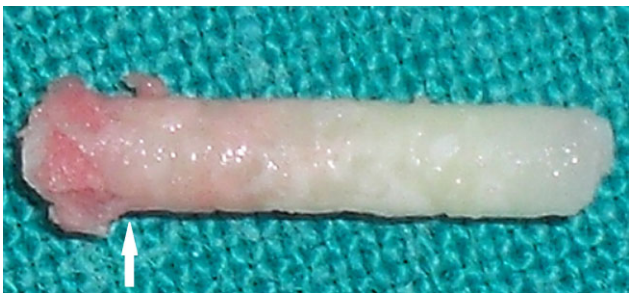

Figure 13 The retrieved core biopsy; the *arrow* is pointing toward the newly formed bone end.

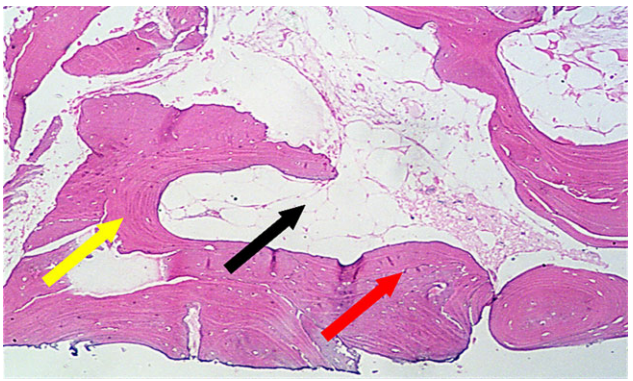

Figure 14 Photomicrograph of the native bone showing mature trabecular bone, clearly seen lamellae (*yellow arrows*), lacunae of osteocytes (*red arrows*), and fatty wide marrow spaces (*black arrows*) (H&E – ×100).

authors[29–32] prefer to cover the osteotomy to exclude nonosteogenic connective tissue infiltration and to prevent the escape of particulate graft materials. Few others support the hypothesis that there is no need for coverage.[33,34] In the present study, the lateral window was not covered with a membrane. This may give a chance for the periosteum of the flap to express its osteogenic effect directly on the coagulum inside the sinus.

The average increase in bone height in the present study was almost 6 mm, which is quite similar to the results of Thor and colleagues,[14] who reported an average bone gain of 6.5 mm in the nongrafted tenting technique. It should be mentioned that the average native bone height in the present study was 3.6 mm, while in Thor and colleagues' study it was 7.01 mm.

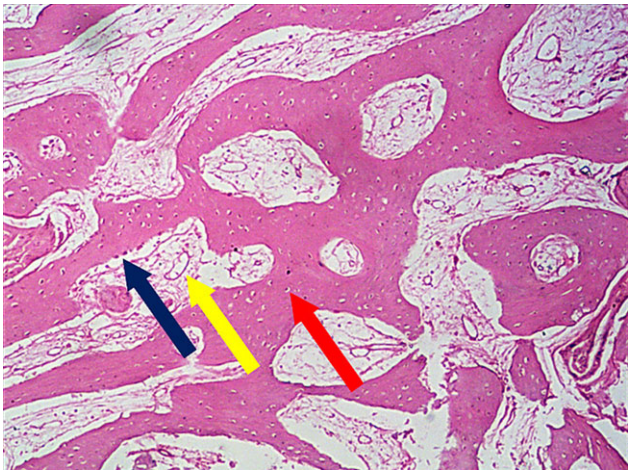

Figure 15 Photomicrograph of the newly formed bone showing interconnecting rods of immature bone, lacunae containing osteocytes (*red arrows*), angiogenesis (*yellow arrows*), and osteoblastic rimming (*blue arrow*) (H&E – ×100).

TABLE 2 Mean Bone Volume % (Bone Area Fraction) for Each Sinus

Patient (No.), Sex, Age (Years), Sinus Side	Native Bone (%)	Newly Formed Bone (%)
(1) F, 34		
R	37.11	55.15
L	31.24	58.36
(2) M, 54		
R	20.51	56.30
L	34.56	66.37
(3) M, 45		
R	41.85	69.93
L	37.75	55.43
(4) M, 18		
R	20.767	32.297
L	18.308	50.112

R, right; L, left; F, female; M, male.

Moreover, the effect of the surface-treated titanium implants should not be neglected. Comparing the immediate postoperative height of the created cavity below the mesh and the elevated schneiderian membrane to the 6 months postoperative bone height, it can be assumed that some volume shrinkage has taken place. These results are similar to those of Schweikert and colleagues, where seven of the eight titanium plates they used were found protruding into the sinus cavity, while the surgically created void under the elevated sinus membrane was reduced to 40.5% of its original volume after 6 months. However, the gained amount of bone was enough for implant placement in the required area below the mesh. During reviewing of the panoramic and cross-sectional cuts of the CBCT 6 months postoperative, it was observed that there was still a small gap between the mesh and the newly formed bone. The maximum bone gain was close to the medial wall of the sinus and gradually decreased toward the lateral osteotomy. More time may be required for bone to completely fill the created space under the mesh. Also, the process of implant placement itself is thought to stimulate more bone formation as assumed by Misch.[35]

Histological examination proved that the newly formed bone was mostly woven bone, which indicates that there is an active process of bone formation and maturation. This finding supports the suggestion

that more time is required to allow the new bone to mature into lamellar bone and completely fill the created space.

The mean bone volume within the newly formed bone in the current study was 55.34%, which is much superior to other research[36–39] studying various types of bone grafting and substituting materials. It also compares favorably with an average bone volume of 20% (range 5.2–29.2%) as reported by Johansson and colleagues in three patients; they used an HA device without bone grafting for two-stage sinus lifting. Our unexpected finding of having more bone volume in newly forming bone regenerate compared with the residual bone may be due to the inherent poor bone quality of the posterior maxilla, with its wide fatty marrow spaces.

The precise mechanism of new bone formation in the maxillary sinus after maintaining the elevated schneiderian membrane in place without grafting, either with mesh as in the present study or with implants (tenting), is not fully understood.[7–14]

It is generally accepted that the process of bone formation and healing necessitates the recruitment, migration, and differentiation of osteogenic cells into osteoblasts. The bone marrow constitutes the most powerful source of mesenchymal stem cells (MSCs), which have the power of transforming into osteoprogenitor cells. It is likely that MSCs could have migrated from the bone marrow in the underlying alveolar bone into the blood-filled sinus during surgery. Another suggested source of bone-forming cells is the periosteum of the lifted sinus membrane, and this goes in accordance with the findings of Srouji and colleagues[18,19] and Kim and colleagues,[29] which confirmed the presence of MSCs in human maxillary sinus membrane. Finally, the osteogenic layer of the periosteum covering the lateral window might also be a source of the osteogenic cells. It should be emphasized that bone regeneration might be a result of all the previously stated sources, but the most effective source for osteoprogenitor cells in nongrafted sinus floor elevation techniques cannot be identified yet.

The results of the present study raised some questions concerning the need for sinus grafting during sinus floor elevation procedures, as it seems that the quality of maintaining the created space under the schneiderian membrane is of much greater importance than the quality of the bone-substituting material.

CONCLUSION

The use of the titanium mesh as a space-maintaining device after schneiderian membrane elevation is a reliable and predictable technique to elevate the floor of the sinus without grafting. Prolonged sinus membrane elevation using the titanium micromesh induces new bone formation into the protected blood clot. Finally, studies with larger samples and longer follow-up are recommended to determine long-term stability of the newly formed bone.

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