Alternative Applications of Guided Surgery: Precise Outlining of the Lateral Window in Antral Sinus Bone Grafting

George A. Mandelaris, DDS, MS,* and Alan L. Rosenfeld, DDS†

Computed tomography (CT) and the application of CT-based guided implant surgery allow clinicians to provide enhanced precision and accuracy in implant surgery. Because of the difficulty in transferring a patient’s often complex anatomic sinus configurations, as viewed on a preoperative CT scan, into precise osteotomy cuts at antral bone graft surgery, a prototype cutting guide was developed. The surgical guide was developed through the use of CT imaging, SimPlant module Oral and Maxillofacial Surgery computer software, and the stereolithographic process to precisely position the lateral window, facilitating schneiderian membrane elevation. This report demonstrates the step-by-step method to perform precise guided sinus window preparation using computer software and a stereolithographically generated surgical guide.

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The lateral window approach to sinus augmentation was originally described in 1977 by Tatum1 and then in 1980 by Boyne and James.2 The goal of this procedure is to increase bone height and volume inferior to the maxillary sinus membrane to enable clinicians to subsequently place dental implants. The lateral approach to sinus augmentation is 1 of the most predictable regenerative surgical procedures performed in guided bone augmentation surgery, and implant survival is highly successful using a multitude of grafting materials.3-11

Imaging techniques, such as computed tomography (CT), are used to aid in the preoperative diagnosis. However, despite the significant improvements made in the availability of CT imaging, difficulty in precisely creating the sinus window remains, and osteotomies at the level of the sinus floor and lateral nasal walls can result in compromised membrane elevation. Inaccurate osteotomy cuts to define the lateral window can potentiate sinus membrane perforation, particularly when the membrane is thin and the anatomic environment is challenging, such as in the presence of septi. Although some perforations might be small and repairable, others can prompt the need to discontinue the surgery.12 The development of a method to enhance the accuracy of the antral sinus lift technique would possibly make the procedure more precise, more time efficient, and potentiate more predictable bone grafting outcomes.

The purpose of this article is to demonstrate a stereolithographically generated prototype cutting guide that facilitates precise osteotomy cuts that accurately define the lateral boundaries of the maxillary sinus. This technique uses 3-dimensional (3D) CT scan imaging and computer software to preoperatively outline the lateral boundaries of the maxillary sinus for antral bone grafting surgery. A case report demonstrating this novel approach has been previously published.13 Medical models and bone-supported cutting guides are created through stereolithography for guided and precise positioning of the lateral window. The cutting guide can be made separately or in combination with partially or totally guided stereolithographically generated CT surgical drilling guides. This report describes how the guide is created, presents a case report demonstrating its use from start to finish, and presents the combination guide for a completely and partially edentulous patient.
Creating a Cutting Guide for Precise Outlining of the Lateral Wall in Antral Sinus Bone Graft Surgery

The patient is referred for multislice spiral CT or cone-beam CT imaging of the maxilla. The Digital Imaging Communication in Medicine (DICOM) data are then formatted to a 3D computer software program (SimPlant Planner, Materialise Dental, Glen Burnie, MD) for diagnostic and treatment planning purposes. The study is then loaded in a different module of the Materialise SimPlant software, called SimPlant OMS (SimPlant Oral and Maxillofacial Surgery, Materialise Dental). This software allows virtual osteotomy cuts to be simulated in 3 dimensions for preoperative planning of oral and maxillofacial operations such as distraction surgery, Le Fort osteotomies, and sagittal split osteotomy techniques.

Once the OMS module is engaged, the following image screens will be viewable: axial, cephalometric, and sagittal and the 3-dimensional reconstruction. The 3D reconstruction is selected and should be viewed in the full screen mode. It can then be enlarged using the zoom function and rotated so the sinus is viewed straight on. The transparency toggle switch is now selected. The transparency tool allows the lateral sinus boundaries to be identified. Next, the start “osteotomy wizard tool” is selected under the “plan surgery” menu. Multiple osteotomy types can be selected for cutting path simulation. For the purpose of creating this cutting guide, “the custom freeform” osteotomy type is selected, which allows the surgeon to...
define multiple osteotomies through points on a surface. The 3D bone object is chosen as the cutting object, and a pen appears when the cursor is brought into the 3D screen. The pen can be used to locate custom, freeform cutting paths (identified as “CP” on the screen) with left mouse clicks in the 3D window. Once the desired cutting path has been created, double click to end. The finished cutting path will be visualized and free-form dimensions identified in millimeters (including the depth of the cut, the thickness of the cut, and the extension front and extension end). These dimensions can be modified, if desired. The cutting path can also be automatically calculated/closed (ie, creating the superior boundary) by checking the appropriate box, and the planned cutting path for the lateral window preparation will be simulated in the 3D reconstruction. The cutting paths can be verified in all planes of space to ensure that the planned osteotomy cuts will maximize the operator’s ability to begin schneiderian membrane reflection directly on the remaining antral bony walls, to ensure the septi are identified accurately, and to ensure that the anterior border has been defined.

After the planned cutting paths are outlined, the plan is sent by electronic mail to Materialise Dental, where a medical model is rapid prototyped using stereolithography. An acrylic bone supported cutting guide is then created. The cutting guide defines the precise location of the desired superior cutting path as outlined using the software, as well as the inferior, mesial, and distal boundaries of the previously outlined lateral window using the preoperative plan. In the simultaneous approach, 1 guide can be fabricated to outline the sinus window osteotomy and also guide implant placement, or 2 separate guides can be made.
for independent preparation of the lateral window and subsequent guided implant placement. The cutting guides remain on the bone surface during outlining of the lateral window. Outlining can be performed using conventional burs for sinus window creation or using piezosurgery inserts. The following case report illustrates this method.

Case Report

The patient was a 54-year-old woman who presented with a bridge from the right maxillary second molar to first premolar in need of replacement. The patient desired an implant-supported fixed restoration with individual teeth. The first molar and second premolar had been missing for several years. Vertical bone height deficiency was present in these areas, necessitating vertical bone augmentation using sinus grafting (Figs 1, 2). Mounted models were obtained, and a diagnostic wax-up was performed to define the prosthetically directed, optimal final tooth position for the first molar and second premolar.

A scanning appliance was fabricated with barium sulfate painted over the occlusal aspect of the diagnostic setup to fit over the provisional bridge. The patient was referred for multislice spiral CT imaging of the maxilla. The scan was formatted to a computer software program (SimPlant Planner; Materialise Dental, Glen Burnie, MD) for diagnostic and treatment planning. Figures 3 and 4 show the cross-sectional

*FIGURE 9.* Bone-supported cutting guide in place, defining desired superior boundary.

*FIGURE 10.* Bone-supported cutting guide in place after lateral window outlining and identification of membrane just before reflection. Anterior, distal, inferior, and posterior lateral wall boundaries are observed. Note, distal aspect of guide has been modified at surgery to enable complete seating intraoperatively.

*FIGURE 11.* Bone-supported cutting guide removed, and sinus bone grafting accomplished after verifying uneventful membrane reflection. Simultaneous implant placement performed manually.

*FIGURE 12.* Direct postoperative radiograph demonstrating complete fill of bone graft at planned anterior portion of antrum (arrow).
and 3D images demonstrating inadequate bone availability to accommodate implant placement.

The cutting paths were defined, and the creation of a bone-supported cutting guide was generated as described (Figs 5-8). A traditional sinus window operation was performed. After full-thickness flap reflection and exposure of the lateral aspect of the maxilla, the bone supported cutting guides were fitted to the underlying bone and verified for stability. The guides were then used to outline the desired, preoperatively planned, configuration of the lateral wall (Figs 9, 10). To fully seat the guide to facilitate defining the inferior cutting paths, the distal aspect of the guide was modified to allow for passive seating on the bone (Fig 10). The lateral window was created using the cutting guide to locate the desired osteotomies. The anterior and inferior boundaries were, in particular, well defined by the cutting guide as planned and outlined by the software. This allowed for more predictable Schneiderian membrane reflection because the reflection was performed precisely on the bone after the boundaries of the lateral window had been accurately identified. The sinus membrane was then easily elevated, because the bone cuts were made at the level of the sinus floor.

After uneventful membrane elevation, bone grafting using a mineralized freeze-dried bone allograft
enhanced with platelet-rich plasma was performed simultaneously with osteotomy site preparation and implant placement (Figs 11, 12). A collagen membrane was then placed over the lateral window, and the incisions were closed.

Discussion

The anatomic orientation of the maxillary sinus is often complex and can be misleading to the surgeon, resulting in inaccurate identification of the lateral wall. Common complications with the sinus bone graft technique include bleeding, membrane perforation, septa, osteomeatal complex obstruction, alveolar ridge fracture, and damage to adjacent teeth. Arguably, the most common of these is membrane perforation. Perforation can result from uncontrolled reflection of the membrane, rather than from remaining in contact with the antral walls. Sinus membrane perforation can lead to a greater incidence of sinus bone graft complications and might lead to poorer bone healing, even without overt clinical signs of postoperative bacterial infection. In general, Schneiderian membrane tears of any magnitude have the potential to increase the risk of postoperative infection and reduce overall graft success. To some degree, tears can be traced back to operator inaccuracy in lateral window positioning, because precise determination of its boundaries are, for the most part, entirely intuitive.

At present, CT-based guided technology does not provide the surgeon with a method to identify and transfer the patient’s, often complex, anatomic con-

FIGURE 17. Three-dimensional reconstruction of maxilla (right side) in SimPlant OMS software and custom freeform cutting path outlining desired maxillary right lateral window position (red arrows).

FIGURE 18. Medical model of maxilla with combination bone-supported cutting guide (SAFE SurgiGuide) for completely edentulous patient.

FIGURE 19. SAFE SurgiGuide system with defined cutting guide outlining anterior, inferior, and distal extent of desired lateral window boundary defined for the maxillary right side.

FIGURE 20. SAFE SurgiGuide system with defined cutting guide outlining anterior, inferior, and distal extent of desired lateral window boundary defined for the maxillary left side.
figurations, as viewed on the preoperative CT scan, into precise osteotomy cuts for lateral window preparation. Transillumination is a common modality used to define the sinus boundaries, but it is not accurate and is not effective in guiding the surgeon to create a precise outline, particularly when important and often misleading anatomic configurations are present in the maxillary skeleton. Furthermore, it does not consider septi and other 3-dimensionally significant anatomic features (Fig 13). The method we have demonstrated uses computer-generated surgical drilling guides that are fabricated using stereolithography and a computer software program that interfaces with the patient’s CT scan.\(^\text{17-19}\) The prototype guide incorporates a different planning module that allows for osteotomy cuts that will precisely position the lateral window according to the 3D imaging and preoperative planning.

To date, we have performed 8 sinus bone graft operations using these prototype cutting guides to facilitate the precise position of the lateral wall. Of the 8 sinus grafts performed, 4 have been exclusively bone-supported cutting guides and 4 have been combination guides in which the inferior and anterior sinus boundaries were combined with the surgical guide used for guided implant placement. Of the 4 combination guides, 2 were tooth-bone supported and 2 were exclusively bone supported. All the cutting guides produced osteotomy cuts that were within 1 mm of the osteotomy sites planned using the CT software module, clinically validating the accuracy of this prototype guide.

Figures 14 to 20 demonstrate the 3D implant and cutting path plan and the stereolithographically generated combination bone-supported SAFE SurgiGuide...
position, the distal and superior boundaries could be identified as the lateral wall. Once the guides were in position, osteotomies were the most helpful in precisely determining the lateral wall. Lithographic cutting guides have demonstrated that the anterior and inferior borders of the antral wall in an edentulous patient, for whom totally guided implant surgery was planned in conjunction with precise outlining of the lateral wall to facilitate simultaneous bilateral sinus augmentation.

Figures 21 to 25 demonstrate the 3D implant and cutting path plan and stereolithographically generated combination, unilateral, tooth-bone supported Navigator (BioMet 3i, Implant Innovations, Palm Beach Gardens, FL) SurgiGuide for a partially edentulous patient. In all cases in which these guides were used, no clinical evidence of sinus membrane perforation was found.

The cutting guides fit extremely well to the anatomic environment and accurately identified the boundaries that were planned preoperatively. Membrane reflection was predictably initiated directly off the remaining inferior and anterior antral walls without sequelae. Perhaps the most practical use of this type of guide would be in the largely pneumatized sinus with aberrant bony morphology. In these situations, confirmation of complete seating and stability of the bone-supported stereolithographic guides will be more predictable, because more surface area is involved for support. The cutting paths and stereolithographic cutting guides defined the mesial, inferior, distal, and superior borders of the antral wall in the initial plan. Our surgical experience using these guides has demonstrated that the anterior and inferior osteotomies were the most helpful in precisely identifying the lateral wall. Once the guides were in position, the distal and superior boundaries could be positioned manually. The superior and distal components to this guide were also difficult to seat. Using only the anterior and inferior aspects did not present problems with fitting the guides to the bone.

References