

Prevalence of Sinus Augmentation Associated with Maxillary Posterior Implants

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Dedication

This thesis is dedicated to my fiancé, Dorothy Skalny, who has supported and encouraged me throughout this challenging residency, my Mom Irena, Dad Bogdan, my sister Aleksandra and all of my family who have been there for me throughout my life and academic career to support, love and encourage me.

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Abstract

Statement of problem. Pneumatization of the maxillary sinus limits the quantity of alveolar bone available for implant placement and may result in a lack of primary stability and difficulty in achieving osseointegration.

Purpose. The purpose of this study was to retrospectively analyze a cohort of patients who had implants placed in the posterior maxilla and calculate the prevalence of sinus augmentation and identify factors associated with it.

Material and methods. With IRB approval, dental records from a population of patients who had implants placed in the maxillary posterior region, between January 2000 and December 2004, were used to create a data base. Independent variables were divided into continuous (age of the patient at stage 1 implant surgery (S1), time between the extraction and S1, time between the extraction and sinus augmentation, time between the sinus augmentation and S1) and categorical (gender, implant failure, American Society of Anesthesiologists system classification, smoking, osteoporosis, residual crestal bone height, implant position, implant proximity, prostheses type, and implant diameter and length). The dependent variable was the incidence of a sinus augmentation procedure. Simple logistic regression was used to assess the influence of each of the factors on the presence of sinus augmentation ($P<.05$).

Results. The final database included 502 maxillary posterior implants with an overall survival rate of 93.2% over a mean follow-up period of 35.7 months. Of 502 implants, 272 (54.2%) implants were associated with a sinus augmentation procedure. Among variables, residual crestal bone height ($P<.001$), implant position ($P<.001$), implant

proximity ($P<.001$), prosthesis type ($P<.001$), implant failure ($P<.01$), and implant diameter ($P<.01$), were statistically associated with sinus augmentation.

Conclusions. Within the limitations of this retrospective study, the results suggest that more than half (54.2%) of the maxillary posterior implants were involved with a sinus augmentation procedure. The prevalence of sinus augmentation increased with decreased residual crestal bone height, more posterior implant locations, and complete or partial edentulism. Sinus augmentation was significantly associated with implant failure and wide implants.

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Chapter 1. Introduction

Applications for the use of endosseous dental implants have expanded for partially and completely edentulous patients, including those with severely resorbed and atrophic residual ridges.¹⁻³ Clinicians considering implant reconstruction of the edentulous posterior maxilla have to account for several anatomic challenges, particularly the maxillary sinus.^{2,4-8} The maxillary sinus is a pyramidal-shaped air and resonance chamber located within the body of the maxilla. It averages 36 to 45 mm in height, 25 to 35 mm in width, and 38 to 45 mm in length anterior-posteriorly, and the floor may extend between the roots of the maxillary molars.⁹

Being the largest of the 4 paranasal sinuses, the maxillary sinus grows progressively as the skull matures; however, the presence of teeth prohibits the inferior growth of the sinus.^{10,11} When teeth are lost, the sinus usually expands inferiorly at the expense of the surrounding bone.¹⁰⁻¹³ Pneumatization or enlargement of the maxillary sinus limits the quantity of alveolar bone available for implant placement and may result in a lack of primary stability and difficulty in achieving osseointegration.^{1,2,5,7,14-19} Augmentation of the maxillary sinus has become a routine treatment option for the atrophic posterior maxilla allowing the placement of implants using either simultaneous or staged procedures.^{20,21} Although the challenges are great, sinus augmentation procedures have been shown to have predictable implant survival rates greater than 90% over 3 to 5 years.^{15,22-25}

When the pretreatment bone height is less than 10 mm, adequate stabilization of implants may not be possible with conventional implant surgical techniques.^{10,26} By

surgically increasing the alveolar height, a bony foundation can be established to permit the placement of implants for prosthetic reconstruction.^{15,27-29} Although pretreatment bone height is frequently the primary predictor for determining the surgical technique that will be used to modify and reduce the sinus cavity,^{21,30,31} the decision as to which bone augmentation technique is used can be affected by host factors, surgical experience, and clinical traditions.^{8,15,30-34}

The most common technique for sinus floor elevation is the antrostomy, first published in 1980²⁷ with a crestal approach¹⁶ and later access was achieved through the lateral wall of the maxilla.³⁵ This can be done as either a 1-stage technique³⁶ where the augmentation and implant placement occur simultaneously or as a 2-stage technique where the graft material is allowed to mature and implant placement is delayed.^{8,22,37,38} Authors have noted that a minimum of 3 to 6 mm of residual crestal bone height is needed to consider the 1-stage technique,^{8,15,33,35,38-41} otherwise, the 2-stage technique is recommended since primary stabilization cannot be assured.^{8,24,31,40} Simultaneous augmentation and implant placement minimizes the cost and number of surgical procedures for the patient and allows for earlier loading.^{2,22,35} On the other hand, a delayed approach allows for primary stabilization due to graft maturation, and it may be more predictable and result in more ideal implant positions.^{14,22,24,29,37,41-44}

The osteotome technique is a less invasive alternative for sinus augmentation that also allows for simultaneous grafting and implant placement.^{45,46} Concave tipped with a sharpened edge, tapered Summers[®]⁴⁵ osteotomes are used to expand the osteotomy both horizontally and vertically while cutting, compressing, and deforming the bone to

facilitate the placement of implants.^{45,47} This can be done with or without the addition of allograft material to achieve apical displacement of the sinus floor.^{45,47} Although the osteotome technique has a narrower range of indications and can be uncomfortable for the patient,³⁰ it conserves osseous tissue and allows implants to be placed in a greater variety of sites.⁴⁵

Regardless of the incidence of sinus augmentation, the posterior maxilla is known to have a thin bony cortex with poor medullary strength and low trabecular density.^{14,48,49} This poor quality of bone has been associated with increased implant failure rates attributed to this insufficient cortex for implant stabilization.^{6,32,48-55} The principles of osseointegration require that there is vital bone tissue with cells capable of connecting to the implant surface.⁵⁶ Rehabilitation of the oral cavity with implants has been shown to be successful and predictable in patients with normal bone volume and density where implants of a standard diameter and length can achieve initial stabilization.⁵⁷

The Wellesley Sinus Consensus Conference of 1996 concluded that a 90% success rate can be expected from implants placed in association with sinus augmentation within 3 to 5 years of function.²² They reported that sinus augmentation should be considered a highly predictable and effective therapeutic modality.²² While Carr⁵⁸ found that implants in augmented sites are 5 times more likely to fail than those placed in sites that did not require augmentation, several studies have found failure rates to be comparable.^{2,37} There also appears to be a correlation between the success of the bone graft and the success of the implant.^{23,43,59}

The posterior maxilla presents with a unique set of anatomic challenges for implant placement and survival due to the structural characteristics of the bone and pneumatization of the sinus. Since dental implants have become a routine treatment option for the replacement of missing teeth, the need to assess of the prevalence of sinus augmentation and identify factors associated with it is indicated. No previous research was found analyzing multiple continuous and categorical variables associated with sinus augmentation and implant therapy in the posterior maxilla.

The specific aim of this study was to retrospectively analyze a cohort of patients who had implants placed in the posterior maxilla, at the University of Minnesota, School of Dentistry, and assess the prevalence of sinus augmentation and identify factors associated with it. The null hypothesis was that none of the variables are associated with the prevalence of maxillary sinus augmentation.

Chapter 2. Literature Review

2.1 History of Implants in Pneumatized Maxilla

With the advent of blade implants, pioneer implantologists began pushing the envelope by not limiting their osteotomies to bone but rather encroaching onto the maxillary sinus and the Schneiderian membrane. Until this time the sinus has been considered a vital structure not conducive to bone grafting. Both Linkow⁶⁰ and Vassos⁶¹ purposely blunted the Bladevent implant and thus was able to push it into the sinus and elevate the membrane higher into the sinus. Geiger⁶² perforated the maxillary sinus when he placed his ceramic implants. After 3 months of integration, he reported that they were firmly fixed in bone. Branemark⁶ and Adel⁶ placed 44 dental implants into the maxillary sinuses and intentionally perforated the sinus membrane. Their study indicated that osseointegration can occur despite a perforated sinus membrane; however, the survival rate for these implants was a less than desirable at 70%. Tatum¹⁶ performed some of the first subantral procedures using autogenous iliac crest and rib bone while Smiler⁸ has reported on the use of non-resorbable grafting material in conjunction with implant placement. It is interesting to note that sinus membrane elevation may naturally occur around teeth with periapical pathology, with simultaneous bone formation below it. This relevant phenomenon, termed “halo formation”, shows that the sinus membrane has properties very similar to periosteum and can deposit bone under various stimuli.¹⁰

2.2 Anatomy

2.2.1 Maxillary Sinus Development

The maxillary sinus was illustrated as early as 1489 by Leonardo da Vinci.⁶³ Being the largest of the 4 paranasal sinuses, the maxillary sinus is only several millimeters in diameter at birth and continuously enlarges with the growth of the skull. As the sinus expands, it occupies the alveolar bone formerly supporting the developing dentition. Once skeletal growth nears completion at 16 to 18 years of age and with the eruption of the third molars, the mature sinus takes on a pyramidal-shape with volume and size dictated by the degree of outward growth.⁸ On average the adult sinus has a volume of 15 ml.¹⁰ The size and shape of the sinus is a key determinant of facial architecture. Smiler⁸ describes the purpose of the sinus is to warm cold air before it enters the lungs, and to modulate the sound of voice. This is supported by the extensive vascularization that occurs in the sinus which indicates a high rate of blood flow through this structure.

Although the size and shape of the sinus is well preserved while the teeth are present, outward expansion of the sinus begins rapidly following the loss of a tooth.^{10,64}

2.2.2 Microscopic Anatomy

The epithelial lining of the maxillary sinus consists of pseudostratified, ciliated columnar epithelium; however, unlike the nasal mucosa, the membranes within the sinus exhibit fewer blood vessels giving the sinus its characteristic pale blue hue.^{8,64} Also, unlike the mucoperiosteum of the oral cavity that lines the alveolar ridges, the periosteal

portion of the sinus membrane differs by featuring decreased numbers of osteoblasts and increased numbers of osteoclasts. This may be the contributing factor to the rapid bone loss following tooth loss. The sinus also features a decreased distribution of elastic fibers within the periosteum. This facilitates its separation and elevation off the floor of the sinus during sinus lift procedures.^{10,64}

2.2.3 Maxillary Sinus Mucous Clearance

Up to 200 cilia per cell propel nearly 1 liter of mucus, produced from serous and goblet cells, towards the ostium.^{8,22} The sticky mucoid layer is exposed to the air within the sinus. It traps bacteria and other debris and is mobile thanks to the lubricating action of the serous layer underneath. This mucociliary clearance mechanism along with a production of nitrous oxide within the sinus has been cause for the belief in the sterile state of healthy maxillary sinuses.

2.2.4 Maxillary Sinus Bacterial Flora

Endoscopic evaluations have invalidated long held beliefs that maxillary sinuses were sterile in health.²² Up to 62.3 % of the sinuses examined exhibited bacterial colonization with cultures of *Streptococcus viridans*, *Staphylococcus epidermis*, *Streptococcus pneumoniae*, *Streptococcus viridans*, *Staphylococcus epidermis*, and *Streptococcus pneumoniae*, yet were completely asymptomatic.^{65,66}

Bacterial colonization can become detrimental to the sinus lift procedure. If a perforation occurs in the membrane during its manipulation, bacterial contamination of the graft site can occur leading to a failure of the bone graft.⁶⁴

2.3 Grafting Materials

A variety of materials can be used to graft the maxillary sinus. Grafting with autogenous bone yields high success rates and is often used as a baseline for the comparison of other grafting materials.^{7,19,23} The absolute biocompatibility of autogenous bone avoids the problems with graft rejection within the sinus, and exhibits osteoconductive and osteoinductive properties and vital osteogenic cells.¹⁹ The process of osteoconduction focuses on the grafts intrinsic ability to act as a framework for the ingrowth of all new bone cells and capillaries. This process contrasts osteoinduction where growth factors, chemical mediators and bone morphogenic proteins in their varying concentrations, control and direct the formation of new bone directly from the graft material itself.²²

The regions most associated with autogenous bone harvesting include the symphysis of the mandible, the anterior iliac crest, the maxillary tuberosity, the external oblique ridge of the mandible and the calvarium.²³

Frequently, the reconstruction of large osseous defects requires large amounts of bone graft material. Obtaining such quantities as is often required for a bilateral sinus graft, may not always be possible. The patient may not be able or wish to undergo complex surgery, since it necessitates a second surgical donor site, increases cost and

surgical time and is associated with donor site morbidity.^{19,67} This has led researchers to consider alternate grafting materials including allografts; materials derived from the same species however with a different genetic composition, xenografts; materials derived from a different species and alloplastic materials; inorganic materials such as metal, ceramic or plastic which are biocompatible, with varying degrees of success.^{19,24}

Hydroxyapatite is available in resorbable and non-resorbable forms and has been used in combination with other grafting materials.^{7,23} This naturally occurring biocompatible mineral is porous and serves as an osteoconductive framework for bone ingrowth; however, unlike autogenous bone, it does not contain any osteoinductive progenitor cells.²³

Composite bone grafts consisting of 50% autogenous bone and either 50% xenograft or 50% demineralized freeze dried bone allograft promote predictable bone formation without the need for harvesting significant amounts of bone. Allogenic grafts and xenografts act solely as a scaffold for osteoinduction. The use of at least 50% autogenous bone and the large volume of host bone made available as a result of the surgical approach promoted a more predictable second phase of bone formation within this scaffold as the graft was gradually replaced.⁶⁸

2.4 1-Stage vs. 2-Stage Implant Placement

Deciding whether to place implants simultaneously with the sinus augmentation procedure or separately from the grafting procedure is a decision that demands a structured approach on an individual patient basis.²²

Implant placement may be classified as delayed or immediate.¹⁵ This classification is based on the timing of implant placement with respect to the timing of the sinus augmentation. Sinus augmentation performed in conjunction with implant placement at the time of the surgery is termed immediate implant placement, or 1-stage, while implant placement performed via a separate surgery from the initial sinus graft is termed delayed implant placement, or 2-stage implant placement.^{15,33,31} The primary deciding factor for choosing between these procedures is initial implant stability. Although the 1-stage procedure saves time and the need for a second surgery, a minimum of 4 mm of crestal bone is required to stabilize an implant in the maxilla.¹ Advocates of immediate implant placement also favor this technique as it is less invasive and doesn't require a second surgery.^{15,33,31}

In situations where the pneumatization and bone resorption have proceeded to such an extent that less than 4 mm is available, the thin crestal bone would be unsuitable to initially stabilize the implant.^{8,15,33} In these situations, the sinus is elevated, grafted, and allowed to heal for 6 to 18 months.³⁰ Following adequate integration and maturation of the bone graft, an osteotomy is made through the ridge crest and the implants are placed.^{15,30,31} Although the treatment time is extended, this 2-stage procedure allows the surgeon to focus on placing the implants in a prosthetically favorable position rather than compromise the angulation due to anatomic restrictions.^{22,44} When immediate implant placement can not be accomplished due to a perforation in the sinus membrane, or poor quality bone, the surgeon has no choice but to proceed with the delayed 2-stage approach.

Wannfors³⁴ and Blomqvist⁴⁴ noted that while the 1-stage procedure was favorable in terms of treatment time, it required a more frequent use of angled abutments to correct the angulations of mal-positioned implants and doubled the individual risk for implant failure as compared to a 2-stage procedure. A common mistake is to place the implants too palatally, mainly due to an undeveloped implant site.⁴⁴

Ultimately, the operators own preferences, experiences, and patient factors, contribute towards an educated decision making process in which the appropriate technique is determined.^{10,22,44}

2.5 Maxillary Sinus Grafting Techniques

Studies of orthodontically intruded maxillary posterior teeth have shown reactive bone formation in the antral floor.²⁷ Even though the roots of these intruded teeth and the floor of the sinus were several millimeters apart, it was found that it was possible to stimulate bone formation under the Schneiderian membrane by applying a force in the direction of the sinus.²⁷ These early studies paved the way for surgeons to attempt grafting and augmenting the floor of the maxillary sinus.

Contemporary sinus augmentation procedures are still technique sensitive and rely heavily on the surgical experience of the surgeon. A sound understanding of prosthodontic principles is essential for surgeons to augment the sinus, place the implants parallel to the axial forces, and load the bone in a timely fashion to minimize bone resorption.²²

Early attempts at augmenting the vertical residual ridge height were achieved by a full-arch iliac crest graft.³⁴ Unfortunately, there were problems associated with this procedure, such as wound dehiscence, prosthetic challenges and an uncertain prognosis. As a result, attempts were made to place the bone in a more protected environment.³⁴ This was some of the pioneering work that was the basis for the sinus augmentation procedures that we perform today.

2.5.1 LeFort I

Early attempts at reconstructing the severely resorbed maxilla have led clinicians to attempt the Lefort I technique.^{24,27} The LeFort technique is a down fracture of the maxilla with a simultaneous interposition of bone grafting material.²⁴ A thin bone block is positioned between the 2 split segments and fixed into position in a sandwich fashion.³⁴ This aggressive procedure suffers from post-operative morbidity which limits its implementation.¹⁴ A decrease in interarch space results following this procedure; therefore, it should be limited to cases with adequate vertical space for restorative materials or cases with a skeletal Class III jaw relationship.^{14,24,27,34}

2.5.2 Lateral Approach

First described in 1980 by Boyne,²⁷ and James²⁷ the lateral antrostomy technique has had few changes and is used widely by clinicians to this day. Being able to access and visualize the sinus and associated vital structures of the sinus is of utmost importance in achieving successful graft integration.

After an initial incision, a full thickness muco-periosteal flap is reflected exposing the entire lateral wall of the maxillary sinus.^{16,23} A rotary instrument is then utilized to create a thin bony window, on the lateral wall, taking extreme care not to penetrate the bone and thus perforate the membrane (Figure 1).^{16,23,28} A series of score marks are then made on the periphery of the bony window at which time it is infractured medially and superiorly by hinging on its superior margin (Figure 2).^{1,23,28}

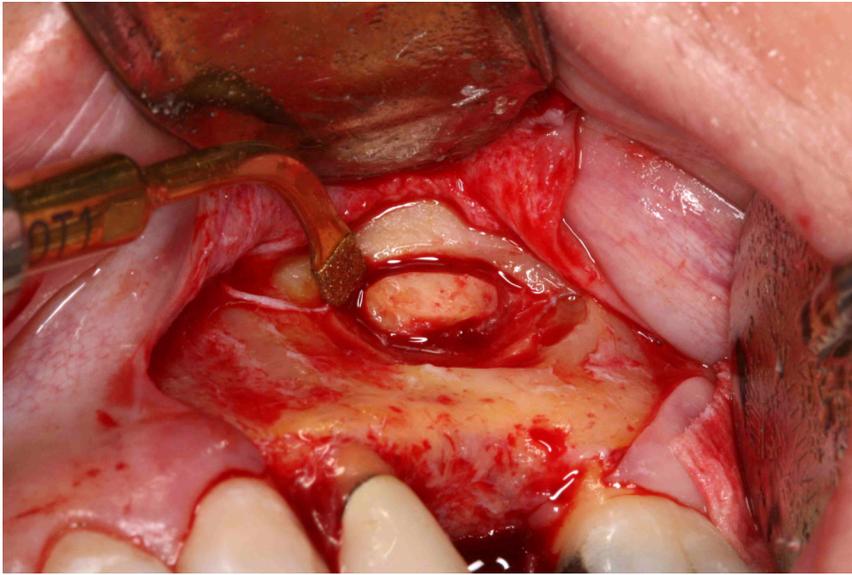


Figure 1. Lateral Window Technique I. The outline of the bony window has been delineated.

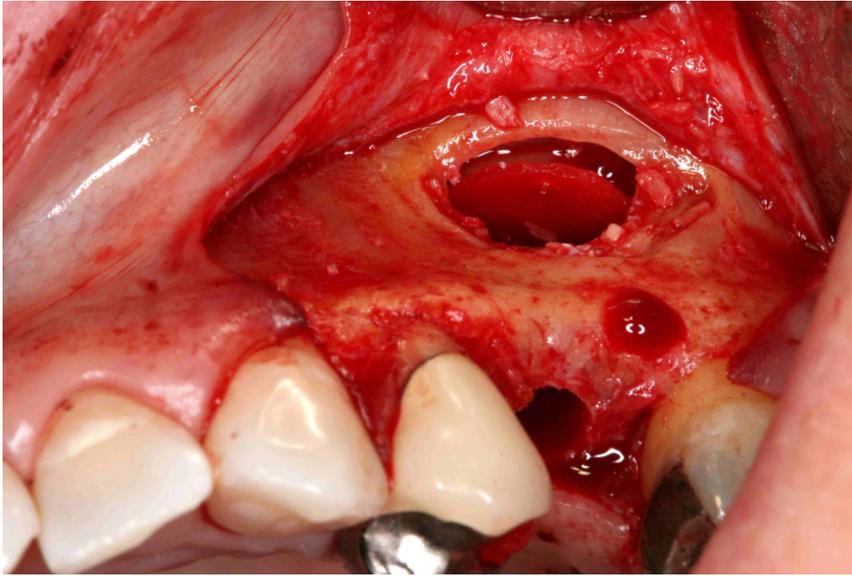


Figure 2. Lateral Window Technique II. The bony window has been upfractured medially and superiorly.

The medial aspect of the bony lateral window now becomes in essence the new floor of the maxillary sinus.¹ The membrane is gently teased off the sinus floor, creating a cavity that can now be packed with bone grafting material (Figure 3). As the bone graft is packed into the sinus cavity, it aids in displacing the sinus membrane up and allows for a tight packing of the sinus graft material.²⁸ It appears that overall, the sinus graft procedure is rather benign with no apparent side effects.²² As long as patency of the ostium is maintained, sinus function and health is restored with an apparent improvement in drainage and function.¹⁰

This technique was favored by Kent³⁵ over Tatum's crestal approach since it allowed for the use of greater amounts of iliac bone, offered direct sinus access and visualization, and it preserves the crestal bone.

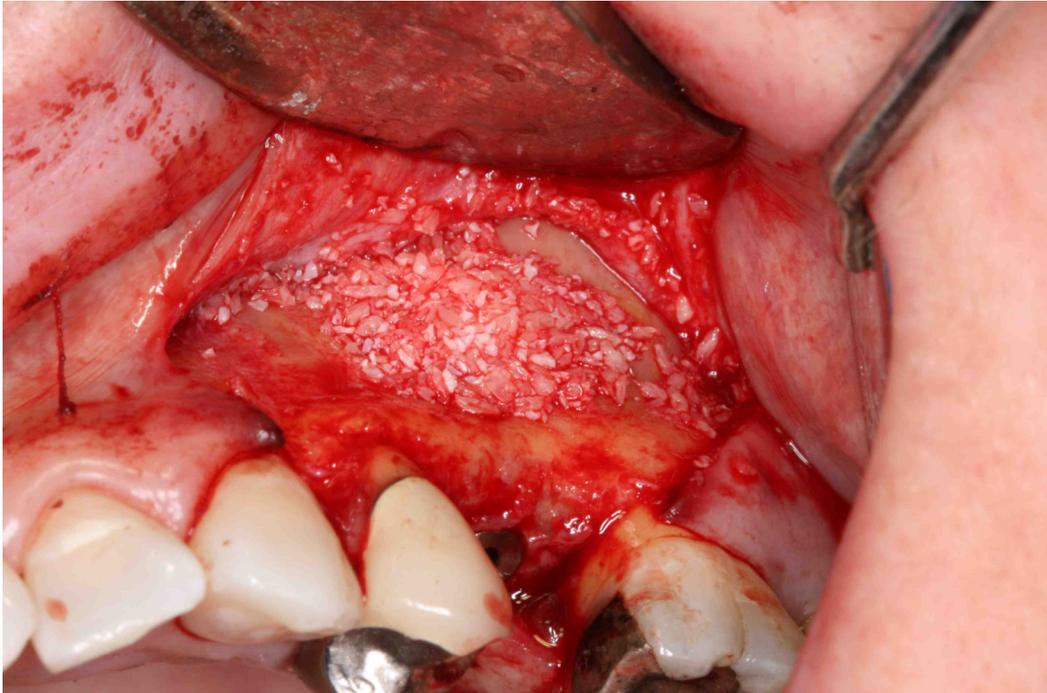


Figure 3. FDBA and BioOss mixture bone graft material.

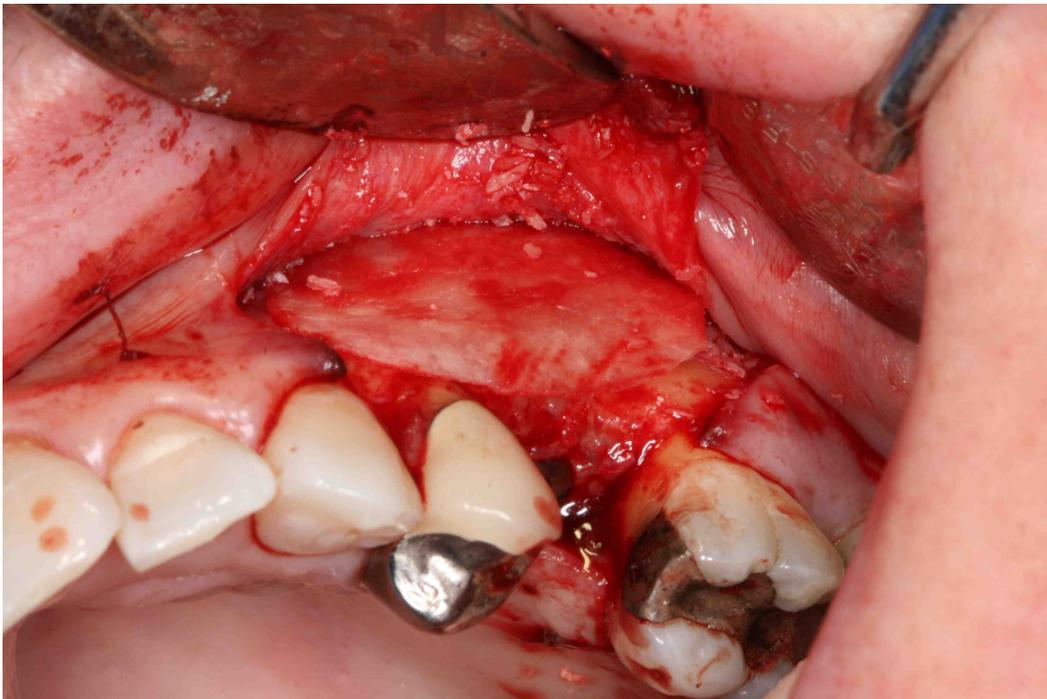


Figure 4. Zimmer Dental BioMend Extend membrane overlaying graft.

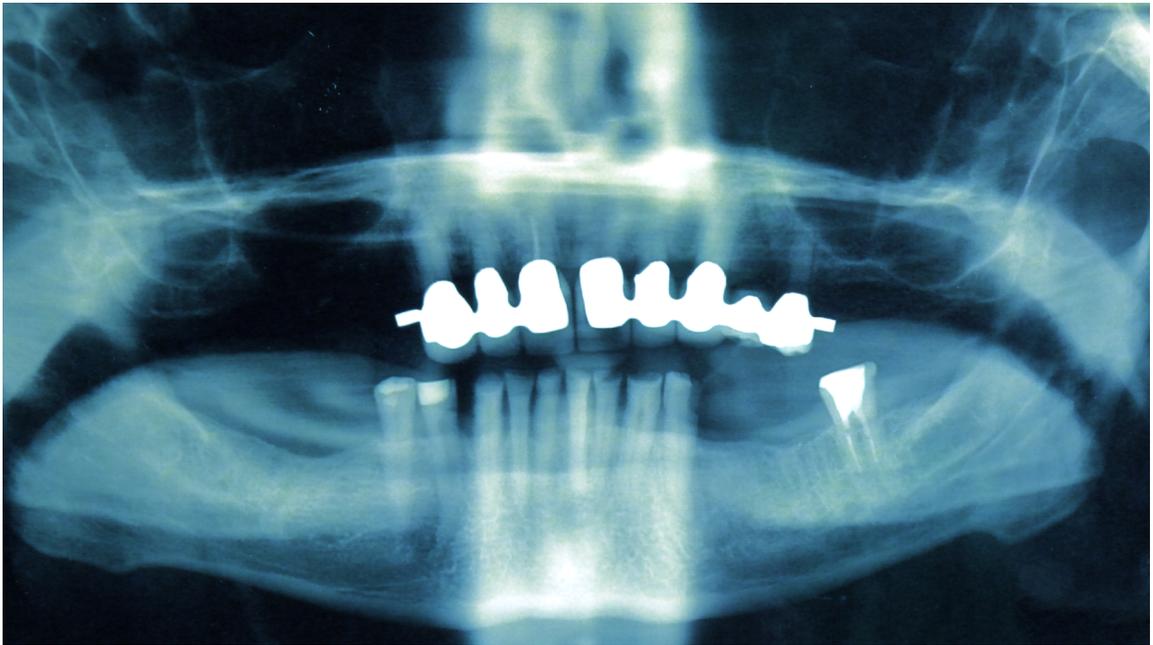


Figure 5. Pantomograph prior to lateral window sinus augmentation.

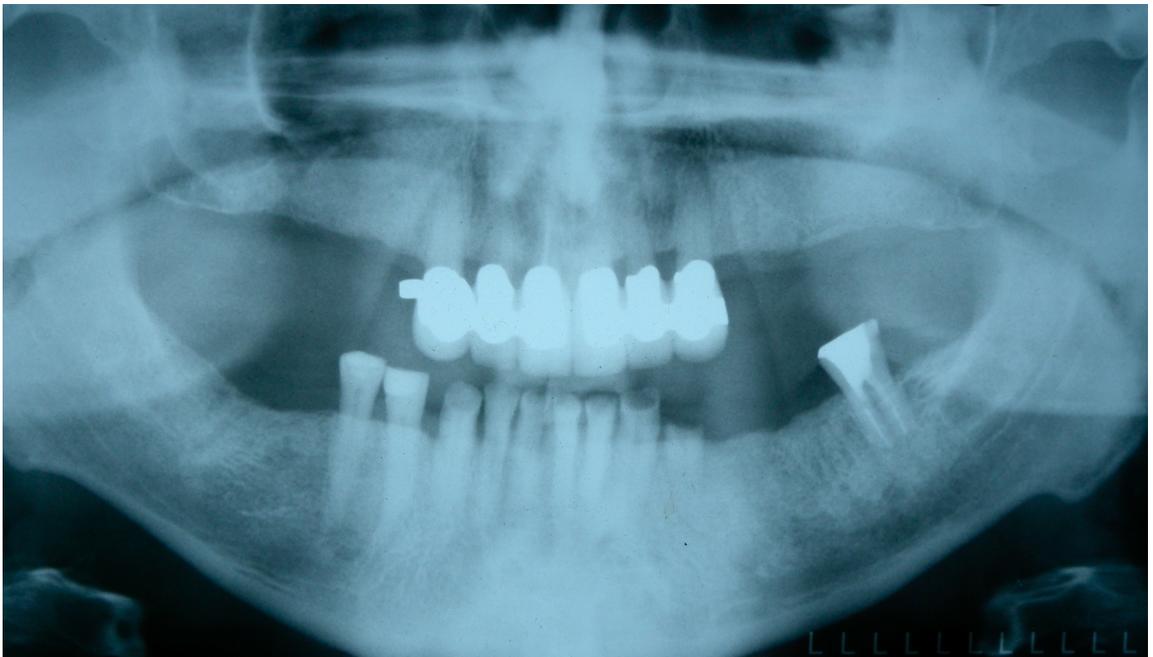


Figure 6. Pantomograph following lateral window sinus augmentation.

2.5.3 Osteotome Technique

The challenges of the sinus graft procedure are compounded by the relatively soft and porous posterior maxillary bone.⁴⁵ The simultaneous implant placement poses a further challenge since initial implant stability may be difficult to achieve. With the osteotome technique, the objective is to maintain as much of the crestal bone as possible, pushing the bone laterally and expanding the osteotomy with progressively larger osteotomes, rather than drilling the bone out.⁴⁵ The lateral expansion of an undersized osteotomy compacts the osseous layer and subsequently increases the interface between the implant and the bone. Progressively larger osteotomes increase the diameter of the osteotomy and simultaneously elevate the Schneiderian membrane.

During a conventional osteotomy preparation, heat is generated as the bone is drilled out. In contrast, the osteotome procedure does not generate heat.⁴⁵ The osteotomes feature a concave tip with a circumferential sharp edge. As this tool is progressively malleted into place, bone is shaved from the walls of the osteotomy and scooped up by the concave tip surface and pushed up towards the sinus, tenting the sinus membrane and consequently elevating the sinus floor. Summers⁴⁵ hypothesized that the semi solid mass of bone being pushed up into the sinus acts like a hydraulic plug to aid in displacing the membrane up from the sinus floor.



Figure 7. Summers Osteotomes.

A limitation of this procedure is that at least 5 mm of crestal bone must be present to provide adequate initial implant stability.⁴⁷ An undersized osteotomy is prepared with a conventional drill and irrigation to within 1 millimeter of the sinus floor. An osteotome with the same diameter as the last drill is used to create a greenstick fracture of the sinus floor. Only after careful release of the membrane from the floor of the sinus can the membrane be displaced upwards.⁴⁷

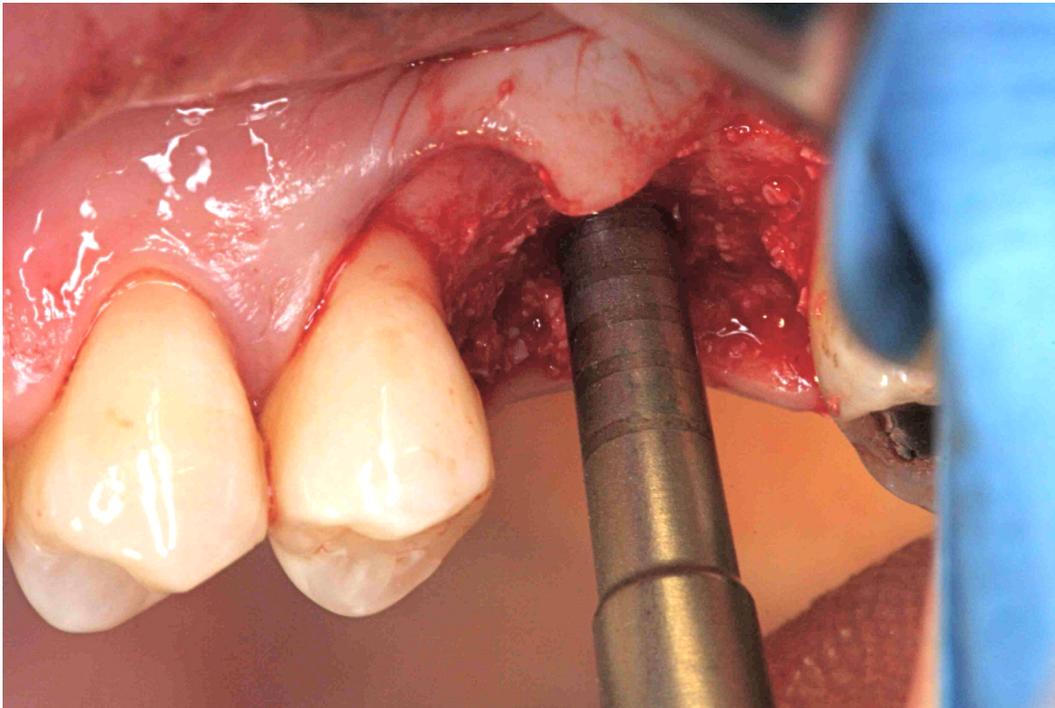


Figure 8. Indirect Sinus Lift. The Osteotome Technique.

Ferrigno⁴⁷ found that despite the benefits the osteotome technique offers, patients preferred the comfort of spiral drills over the repetitive pounding with osteotomes.

2.5.4 Minimally Invasive Sinus Surgery

Halpern⁶⁹ described a procedure that is a modification of the Summers Osteotome technique. Utilizing an osteotome of the widest diameter and an attached stop, the sinus floor is upfractured precisely 2 mm, and the sinus membrane is elevated. The position of the stop is precisely calculated to be 2 mm greater than the height of the alveolar ridge. This mechanical stop limits the chances of perforating the membrane when the osteotome is malletted to upfracture the floor of the sinus. A resorbable membrane is then introduced

into the sinus through the osteotomy. It is oriented to lie flat and directly adjacent to the Schneiderian membrane. This resorbable membrane serves to absorb the pressures and forces of the graft material as it is packed into the sinus and contain any graft material should a perforation occur. Once an adequate height of graft is attained, simultaneous implant placement can begin.⁶⁹ Radiographically, confirmation of a successful procedure should yield a dome shaped sinus floor elevated as required up to 10 mm.

2.6 Non-Grafted Implant Options

Placing the implants in the anterior maxilla at angulations of up to 30 degrees with respect to the horizontal plane is a method primarily designed to avoid maxillary sinus grafting. Techniques have been devised with the intent on cantilevering the implants distally up to the first molar much in the same manner as a mandibular implant retained/supported fixed detachable prosthesis.⁷⁰

However, unlike the mandible, the maxilla is composed of weaker and softer bone, warranting caution when attempting this technique.

Implants placed in the zygoma are another approach that utilizes tilted implants. However a high failure rate of up to 29 % described by one 4-year follow up study, and complications including sinusitis, poor oral hygiene and gingivitis have shed caution when attempting this procedure.⁷⁰

2.7 CAD/CAM Guidance

With advances in digital imaging obtained by computerized tomography, some have suggested the use of computer generated images to virtually place the implant in sites such as the anterior or posterior sinus wall, the pterygoid process, the palatal curvature and septa within the sinus.⁷⁰ Septa have been found in 31.7% of the sinuses. These had a mean height of 7 mm and were located between the first and second premolars.

It has been suggested that these techniques reduce the invasiveness of the surgical procedures. The planned implants are virtually positioned within a three dimensional image of the maxilla and a surgical stent is then fabricated from this data. Following proper surgical preparation procedures, the stent is placed intraorally and fixed in place. Removable sleeves of the corresponding diameter are inserted and the drilling sequence is initiated.⁷⁰

By avoiding sinus grafting and the healing period, reducing patient discomfort and minimizing the invasiveness of the procedure, it is hoped that this procedure will also benefit the patient by reducing surgical site morbidity and cost. These benefits must be weighed against the risks of placing implants in unfavorable positions and angulations. Moreover, the lack of bone volume and the potential for surgical complications is increased if the surgeon relies solely on the surgical guide.

2.8 Implant Success Rates

The high success rates enjoyed by modern screw type dental implants have been well established in the literature. Although studies claim posterior maxillary success rates over 90%, failure rates as high as 35% can be encountered.^{51,71} Sites with an insufficient quality and quantity of bone prevent the placement of adequate length implants and initial fixation.

The risk of implant failure increases dramatically when sinus grafting is performed in conjunction with implant placement. Wannfors³⁴ noted that in grafted areas, the risk for implant failure among 1-stage procedures was twice as high as in 2-stage procedures. Moreover, regardless of the surgical technique used to place the implants, non-grafted sinuses experienced significantly lower failure rates than grafted sinuses. In a meta analysis, Bornstein⁷² recognized the location within the maxillary arch has a significant predictive value for implant success or failure.

2.9 Residual Crestal Bone Height:

In 1983, Branemark⁵⁶ stated that 10 mm of residual crestal bone was the crestal bone height required to achieve predictable success rates. Despite these claims, many practitioners aim to achieve as much bone as possible with the aim of placing the longest implant possible. The reasoning behind this philosophy is that for every 3 mm increase in implant length, the surface area of the implant that is in contact with the supporting bone increases by 10 percent.¹⁸ This increase in implant length is also important at the time of

implant placement following extractions, where the apical portion of the implant can provide initial stability.¹⁸

Although the 10 mm implant height can be applied in most situations, in the weak bone of the posterior maxilla as much as 15 mm to 20 mm may be desired.¹⁸ Moreover, inexperienced clinicians will often choose to augment the sinus beyond the required height to have a safe zone with room for error.

Contemporary clinicians often utilize residual crestal bone height to base their decisions on the type of sinus augmentation that will be performed. Jensen²² has described residual crestal bone height as a prognosticator for the type of graft that will be utilized and the success or failure of the implants and recommends sinus grafting in situations with less than 8 mm of residual crestal bone. It has been observed that implant failure occurs more frequently in sinuses with a corresponding decrease in residual crestal bone height.²²

2.10 Implant Diameter

There are many factors that must be considered when selecting the appropriate diameter implant. The need to minimize the stresses transferred from the implant to the bone is a prime consideration for the use of wider diameter implants. Misch¹⁸ has shown that for every 0.25 mm increase in implant diameter, there is a 10 percent gain in surface area, and by increasing implant diameter, stresses at the crestal bone interface are minimized. It can be quickly calculated that if the implant diameter is increased by 1.0 mm, a 40% increase in surface area will be attained.

The importance of implant diameter becomes even more apparent when initial fixation of the implant fixture is desired. Implants placed into soft trabecular bone are largely held in place by their wide diameter necks that compress the crestal bone as they are surgically implanted. This is critical for stabilization in the posterior maxilla where the large marrow spaces, sparse trabeculae, and small quantities of native bone do not lend themselves to rigid initial stabilization. Summers⁴⁵ recognized that despite all efforts to compress the bone and prepare the osteotomy with osteotomes, it wasn't until the coronal, widest, aspect of the implant body was inserted that initial fixation was achieved.

2.11 Health Status

The need to classify patients in terms of their overall general health has been achieved through the use of the American Society of Anesthesiology (ASA) Classification System.⁷³ First introduced in 1941 by Saklad,⁷⁴ the system was designed for a uniform method of data comparison. Patients who are overall healthy are classified as ASA I. Patients displaying signs of mild systemic disease are classified as ASA II. ASA III patients are those exhibiting moderate to severe systemic disease. Patients classified as ASA IV, V, and VI, are deemed unfit for dental implant treatment due to life threatening conditions, and treatment should be delayed until they at least attain level ASA III or better.^{72,75}

2.12 Osteoporosis

The definition of osteoporosis based on bone mass and bone density is not entirely associated with an increased predisposition to non-violent mandibular fracture.⁷² Many patients diagnosed with osteoporosis present themselves for dental treatment with mandibular and maxillary bone levels not at all different from normal, non-diagnosed patients, and there is very little evidence relating maxillary or mandibular bone mass with skeletal bone mass.⁷² It is for these reasons that The World Health Organization has established criteria for the diagnosis of osteoporosis. With the aid of x-ray absorptiometry, a diagnosis of osteoporosis is made if the bone mineral density is 2.5 standard deviations below that of a mean young population.

The literature does not seem to indicate a strong association between osteoporosis and implant failure. However, when failures of implants placed in osteoporosis patients are analyzed, the focus shifts to oral bisphosphonates, the medication to treat osteoporosis.⁷² Bornstein⁷² concluded that oral bisphosphonates for the treatment of osteoporosis should be avoided in patients that had underwent implant therapy, while those patients which require oral bisphosphonates or have taken oral bisphosphonates in the past should avoid dental implant placement.

2.13 Smoking

Cigarette smoking is now recognized as a detrimental risk factor for implant placement in the grafted posterior maxilla.^{20,50,68,76} Until recently, the toxic effects of smoking were primarily attributed to nicotine.²⁰ Current studies indicate that nicotine,

carbon monoxide, and hydrogen cyanide, are just some of the by-products of cigarette smoking that have a negative impact on dental health.⁶⁸

By interfering with the production of red blood cells, macrophages, and fibroblasts, nicotine alters the normal healing of tissues.⁷⁶ Nicotine also increases microclots and has a negative effect on microperfusion. Through the systemic release of epinephrine and norepinephrine, platelets sticking together and causing the narrowing of blood vessels.⁷¹ Vasoconstrictive effects of nicotine have also been shown to act also locally by being absorbed directly by the oral mucosa. This direct absorption may magnify the exposure of the implants to nicotine by acting locally in the oral cavity, and systemically.^{50,68}

Smoking also induces polymorphonucleocyte dysfunction which compromises initial wound healing. It should be noted that chalcones, hormones formed at wound sites which inhibit epithelialization, are a result epinephrine release. Hydrogen cyanide is a chemical which inhibits oxidative metabolism cycles by interfering with enzyme function and cellular transport. Barone²⁰ noted a higher prevalence of acute sinus infection following the sinus graft procedure. It occurred on 14.2% of the smokers compared to only 2.2% of the non-smokers.²⁰

Carbon monoxide is a by-product which competes for the oxygen binding sites on hemoglobin molecules. As a result, hemoglobin molecules within the alveoli are saturated with carbon monoxide and not oxygen, impairing the delivery of oxygen to the tissues and affecting metabolic function. Studies have shown the velocity of blood flow to the fingers was reduced by 40% after smoking a single cigarette.⁵⁰

It has been reported that smokers exhibit greater marginal bone loss around implants, and studies have shown that smokers experience twice the implant failure in the posterior maxilla when compared to non-smokers.⁵⁰ Failure rates of 11.28% have been reported for smokers, in contrast to 4.76% for non-smokers.^{50,71} Other studies have shown failure rates as high as 19.10% in smokers and 10.93% in non-smokers.^{50,71} Regardless of which study is examined, the ratio between the two groups remains the same. It has also been shown that the quantity of cigarette smoking has a correlation to higher marginal bone loss rates and higher implant failure rates.

It becomes apparent that the healing of surgical sites following implant placement would be negatively affected in smokers due to nicotine exposure, and toxic by-products.⁷¹

2.14 Complications:

2.14.1 Perforation of the Sinus Membrane

A frequent complication of the sinus augmentation procedure is the tearing or perforation of the Schneiderian membrane.⁷⁷ This can be caused by either the medially directed infracturing of the lateral wall of the sinus or the upfracturing of the inferior sinus floor as in the osteotome technique.⁸ In either case, the thin bony wall fractures suddenly, creating sharp bony edges that facilitate membrane perforation and driving the instrument that is being used into the sinus. Barone¹⁹ calculated that sinus membrane perforations occur between 7% to 44% of the time during surgical procedures.^{20,77} Implementing the Valsalva maneuver, the integrity of the membrane may be verified.⁴⁷

Repairs of sinus membrane perforations may be performed with the aid of Gelfoam, surgical collagen, or a cellulose membrane, while larger defects are repaired by lifting the membrane of the wall of the sinus, folding it over onto itself and placing a resorbable collagen wound dressing to facilitate repair.⁸

Alternative postoperative complications of the sinus graft procedure may include graft loss due to wound dehiscence, infection, bleeding and sinusitis.^{1,77} However, there has been correlation found between postoperative complications and implant survival.³⁴

2.14.2 Lack of Sufficient Quality or Quantity of the Bone Forming in the Graft

Following the bone augmentation procedure, inadequate amounts of bone may still be present prohibiting the placement of dental implants.⁶⁴ Moreover, the type of graft initially placed may not lead to a biologic generation of new bone, at which time the original bone graft can be removed and replaced with a new combination of bone grafting materials. A secondary access of the sinus is facilitated by the initial lateral wall cuts and infracturing procedures.

2.14.3 Donor Site Morbidity

The significant postoperative pain following an iliac crest graft and the possibility of an adynamic ileus is a factor that cannot be underestimated.^{28,67} Hospitalization and the application of general anesthesia compounds the complexity of this procedure and increases risk associated with the procedure.^{28,67}

2.15 Bone Type

Four types of bone were recognized and described by Branemark⁵⁶ and classified according to the ratio of hard, high density cortical bone to soft, trabecular low density bone. Type I bone is primarily composed of cortical bone and very little cancellous bone. Type II and Type III bone have progressively less cortical bone and more cancellous trabecular bone. Type IV bone is primarily composed of trabecular cancellous bone with little cortical bone, and is recognized for having poor strength.^{14,16,17,45,48,50}

In the mandible, implant placement is favorable because of mainly Type II and Type III bone present. This bone type provides a dense crestal cortex for initial fixation of the implant and the possibility of engaging both the lingual and buccal cortical plates. The success of mandibular implants has been largely regarded as a result of the ideal bone present which has adequate strength to stabilize the implant and adequate blood supply for bone remodeling and osseointegration.⁴⁵

In the maxilla, the nearly absent crestal cortical bone does not allow for rigid initial fixation. The maxilla is primarily composed of Type III and Type IV bone, with Type IV bone mainly making up a vast majority of the posterior maxilla.⁴⁸ The large marrow spaces within this low density trabecular bone offer less bone to surround the entire surface area of the implant, and hence provide less bone cells for osseointegration and bone remodeling. These maxillary implants require more time to osseointegrate fully and often display signs of failure already at stage II surgery if osseointegration does not occur.⁵¹ Tatum recognized early that the maxillary bone requires 4 to 5 months to undergo all the repair processes. The key to successful integration lies with the formation

of a stress-bearing surface adjacent to the implant.¹⁶ It is also widely recognized that maximum force generation occurs in the posterior regions of the maxilla. The high occlusal loads, combined with bone that is less able to withstand such loading and potentially less than ideally osseointegrated implants predisposes these implants to failure.^{14,51}

2.16 Combined Risk Factors

The interrelation of factors affecting dental implant therapy may have a summative effect that may far exceed the effect of each factor alone. Medications for many of the chronic diseases may undergo chemical interactions which are significantly more detrimental to implant integration than if each drug was administered individually.⁷² Many elderly dental patients which desire implant treatment take multiple medications for a multitude of medical conditions. This theory is supported by studies which indicate that peri-implant bone loss is associated with smoking and interleukin-1 gene, while each of these factors alone is not associated.⁷²

Chapter 3. Objectives and Hypotheses

3.1 Statement of Problem

Currently, there are no studies available examining the prevalence of sinus grafting in the posterior maxilla, nor factors that may influence or be associated with this procedure.

3.2 General Objective

The objective of this study was to retrospectively determine the prevalence of sinus augmentation among dental implant patients at the University of Minnesota, and identify factors associated with this procedure. This knowledge may aid treatment planning and patient education and decision making prior to proceeding with dental implant therapy.

3.3 Specific Objective

The specific objective of this study was to retrospectively analyze a cohort of patients at the University of Minnesota who had implants placed in the posterior maxilla.

3.4 Null hypothesis (H_0)

The null hypothesis for this study is that none of the variables are associated with the prevalence of maxillary sinus augmentation.

3.5 Alternate Hypothesis (H₁)

The alternate hypothesis for this study is that there are factors significantly associated with the prevalence of maxillary sinus augmentation.

Chapter 4. Materials and Methods

With institutional review board approval, dental records from a population of patients who had implants placed in the maxillary posterior region at the University of Minnesota, School of Dentistry, between January 2000 and December 2004, were used to create a data base. The criteria for study inclusion was that maxillary posterior implant placement was completed at the School of Dentistry during the time period specified. Exclusion criteria included patients with inadequate or unavailable dental records or cancer patients who had implants placed in a reconstructed maxilla (most often with bone from the iliac crest). The database was created using public domain statistical software for epidemiology (Epi Info; Centers for Disease Control and Prevention, Atlanta, Ga).

Information retrieved from the dental records was divided into continuous and categorical independent variables. The dependent variable was the incidence of a sinus augmentation procedure.

Four continuous variables included the age of the patient at stage 1 implant surgery (S1), time between the extraction and S1, time between the extraction and sinus augmentation, and time between the sinus augmentation and S1.

Eleven categorical variables were subdivided into demographic, health status, anatomic, and implant variables. The patient's gender was recorded as the demographic variable. Health status variables included the classification according to the (ASA) system⁷³ where patients were categorized either as a normal healthy patient (ASA I), as having mild systemic disease (ASA II), or as having severe systemic disease (ASA III).

Patients who dental records identified themselves as a current tobacco user were recorded as smokers. Those with a history of smoking in the past or those who have never smoked were considered non-smokers. Patients were recorded as having osteoporosis if they indicated in the medical history documents as having the condition.

Anatomic variables recorded included the residual crestal bone height (> 12 mm, 8 to 12 mm, < 8 mm) measured from a pre-treatment panoramic radiograph and reduced to 80% of the original value to compensate for radiographic distortion,³² Residual crestal bone heights were grouped according to recommended or typical surgical techniques used to augment the sinus relative to the height of the residual bone. Heights greater than 12 mm are most likely not to be involved in sinus augmentation procedures, while those with 8 to 12 mm may have an osteotome procedure, and those with less than 8 mm are most likely to have a lateral antrostomy.¹⁰ Other anatomic variables included the implant position (first premolar, second premolar, first molar, second molar), implant proximity (1 or 2 adjacent teeth, 1 tooth and 1 implant, 1 or 2 adjacent implants, no adjacent tooth or implant), and prosthesis type (single crown, fixed partial denture, complete denture). Implant variables included implant failure, the diameter of the implant (< 3.7 mm, 3.7 to 4.9 mm, > 4.9 mm), and the length of the implant (14 to 16 mm, 13 mm, 10 to 12 mm). Implant failure was defined as complete removal of the implant for any reason. Crestal bone loss typical of a failing implant was not included in the failed implant data.

Descriptive statistics were calculated for all study variables. Univariate analyses were used to assess the influence of each of the independent variables on the prevalence of sinus augmentation. Since the independent predictors were analyzed one at a time, the

effect of each of the predictors on the incidence of sinus augmentation was estimated using a simple logistic regression. A likelihood-ratio test was used to assess the statistical significance of the effect of each of the variables on sinus augmentation. The independent variables were considered statistically associated with sinus augmentation if the corresponding P value was less than the level of significance of 0.05. All analyses were conducted using statistical software (SAS Version 9.2; SAS Institute, Inc, Cary, NC).

Chapter 5. Results

Five hundred and eighty-one implants were placed in the posterior maxilla at the University of Minnesota, School of Dentistry, between January 2000 and December 2004. Of those implants, 66 were excluded due to inadequate or unavailable dental records and 13 were excluded due to implant placement in a reconstructed maxilla of a cancer patient. The final database included 502 maxillary posterior implants. The mean duration of follow-up for the 468 survived implants was 35.7 months with a range of 0 months to 8.3 years from S1 surgery to the last recall appointment.

Table 1 summarizes the results of the descriptive statistics for the continuous variables as well as the odds ratio and *P*-value for the incidence of sinus augmentation for the age of the patient at S1 and the time between the extraction and S1. The time variables have different numbers of implants with available data as not all patients had the tooth extracted at the School of Dentistry and not all patients required a sinus augmentation procedure prior to implant placement. Of the 502 implants included in the cohort, the mean age of all patients was approximately 55 years with a range of 18 to 84 years of age at the time of S1 surgery.

Table 1. Descriptive Statistics (502 posterior maxillary implants) for continuous variables. Odds Ratio and *P*-value for the incidence of sinus augmentation (dependent variable) are also presented.

Variables (n)	Sinus augmentation		No augmentation		Odds ratio	<i>P</i> -value
	Mean (range)	Mode	Mean (range)	Mode		
Age at stage 1 (S1) surgery (502 implants)	55.5 y (20 -80)	50-59 y	54.9 y (18 -84)	50-59 y	1.004	0.608
Time between extraction and S1 surgery (264 implants)	26.4 m (0-451)	7-12 m	10.4 m (0 -124)	1-6 m	1.008	0.096
Supplemental Variable	Augmentation					
	Mean (range)	Mode				
Time between extraction and sinus augmentation (131 implants)	23.6 (0-447) m	1-6 month (74 implants)			-	-
Time between sinus augmentation and S1 surgery (268 implants)	3.3 (0-19) m	0 month (115 implants) 4-6 month (98 implants)			-	-

*Significant association ($P < .05$)

Table 2 summarizes the results of the descriptive statistics for the categorical variables as well as the odds ratio and *P*-value for the incidence of sinus augmentation. Of the 502 maxillary posterior implants placed, 272 (54.2%) were placed in association with a sinus augmentation procedure (210/272 or 77.2% with the lateral antrostomy). The majority of the patients were female (66.9%), were either healthy (ASA I; 36.5%) or had mild systemic disease (ASA II; 53.5%), were non-smokers (88.5%), and did not report a history of osteoporosis (95.4%). Neither the demographic variable ($P = .089$) or the health

status variables ($P=.510$, $.689$, $.059$, respectively) were statistically associated with the incidence of sinus grafting.

When the residual crestal bone height was greater than 12 mm (48.9%), sinus augmentation was required for 47/240 implants (19.6%). Conversely, when the residual crestal bone height was less than 8 mm (25.2%), sinus augmentation was required for 118/124 implants (95.2%). The association between residual crest bone height and sinus augmentation was statistically significant ($P<.001$).

When considering the implants that survived (93.2%), sinus augmentation was required for 244/468 implants (52.1%), while for those that failed (6.8%), sinus augmentation was required for 28/34 implants (82.4%). The association between implant failure and sinus augmentation was statistically significant ($P<.01$).

Table 2. Descriptive statistics (502 posterior maxillary implants) for categorical variables. Odds ratio and P -value for the incidence of sinus augmentation (dependent variable) are also presented.

Variables	Total No. Implants	Percent (%)	Implants in augmented sinuses	Percent (%)	Odds Ratio	P -value
Sinus augmentation status						
No augmentation	230	45.8	-		-	-
Augmentation	272	54.2	-		-	-
• Lateral approach	(210)	(41.8)	-		-	-
• Osteotome	(62)	(12.4)	-		-	-
Demographic variable						
Gender						.089
Female (baseline)	336	66.9	191	56.9		
Male	166	33.1	81	48.8	0.72	.089

Health status variables						
ASA status (499 implants)						.510
ASA I (baseline)	182	36.5	97	53.3		
ASA II	267	53.5	143	53.6	1.01	.957
ASA III	50	10.0	31	62.0	1.43	.274
Smoking						.689
No (baseline)	444	88.5	242	54.5		
Yes	58	11.5	30	51.7	0.89	.689
Osteoporosis						.059
No (baseline)	479	95.4	255	53.2		
Yes	23	4.6	17	73.9	2.49	.059
Anatomic variables						
Adjusted residual crestal bone height (491 implants)						<.001*
> 12 mm (baseline)	240	48.9	47	19.6		
8 - 12 mm	127	25.9	96	75.6	12.71	<.001
< 8 mm	124	25.2	118	95.2	80.76	<.001
Implant position						<.001*
First premolar (baseline)	171	34.0	67	39.2		
Second premolar	170	33.9	90	52.9	1.75	.011
First molar	142	28.3	99	69.7	3.57	<.001
Second molar	19	3.8	16	84.2	8.28	.001
Implant proximity						<.001*
1 or 2 teeth (baseline)	164	32.7	62	37.8		
1 tooth and 1 implant	154	30.9	76	49.0	1.58	.044
1 or 2 implants	160	31.9	117	73.1	4.48	<.001
No tooth or implant	23	4.5	17	73.9	4.66	<.01
Prosthesis type (435 implants)						<.001*
Single crown (baseline)	222	51.0	94	42.3		
Fixed partial denture	159	36.6	96	60.4	2.07	0.001
Complete denture	54	12.4	34	63.0	2.31	<.01

Implant Variables						
Implant failure						<.01*
Survived (baseline)	468	93.2	244	52.1		
Failed	34	6.8	28	82.4	4.28	<.01
• No augmentation	(6)	(1.2)				
• Augmentation	(28)	(5.6)				
Diameter						<.01*
< 3.7 mm (baseline)	77	15.3	39	50.7		
3.7 - 4.9 mm	389	77.5	206	53.0	1.10	.711
> 4.9 mm	36	7.2	27	75.0	2.92	.017
Length						.220
14 - 16 mm (baseline)	131	26.1	63	48.1		
13 mm	349	69.5	198	56.7	1.42	.091
10 - 12 mm	22	4.4	11	50.0	1.08	.868

*Significant association ($P<.05$)

Table 3 summarizes the significant univariate relationships between the categorical independent variables and the incidence of sinus augmentation and reports their confidence intervals. Implants placed in residual crestal bone height less than 8 mm were 80.76 times ($P<.001$) more likely to be associated with a sinus augmentation procedure than those placed in residual crestal bone heights greater than 12 mm. Implants placed in the position of the first molar are 3.57 times ($P<.001$) more likely to be associated with a sinus augmentation procedure than those placed in the first premolar position. Implants restored with a fixed partial denture are 2.07 times ($P<.001$) more likely to be associated with a sinus augmentation procedure than an implant restored with a single crown. Implants that failed are 4.28 times ($P<.01$) more likely to be associated with sinus augmentation than those implants that survived.

Table 3. Univariate analysis for factors significantly associated with sinus augmentation.

Variables	Odds Ratio	Confidence Interval	<i>P</i> -value
Residual crestal bone height (491 implants)			<.001*
> 12 mm (baseline)			
8 - 12 mm	12.71	(7.596:21.290)	<.001
< 8 mm	80.76	(33.498:194.699)	<.001
Implant position			<.001*
First premolar (baseline)			
Second premolar	1.75	(1.139:2.685)	.011
First molar	3.57	(2.230:5.727)	<.001
Second molar	8.28	(2.323:29.502)	.001
Implant proximity			<.001*
1 or 2 teeth (baseline)			
1 tooth and 1 implant	1.58	(1.013:2.472)	.044
1 or 2 implants	4.48	(2.795:7.169)	<.001
No tooth or implant	4.66	(1.745:12.454)	<.01
Prosthesis type (435 implants)			<.001*
Single crown (baseline)			
Fixed partial denture	2.07	(1.371:3.141)	.001
Complete denture	2.31	(1.254:4.274)	<.01
Implant failure			<.01*
Survived (baseline)			
Failed	4.28	(1.742:10.538)	
Diameter			<.01*
< 3.7 mm (baseline)			
3.7 - 4.9 mm	1.10	(0.673:1.789)	.711
> 4.9 mm	2.92	(1.216:7.025)	.017

*Significant main associations ($P < .05$)

Additionally, the statistics on implant failure rates among the different sinus augmentation technique groups were performed and are presented in Table 4. Maxillary posterior implants were placed in augmented sinuses (54.2%) more often than in natural bone with adequate height (45.8%). When sinus augmentation was required, the 2-stage lateral antrostomy was used most frequently among all the implants (30.7%), followed by the osteotome technique (12.4%), and the 1-stage lateral antrostomy (11.1%). The lowest failure rate occurred when the implants were placed in areas with adequate pretreatment bone height (2.6%). Although the 2-stage lateral antrostomy had the highest failure rate (12.3%), there was no statistical difference between the 3 augmentation techniques ($P=.117$).

Table 4. Statistics on Implant Failures Rates among Different Sinus Augmentation Technique Groups.

Variables	Total No. Implants	Percentage (%)	No. Failed Implants	Failure Rates (%)	P-value
No sinus augmentation	230	45.8	6	2.6	
Sinus augmentation technique groups					.117
LA 1-stage	56	11.1	2	3.6	
LA 2-stage	154	30.7	19	12.3	
Osteotome	62	12.4	7	11.3	
Total	502	100	34		

Chapter 6. Discussion

The data support rejection of the null hypothesis, as there were statistically significant variables associated with the prevalence of sinus augmentation. The overall prevalence of sinus augmentation within this implant database was 54.2%. This prevalence data needs to be interpreted cautiously. If a patient wants to know the average chances of requiring sinus augmentation procedure for posterior maxillary implants in general public, the answer can be higher than 54.2% since this retrospective study could not include some of the patients who might have given up the implant treatment due to the need for a sinus augmentation procedure. Also, this prevalence is based on per implant, not per patient.

Considering the challenges apparent with maxillary posterior implants, such as pneumatization of the sinus and low trabecular bone density, the survival rate of the implants in this database is 93.2% over a mean follow-up period of 35.7 months and a range from 0 months to 8.3 years. This survival rate compares well with other published studies.^{23,25,43,50,59} Several studies have shown that implant success rates in the posterior maxilla are the lowest of the intraoral regions mostly due to poor bone quality.^{14,48-51,53-55} Carr⁵⁸ reported that implants were 5 times more likely to fail in augmented sites than non-augmented sites. On the other hand, Olson²⁹ found increased survival rates for implants placed in grafted sinuses than non-grafted. Even though this study reported overall high survival rate of 93.2%, the results of this study showing that failed implants have a 4.3 times higher chance of being associated with sinus augmentation are in

agreement with Carr.⁵⁸ Implant survival may be more related to the amount of residual bone supporting the implant rather than the grafted bone.³

Bone availability is a primary factor when evaluating patients as a candidate for implant therapy.^{10,18,26,27,29,37} Block²⁶ stated that when the thickness of bone between the alveolar crest and floor of the sinus is less than 10 mm, sinus augmentation is necessary to support long implants and the subsequent prosthesis. Misch¹⁰ proposed 4 subantral treatment options for the posterior maxilla that varied depending on the available bone height. Most authors base the selection of the sinus augmentation technique on the vertical dimension of the residual bone, from a 2 step lateral antrostomy in situations with a severely resorbed maxilla to the less invasive osteotome technique when there is only mild resorption.^{16,24,27,30,31,35,45,47} The results of this study are in agreement with those studies since the prevalence of sinus augmentation increased by a factor of 12.71 when the residual crestal bone height was between 8 and 12 mm and by a factor of 80.76 when the residual crestal bone height was less than 8 mm ($P<.001$). The surgeons at the University of Minnesota might have used the same residual bone height as a primary factor when making a treatment plan.

Resorption of the alveolar bone and enlargement of the maxillary sinus subsequent to tooth extraction combined with a possible loss of alveolar bone due to periodontal disease prior to tooth extraction, leaves a clinical situation that complicates the placement of implants.^{6,10,19,26-28,32,37} Even though time between extraction and S1 surgery was not significantly associated with sinus augmentation in current study, it was borderline ($P=.096$). For those who had a sinus augmentation procedure, the mean time

between the extraction and S1 was 26.4 months (mode 7-12 months), while for those who did not require a sinus augmentation procedure, the mean time decreased to 10.4 months (mode 1-6 months) (Table 1). The mean time between extraction and sinus augmentation was 23.6 months, while the mean time between sinus augmentation and S1 surgery was 3.3 months, considering that 43% (115/268) were placed simultaneously.

Resumption of maxillary sinus pneumatization after the age of 20 or the eruption of the third molars can occur after posterior tooth extraction.¹¹ The proximity of the inferior wall of the maxillary sinus to the dentition is closest in the second molar region, which frequently causes a loss of the thin bone between the alveolar socket and the sinus during extraction resulting in expansion of the sinus.¹¹⁻¹³ This relates to the results of this study that have shown sinus augmentation was more prevalent in molar sites than premolar sites ($P<.001$).

Pneumatization has also been shown to be higher when adjacent posterior teeth are extracted due to reduced bone resistance to sinus expansion.¹¹ In posterior single tooth edentulous sites, roots of the adjacent teeth appear to prevent or decrease sinus pneumatization as negligible expansion has been found.¹¹ Those findings also agree with the results from this study where implants sites adjacent to either another implant or an edentulous site had an increased prevalence of sinus augmentation than those that are adjacent to natural teeth ($P<.001$). The type of prosthesis, such as a complete denture compared to a single crown, implies that adjacent teeth are missing and those prostheses had an increased requirement for sinus augmentation ($P<.001$).

Implant diameters higher than 4.9 mm had a 2.8 times greater chance to be associated with sinus augmentation than regular (3.7 to 4.9 mm) or narrow diameter (less than 3.7 mm) implants ($P < .01$). Relatively wide bucco-lingual ridge dimensions of the posterior maxilla might have encouraged surgeons to place wider implants to improve the biomechanics of the implants placed in augmented bone. Those implants that were 13 mm in length had a 1.4 times higher chance to be associated with sinus augmentation than implants that were 14 to 16 mm in length, although this was not significant ($P = .22$). It is quite interesting to find out that 13 mm implant was most popular implant length used in augmented bone (73%). Regardless of the technique used to augment the sinus, the resultant vertical bone available at S1 might have been close to 13 mm.

Osteoporosis had a borderline significance ($P = .059$) showing 2.5 times higher chance to be associated with sinus augmentation. A small sample size (23/502) of osteoporosis group questions the significance of association.

Chapter 7. Summary and Conclusion

Within the limitations of this retrospective study, the results suggest that more than half (54.2%) of the maxillary posterior implants in this database were associated with a sinus augmentation procedure. The prevalence of sinus augmentation increased with decreased residual crestal bone height, more posterior implant locations, and complete or partial edentulism. Sinus augmentation was significantly associated with implant failure and wide implants.

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