COMPLICATIONS DURING AUGMENTATION IN MAXILLARY SINUSES ASSOCIATED WITH INTERFERING SEPTA

by

VALENTIN EMANUEL DABULEANU

B.Sc., York University, 2006
D.D.S., University of Toronto, 2010

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE AND POSTDOCTORAL STUDIES

(Craniofacial Science)

THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

May 2014
© Valentin Emanuel Dabuleanu, 2014
ABSTRACT

Objective:
This retrospective chart review assessed the prevalence and severity of sinus membrane tear complications as they related to the presence of sinus septa.

Methods:
The study included 67 patients treated at two private periodontal practices. 79 sinus lifts were performed by one operator (T.I.), a periodontist. 107 implants were placed. The effect of patient-, implant design-, bone graft-, implant placement timing-, and intrasurgical-related risk factors on implant survival, marginal bone loss, sinus membrane tears, major postoperative complications, and operating time were evaluated. Preoperative Cone Beam Computed Tomography (CBCT) images were evaluated using Kodak 3D Imaging v2.4 software and the distribution of interfering septa according to Class I (buccal-lingual direction), Class II (mesial-distal direction), Class III (horizontal orientation), and Class IV (combinations of Class I, II, or III) was assessed. Radiographic measurements of marginal bone loss (mm) were made using Image J v1.46 software.

Results:
Interfering septa were identified in 48.1% of sinuses. Of sinuses with septa, 71.1% of these contained a Class I septum. The overall implant survival rate was 100%. Patient-related risk factors were not found to be significantly associated with marginal bone loss, the occurrence of sinus membrane tears, or any major postoperative complications. Non-platform-shifted implants were found to be significantly associated with increased marginal bone loss (P<0.001). Sinus membrane tears were not found to be associated with either major postoperative complications or increased marginal bone loss. The presence of a septum on the pre-operative CBCT scan was found to be significantly associated with the occurrence of a sinus membrane tear (P<0.001).
Conclusions:
The identification of interfering septa on preoperative CBCT scans was associated with the occurrence of intrasurgical sinus membrane tears, however the occurrence of tears was not associated with major postoperative complications or implant marginal bone loss.
PREFACE

This dissertation is based on existing clinical and radiographic data from the private periodontal practices of Dr. Tassos Irinakis. I have collected this data and performed interpretations and measurements under the guidance of Dr. Tassos Irinakis. I have carried out the statistical analyses under the supervision of Dr. Yolanta Aleksejuniene. The Clinical Research Ethics Board (The University of British Columbia) approved the present study (Approval number H10-00464).
TABLE OF CONTENTS

ABSTRACT .......................................................................................................................... ii
PREFACE ........................................................................................................................... iv
TABLE OF CONTENTS ....................................................................................................... v
LIST OF TABLES ................................................................................................................ viii
LIST OF FIGURES ............................................................................................................. ix
LIST OF ILLUSTRATIONS ............................................................................................... xi
LIST OF ABBREVIATIONS ............................................................................................... xii
ACKNOWLEDGEMENTS ..................................................................................................... xiii

1. INTRODUCTION ............................................................................................................. 1

2. REVIEW OF THE LITERATURE ..................................................................................... 3
   2.1 Maxillary Sinus Anatomy ......................................................................................... 3
   2.2 Alternatives to Performing a Sinus Lift ...................................................................... 6
   2.3 Development of the Sinus Lift .................................................................................. 7
   2.4 Indications & Contraindications for Sinus Lift Surgery ............................................. 8
   2.5 Pre-operative Planning ............................................................................................ 10
       2.5.1 Cone beam computed tomography .................................................................. 10
       2.5.2 One- or two-stage technique ................................................................. 12
   2.6 Sinus Lift Bone Grafting Options ............................................................................ 12
       2.6.1 Introduction ..................................................................................................... 12
       2.6.2 Autogenous graft .......................................................................................... 13
       2.6.3 Implant survival as per graft material ................................................................ 13
       2.6.4 Xenograft, allograft, alloplast ....................................................................... 16
       2.6.5 Biomimetic and stem cell technology ............................................................. 18
       2.6.6 Direct approach – without bone graft material ................................................. 20
       2.6.7 Bone grafts - summary .................................................................................... 21
   2.7 Sinus Lift Techniques ................................................................................................ 21
       2.7.1 Direct approach – one/two-stage – rotary/piezo access .................................... 21
       2.7.2 Indirect approach – one-stage – rotary/osteotome/piezo access ....................... 25
   2.8 Complications in Sinus Lift Surgery .......................................................................... 28
       2.8.1 Introduction ..................................................................................................... 28
       2.8.2 Incidence of perforations ................................................................................ 28
       2.8.3 Management of perforations .......................................................................... 30
       2.8.4 Incidence and management of bleeding .......................................................... 32
       2.8.5 Incidence and management of sinusitis .......................................................... 34
       2.8.6 Incidence and management of wound dehiscence and infection ...................... 35
       2.8.7 Other complications ....................................................................................... 36
   2.9 Implant Success and Survival in the Posterior Maxilla ............................................. 37
       2.9.1 Evolving definitions ......................................................................................... 37
2.9.2 Implant survival in the augmented versus healed sinus
2.9.3 Implant survival in the augmented sinus without graft material
2.9.4 Implant survival after perforations
2.9.5 Implant survival after infection
2.9.6 Implant survival in smokers
2.9.7 Implant survival in patients with diabetes
2.9.8 Implant survival in patients with osteoporosis
2.9.9 Implant survival in patients with periodontal disease
2.9.10 Implant survival according to implant surface type
2.9.11 Implant survival for short implants
2.9.12 In summary

3. OBJECTIVES

4. MATERIALS AND METHODS

5. RESULTS

5.1 Population, Sinus, Bone Graft and Implant Distribution
5.1.1 Marginal bone loss and intra-examiner reliability

5.2 Patient-Related Factors
5.2.1 Patient age and marginal bone loss
5.2.2 Patient age and membrane tears
5.2.3 Patient age and major complications
5.2.4 Gender and marginal bone loss
5.2.5 Gender and membrane tears
5.2.6 Gender and major complications
5.2.7 Pertinent medical history and marginal bone loss
5.2.8 Pertinent medical history and membrane tears
5.2.9 Pertinent medical history and major complications
5.2.10 Smoking status and marginal bone loss
5.2.11 Smoking status and membrane tears
5.2.12 Smoking status and major complications

5.3 Implant Design-Related Factors
5.3.1 Implant brand surface and marginal bone loss
5.3.2 Implant shape and marginal bone loss
5.3.3 Nobel Replace series and marginal bone loss
5.3.4 All implants, platform-switching and marginal bone loss
5.3.5 Nobel implants, platform-switching, and marginal bone loss
5.3.6 Platform-switched Nobel versus non-Nobel implants and marginal bone loss

5.4 Bone Grafting-Related Factors
5.4.1 Graft material and marginal bone loss
5.4.2 Graft consistency and operating time
5.4.3 Graft consistency and major complications

5.5 Factors Related to Timing of Implant Placement
5.5.1 Implant placement timing and operating time
5.5.2 Implant placement timing and sinus membrane tears
5.5.3 Implant placement timing and major postoperative complications......93

5.6 Intrasurgical-Related Factors.................................................................93
  5.6.1 Sinus membrane tears and marginal bone loss..................................93
  5.6.2 Radiographic septum and sinus membrane tears................................95
  5.6.3 Sinus lift boundaries and sinus membrane tears...............................97
  5.6.4 Sinus location and sinus membrane tears.........................................98
  5.6.5 Sinus membrane tears and major postoperative complications..........99

5.7 Osstell-Related Factors........................................................................100
  5.7.1 Osstell reading versus marginal bone loss......................................100

5.8 Effect of Implant Loading.................................................................102
  5.8.1 Marginal bone loss during the first year of loading..........................102

6. DISCUSSION............................................................................................103
  6.1 Sinus Septa Prevalence and Orientation..............................................103
  6.2 Patient-Related Factors.......................................................................104
    6.2.1 Patient age......................................................................................104
    6.2.2 Gender...........................................................................................104
    6.2.3 Pertinent medical history...............................................................105
    6.2.4 Smoking........................................................................................105

6.3 Implant Design-Related Factors...........................................................106
  6.3.1 Implant surface and shape..............................................................106
  6.3.2 Nobel Replace series........................................................................106
  6.3.3 Platform-switching..........................................................................107

6.4 Bone Grafting-Related Factors............................................................108
  6.4.1 Graft material and marginal bone loss............................................108
  6.4.2 Graft consistency and operating time..............................................108
  6.4.3 Graft consistency and major complications....................................109

6.5 Factors Related to the Timing of Implant Placement............................109

6.6 Intrasurgical-Related Factors...............................................................109
  6.6.1 Sinus membrane tears and marginal bone loss...............................109
  6.6.2 Radiographic septum and sinus membrane tears............................110
  6.6.3 Sinus lift boundaries and sinus membrane tears............................110
  6.6.4 Sinus membrane tears and major postoperative complications........111

6.7 Osstell-Related Factors........................................................................111

6.8 Implant Success During the First Year of Loading..................................111

6.9 Limitations of the Study.........................................................................112

6.10 Clinical Considerations and Suggestions for Future Research..............113

7. CONCLUSION............................................................................................114

BIBLIOGRAPHY............................................................................................115

APPENDICES..................................................................................................126
LIST OF TABLES

Table 1. Age regarding marginal bone loss.................................................................62
Table 2. Patient gender regarding marginal bone loss.................................................66
Table 3. Pertinent medical history regarding marginal bone loss...............................70
Table 4. Smoking status regarding marginal bone loss.............................................73
Table 5. Implant brand surface regarding marginal bone loss.................................77
Table 6. Implant shape regarding marginal bone loss...............................................79
Table 7. Nobel Replace series regarding marginal bone loss.....................................80
Table 8. Implant platform-switching regarding marginal bone loss..........................82
Table 9. Nobel implant platform-switching regarding marginal bone loss.................83
Table 10. Marginal bone loss for Nobel platform-switched and Non-Nobel implants......................................................................................................................85
Table 11. Graft material regarding marginal bone loss..............................................88
Table 12. Operating time and the effect of graft consistency.....................................89
Table 13. Operating time and implant placement timing..........................................92
Table 14. Sinus membrane tears regarding marginal bone loss...............................94
Table 15. The distribution of all tears according to septal class..................................96
LIST OF FIGURES

Figure 1. Example of a CBCT image .............................................11
Figure 2. Box plot representation ...................................................56
Figure 3. Radiographic septal classes identified as per CBCT imaging ...........................................57
Figure 4. Distribution of implants ..................................................................................58
Figure 5. Distribution of graft material at the sinus level ...............................................59
Figure 6. Box plot of marginal bone loss measurements at the latest follow-up ..........60
Figure 7. Distribution of age groups ............................................................................61
Figure 8. Average implant marginal bone loss per patient according to age group...62
Figure 9. Membrane tears according to age group .......................................................63
Figure 10. Major postoperative complications according to age group ..................64
Figure 11. Distribution of patients according to gender ..............................................65
Figure 12. Distribution of implants according to gender ..............................................65
Figure 13. Marginal bone loss per patient according to gender ..................................66
Figure 14. Membrane tears according to age group .......................................................67
Figure 15. Major postoperative complications according to gender ..........................68
Figure 16. Distribution of patients according to pertinent medical history ..........69
Figure 17. Marginal bone loss per patient according to pertinent medical history ...70
Figure 18. Membrane tears according to pertinent medical history ............................71
Figure 19. Postoperative complications according to pertinent medical history ....72
Figure 20. Marginal bone loss per patient according to smoking status ................73
Figure 21. Membrane tears according to smoking status ..............................................74
Figure 22. Postoperative complications according to smoking status .......................75
Figure 23. Marginal bone loss according to implant brand surface ..........................76
Figure 24. Marginal bone loss according to implant shape .........................................78
Figure 25. Marginal bone loss according to Nobel Replace model ..............................80
Figure 26. Marginal bone loss according to implant platform-switching ................81
Figure 27. Marginal bone loss according to Nobel implant platform-switching .......83
Figure 28. Marginal bone loss according to Nobel platform-switched and Non-Nobel implants .................................................................85
Figure 29. Marginal bone loss according to graft material ..........................................87
Figure 30. Operating time and the effect of graft consistency .....................................89
Figure 31. Postoperative complications at the sinus level .........................................90
Figure 32. Graft consistency as it relates to postoperative complications .................90
Figure 33. Operating time and implant placement timing ...........................................91
Figure 34. Implant placement timing as it relates to membrane tears ......................92
Figure 35. Implant placement timing as it relates to postoperative complications 93
Figure 36. Marginal bone loss according to sinus membrane tears ............................94
Figure 37. The frequency of all sinus membrane tears ..............................................95
Figure 38. The frequency of small and large tears in sinuses with septa ..............96
Figure 39. The frequency of small and large tears in sinuses without septa ..............96
Figure 40. Septum identified by CBCT analysis as they relate to membrane tears ...97
Figure 41. Sinus lift boundaries as they relate to membrane tears ............................98
Figure 42. Sinus location as it relates to membrane tears.................................99
Figure 43. Postoperative complications as they relate to membrane tears..........100
Figure 44. Marginal bone loss at integration check compared with ISQ..............101
Figure 45. Marginal bone loss at latest follow-up compared with ISQ value.........101
Figure 46. Average marginal bone loss ≥1.5mm after one year of loading..........102
Figure 47. Average marginal bone loss ≥1.0mm after one year of loading..........102
LIST OF ABBREVIATIONS

PSAA – Posterior Superior Alveolar Artery..........................................................4
BAOSFE – Bone-Added Osteotome Sinus Floor Elevation...............................7
CT – Computed Tomography............................................................................10
CBCT – Cone Beam Computed Tomography..................................................10
ALARA – As Low As Reasonably Achievable..................................................11
BMP – Bone Morphogenetic Protein...............................................................13
CSR – Cumulative Survival Rate.....................................................................17
rhBMP-2 – recombinant human Bone Morphogenetic Protein 2.....................18
ACS – Absorbable Collagen Sponge..............................................................18
PRP – Platelet-Rich Plasma............................................................................18
rhPDGFββ – recombinant human Platelet Derived Growth Factor ββ..............19
GEM 21S - Growth-factor Enhanced Matrix 21S..........................................19
DASK - Dentium Advanced Sinus Kit............................................................23
CAS – Crestal Approach Sinus.......................................................................27
HPISE – Hydrodynamic Piezoelectric Internal Sinus Elevation........................27
BPPV – Benign Paroxysmal Positional Vertigo..............................................37
ONJ – Ostonecrosis of the Jaws.................................................................45
SLA - Sand-blasted Large grit Acid-etched......................................................52
TI – Tassos Irinakis.......................................................................................52
ISQ – Implant Stability Quotient.................................................................55
IQR – Interquartile range.............................................................................55
ACKNOWLEDGEMENTS

I would like to thank my thesis committee, Dr. Tassos Irinakis, Dr. Jolanta Aleksejuniene, Dr. Hannu Larjava, and Dr. Colin Wiebe for their commitment and direction in the development of this manuscript, and for Dr. Aleksejuniene’s fundamental assistance with the statistical analyses.
1. INTRODUCTION

Missing teeth may result in both a functional and cosmetic deficit, and have traditionally been replaced with removable or fixed prostheses, known simply as dentures and bridges. Dental implants, which are inserted into the jawbones and used to support prosthesis, have revolutionized dentistry as they provide the ability of supporting free-standing prostheses without the need of splinting to adjacent teeth as in a bridge, or depending on soft tissue support as in a conventional denture. Dental implants rely on osseointegration, which is the maintenance of a direct structural and functional connection between living bone and the implant surface.

The posterior maxilla presents a unique challenge when planning an implant prosthetic rehabilitation of edentulous sites. Common problems facing the clinician are a lack of bone volume by way of resorption of the alveolar process and pneumatization of the maxillary sinuses, as well as poor bone quality. This bone can be regenerated however through grafting with autogenous, allogenic, xenogenic, or alloplastic bone, or with a surgical suspension of the sinus membrane that does not necessitate grafting. Sinus lift surgery is the most common procedure in use today in conjunction with implant placement in the posterior maxilla.

Very few studies have specifically investigated the relationship between the orientation of maxillary sinus septa and the occurrence of intrasurgical complications, such as sinus membrane tears, as well as postoperative complications, such as the development of graft necrosis and persistent sinusitis, and long-term implant marginal bone loss. The vast majority of research within the field of sinus lift surgery pertains to the use of autogenous graft as opposed to bone replacement grafts. The use of non-autogenous particulate bone replacement graft has now become the most popular type of graft used during sinus lift surgery. The primary objectives of the present study were to assess the prevalence and severity
of sinus membrane tear complications as they relate to the presence of sinus septa, and to develop a classification system based on these findings. Secondary objectives included the evaluation of other clinical-, implant- or patient-related factors, which may impact on marginal bone loss, as measured on intraoral radiographs.
2. REVIEW OF THE LITERATURE

2.1 Maxillary Sinus Anatomy
The human maxilla contains numerous anatomic structures including the maxillary sinus, the pterygoid plates, the lateral nasal walls, associated nerves, arteries and veins, and teeth. The shape of the maxillary sinus is pyramidal, with the base of this pyramid being the shared lateral wall of the nasal cavity and medial wall of the sinus. The base points towards the zygomatic process of the maxilla. The roof of the sinus is also the shared floor of the orbit. A drainage port for the sinus, the antro-nasal foramen, lies high on the medial wall of the sinus. This port opens into the nasal cavity between the middle and lower nasal conchae.4,5

The average dimensions of the adult maxillary sinus are a width of 25-35mm, a height of 36-45mm, and a length of 38-45mm. Its convex floor is approximately 1cm below the nasal floor, with its deepest point usually being in the first molar region. Roots of the maxillary teeth frequently cause convolutions in the floor of the sinus.5 Anteriorly the sinus extends to the canine or premolar region. The maxillary sinus will maintain its overall size while the posterior teeth remain in function, but tends to expand with age and especially when posterior teeth are lost. The direction of this expansion is both inferiorly and laterally. At the edentate stage expansion often continues such that only a paper-thin bony wall on the lateral and occlusal sides are left. One theory for this expansion is that the alveolar bone exhibits atrophy as the strain from occlusal function is reduced.4

The presence of one or more septa, dividing the maxillary sinus into separate compartments, is a phenomenon first described by A. S. Underwood in 1910.6 There is a wide anatomical variation in their prevalence, size, location, and morphology, irrespective of the degree of atrophy.7 The prevalence of septa can be calculated either at the sinus level, where it is based on the number of sinuses which have one or more septa, or at the patient level, where a count is made based on the number of patients who have at least one septa in either sinus. The overall prevalence at the
sinus level is between 16% and 48%\textsuperscript{7-16} while the prevalence at the patient level is between 21% and 69%.\textsuperscript{9,10,17-21}

In a retrospective study, Neugebauer et al (2010)\textsuperscript{21} found most patients with septa (24.6%) to show one septum in one sinus, while 13.7% showed one septum in each sinus. Septa are most commonly found in the area of the first molar.\textsuperscript{21-23} Septa may be classified either as “primary” or congenital septa, or “secondary” septa which develop following tooth loss and bone resorption of the maxillary alveolar process.\textsuperscript{18} Although it has been proposed that septa act as masticatory force-carrying struts during the dentate phase of life\textsuperscript{24} and disappear slowly as teeth are lost\textsuperscript{5}, evidence in the literature suggests that septa are more prevalent in edentulous regions.\textsuperscript{7,18} Septa in the anterior maxillary sinus tend to be antero-laterally directed from the medial wall of the sinus, while septum located more posteriorly tend to be laterally directed. The direction of septa might be influenced by growth patterns of both the maxilla and palatine bones.\textsuperscript{14} The mean septal height for septa in a sagittal orientation has been found to be 11.7±6.08mm, while the mean height in a transverse orientation was 7.3±5.08mm.\textsuperscript{7} Septa in edentulous maxilla are shorter than those found in dentate cases.\textsuperscript{18}

The maxillary blood supply is essential for preserving the vitality of the region affected by any sinus lift surgery. It is also critical for the integration of any grafting material being used as well as for wound healing. In the atrophied edentulous maxilla the overall vascularity decreases as bone resorption progresses.\textsuperscript{25} The maxillary sinus is perfused primarily by the maxillary artery, with the anterior ethmoidal and superior labial arteries contributing to a lesser extent. The greater/lesser palatine and sphenopalatine arteries supply the sinus floor via penetration through the bony palate. The posterior superior alveolar artery (PSAA) has tributaries that perfuse the posterior and lateral walls. The PSAA and infraorbital artery anastomose in the bony lateral wall, a mean of 16-19mm superior to the alveolar crest.\textsuperscript{25,26} These arteries also supply the Schneiderian membrane. The two anastomoses between these arteries form a double arterial arcade, supplying
the lateral wall of the sinus and parts of the alveolar process. The PSAA can be found either intraosseous within the bony lateral wall or extraosseous medial or lateral to the wall. Its mean diameter has been found to be 1.2-1.3mm with a range of 0.5-2.5mm. Venous drainage of the maxilla is through the sphenopalatine vein into the pterygomaxillary plexus. The sinus is innervated from branches of the maxillary nerve.

The sinus is lined with respiratory epithelium, or pseudo-stratified ciliated columnar epithelium, that covers a loose and highly vascular connective tissue. Underneath the connective tissue and immediately adjacent to the bony walls is periosteum. This epithelium, connective tissue and periosteum make up the Schneiderian membrane. The ciliated epithelium transport fluids such as pus and mucous towards the antro-nasal foramen, or the ostium. Non-hemolytic and alphahemolytic streptococci as well as Neisseria species are normal microbiota which inhabit the sinus. Staphylococci, diptheriods, pneumococci, as well as Hemophilus, Mycoplasma, and Bacteroides species are also found in smaller amounts.

The fact that the antro-nasal foramen lies high on the medial wall of the sinus is a benefit to sinus lift surgery as it is likely not to interfere with graft placement and healing, or normal sinus function. It has been proposed that a maxillary sinus floor elevation may even in fact improve symptoms of sinusitis by bringing the floor of the sinus closer to the drainage port.

Two important walls of the maxillary sinus that pertain to sinus lift surgery are the lateral or buccal wall and the medial or nasal wall. The lateral wall contains thin compact bone, and houses neurovascular canals to the anterior teeth. The lateral wall, on the facial aspect, is covered by periosteum and muscular tissue containing the facial artery and vein, the lymphatic system, and the infraorbital nerves. Posterior teeth if present are innervated from branches of the maxillary nerve entering through the maxillary tuberosity. The internal wall is rectangular in shape.
Its inferior part corresponds with the inferior meatus of the nasal cavity. The antro-nasal foramen is located mid-way up this wall and enters the middle meatus.

### 2.2 Alternatives to Performing a Sinus Lift

There are several alternative techniques available which avoid manipulation of the sinus that have been used in the past. Onlay bone grafts may be used for a horizontal or vertical augmentation of the residual ridge\(^1\), however vertical ridge augmentation using block grafting does not achieve a predictable bone height gain.\(^29\) Although horizontal ridge augmentation by way of guided bone regeneration is predictable, augmentation in a vertical direction is not.

Another option is the placement of implants that are tilted mesially or distally such that they do not enter the sinus cavity, provided these regions have adequate bone quantity.\(^22\) One advantage to this treatment option is that longer implants, with lengths of up to 15mm, can be placed and anchored with larger cortical bone contact.\(^30\) Furthermore, zygomatic implants can be used which either pass through the sinus cavity or laterally and into the zygomatic process.\(^1\) Although these implants yield high survival rates, when complications such as infection occur their removal is challenging.\(^31\) Furthermore, non-axial implants risk an uneven loss of crestal bone after remodelling is complete, leading to increased probing depths.\(^4\)

The simplest solution is placing short implants which greatly reduce the chances of entering the sinus cavity upon insertion. Short implants, ≤8mm in length, when placed without grafting offer the opportunity of a less complex, cheaper, and faster treatment.\(^1\) The success of short implants will be discussed later.

It is possible that in the future the combination of improved implant surface topographies as well as improved surgical techniques may further shift the implant surgeon in favour of short implants.
2.3 Development of the Sinus Lift

The sinus lift has been variously described in the literature as sinus floor augmentation, sinus floor elevation, or augmentation of the atrophic maxillary sinus.\(^1\) Prior to this procedure, clinicians were limited in their armamentarium as to the placement of implants in the posterior maxilla. This particular anatomical region provided the problem of reduced vertical bone height. Elevation of the maxillary sinus floor, or the Schneiderian membrane, is an option in overcoming this obstacle.\(^2,2\) The sinus lift has now become a standard procedure in the treatment of the severely resorbed maxilla before the insertion of implants. It is one of the most reliable procedures in pre-prosthetic surgery.\(^3,2\)

The sinus lift was first reported by Boyne in the 1960s. Boyne and James (1980)\(^3,3\) published a technique on the elevation of the maxillary sinus floor in patients with large, pneumatised sinus cavities in preparation for the placement of blade dental implants. A two-stage procedure was described, whereby autogenous particulate iliac bone was grafted using a modified Caldwell-Luc procedure. In 1986 Tatum described a crestal or transalveolar approach for sinus floor elevation. A “socket former” was used to prepare the implant site by hand tapping, creating a “green-stick” fracture of the sinus floor. The root-formed implant was then immediately inserted.\(^3,4\) In 1994 Summers published another crestal approach, the bone-added osteotome sinus floor elevation (BAOSFE), commonly referred to as the Summer’s technique. Tapered osteotomes with increasing diameters are used to compress soft, type III and IV bone at the implant site by pushing and tapping, while packing bone and raising the sinus membrane.\(^3,5\) The compression of this soft bone results in an increase in bone density and therefore primary stability of inserted implants.\(^3,6\) Volume below the elevated sinus membrane is further increased by the addition of autogenous, allogenic, or xenogenic bone grafts.

A common goal exists in the dental profession today which is to develop a surgical technique that is simpler to perform and which minimizes the chance of
postoperative complications. Currently, two main techniques of the sinus lift are in popular use. The direct sinus lift approach by means of a lateral window modified Caldwell-Luc procedure can involve either simultaneous implant placement, considered a one-stage technique, or delayed implant placement after a healing period, a two-stage technique. The indirect sinus lift approach by means of a crestal access involves a one-stage technique.

2.4 Indications & Contraindications for Sinus Lift Surgery

The main indication for the direct sinus lift is reduced residual bone height, neither allowing the standard placement of implants nor placement in combination with a minor sinus floor elevation via the indirect approach. The main indications for the indirect sinus lift include a flat sinus floor with a residual ridge height of at least 5mm, as well as an adequate crestal ridge width for implant placement.

The direct sinus lift is a more invasive treatment modality than the indirect sinus lift, whether or not performed as a one- or two-stage procedure. However, this technique allows most edentulous areas in the maxilla to be restored with an implant supported prosthesis. Thus it may be considered more versatile. Both techniques, however, are universally-accepted and predictable pre-prosthetic procedures.

Medical contraindications include chemotherapy or radiation of the head and neck region within the preceding 6 months of sinus lift surgery, immunocompromised patients or those with medical conditions affecting bone metabolism, patients with poorly controlled diabetes, and those with a history of drug or alcohol abuse. Non-compliant patients should not be considered for sinus lift surgery. Smoking is not an absolute contraindication to sinus lift surgery as of yet.

Conditions such as viral, bacterial, and mycotic rhinosinusitis, allergic sinusitis, sinusitis caused by intra-sinus foreign bodies, and odontogenic sinusitis resulting
from necrotic pulp tissue are all abnormal conditions that may be clinically asymptomatic but are still contraindications for sinus lift surgery. All odontogenic cysts must be treated preoperatively. Absolute local contraindications include acute sinusitis, allergic rhinitis, chronic recurrent sinusitis, tumours and hypofunctional mucosa. If surgery is still carried out under any of the above-mentioned conditions, it may result in a disruption of the fine mucociliary balance, triggering mucous stasis, a suprainfection, or subacute sinusitis.\textsuperscript{4} Chronic sinusitis, recognized intrasurgically as a thick, spongy membrane, can be recognized pre-operatively as an increased radiopacity within the sinus. Previous sinus surgery may be considered a contraindication since the resulting scar tissue does not allow preparation of an intact, healthy mucosal tissue. Sinus floor convolutions, such as those caused by dental roots, challenging septum, and narrow sinuses may also be contraindications.\textsuperscript{5}

Several contraindications exist that are unique to the indirect sinus lift by means of the osteotome. Those with a history of inner ear complications and positional vertigo are not suitable for the indirect sinus lift. Also, if an oblique sinus floor, or one with >45 degree inclination, exists at the site of implant placement, there is an increased risk of sinus membrane perforation.\textsuperscript{4} Furthermore, the indirect technique is contraindicated in the presence of interfering septa.\textsuperscript{3}

Nasal cavities with larger infraorbital ethmoid cells are more likely to have mucosal thickening and therefore cause obstruction of the maxillary sinus ostium. The prevalence of mucosal thickening in the maxillary sinus has been reported at 59%.\textsuperscript{42} The presence of mucosal thickenings in the maxillary sinus floor usually indicate the presence of irritative stimuli, often due to an odontogenic infection.\textsuperscript{43}
2.5 Pre-operative Planning

2.5.1 Cone beam computed tomography

To avoid complications during a sinus lift procedure, meticulous pre-surgical visualization of the maxillary sinus by means of computed tomography (CT) is recommended, as it has been shown to have higher sensitivity and specificity in the identification of septa than panoramic radiography. Cone beam computed tomography (CBCT) imaging is frequently used to evaluate sinus anatomy prior to dental implant placement. It can generate high resolution isotropic volumetric data with high geometric accuracy and at a low effective radiation dose. Relative to medical CT, dental CBCT can be recommended as a dose-sparing technique, with a reduction in dose of up to 12.3x.

Panoramic radiography has been found to lead to a false diagnosis regarding the presence or absence of septa in 21% to 46.5% of cases. In comparison, the use of CBCT imaging with high spatial resolution allows for the detection of septa with a frequency nearly as high as that found with clinical inspection. The CT scan provides the most reliable preoperative identification of the size and shape of the maxillary sinus, especially as it relates to a narrow sinus. The surgical plan may then be modified accordingly. CT imaging allows for the better detection of any pathology that may be a contraindication to surgery. It also allows for better prediction of intrasurgical bleeding complications. In a study of pre-operative CT scans of patients undergoing sinus lift surgery, Guncu et al (2011) found that the PSAA could be visualized in 64.5% of sinuses. When seen with CT imaging, the PSSA is intraosseous with an incidence of between 53% to 68.2%.

Faint dome-shaped radiopaque lesions at the base of the maxillary sinus may present as obstacles during sinus lift surgery, and should be identified to prevent further complications. Three cystic lesions may be discovered during a routine pre-operative CT scan: pseudocysts, retention cysts, and mucoceles. Pseudocysts lack an epithelial lining. Retention cysts are abnormally enlarged glandular ducts that are
lined with epithelium. Mucoceles, accumulations of mucous, are formed when the sinus ostia are obstructed. As fluid pressure increases against the internal walls of the sinus cavity, bone resorption may be evident. This radiographic feature will distinguish a mucocele from a pseudocyst and retention cyst.

Following a staged sinus lift approach cone beam computed tomography is an ideal means of determining how the bone substitute is positioned in relation to the adjacent bone. Using such imaging eliminates all uncertainty such that exact implant dimensions and their relative positioning can be determined pre-operatively. In conclusion, CT images can be useful to the clinician in both diagnosing and treatment planning in that they enhance the accuracy of diagnostic decisions and help in the formulation of an adequate treatment plan. Due to the fact that the prevalence of septa is relatively high, and both the success of the sinus lift procedure as well as the occurrence of complications are related to their presence, CBCT imaging is highly recommended as part of the preoperative protocol. CBCT imaging should be achieved in keeping with the principle, however, that radiation doses are As Low As Reasonably Achievable (ALARA).

Figure 1. Example of a CBCT image depicting the maxillary sinuses as well as adjacent structures
2.5.2 One- or two-stage technique

The amount of residual bone available directly affects the possibility of achieving primary implant stability and will dictate whether a one- or two-stage technique can be used. The success and survival of implants placed via both the direct and indirect approaches will be discussed later. With regards to the indirect approach, which is always considered a one-stage technique, a minimum cut off of 5 to 6mm residual ridge height has been proposed as a requirement. Evidence however does also support cut offs of 1.5 to 4mm. Thus overall, the decision to proceed with a one-stage technique ultimately rests with the surgeon, their experience, and the minimum residual ridge height they are comfortable with.

2.6 Sinus Lift Bone Grafting Options

2.6.1 Introduction

There are differences in opinion on the necessity of grafting material when performing a sinus lift, either by a direct or indirect approach. These differences are reflected in the large body of research which exists to date on the success and survival of implants placed with and without grafting material, as well as on the various grafting materials that are available when grafting is desired. Overall, the transition from autogenous bone to bone replacement grafts as a donor material has been one of the largest trends in direct sinus lift surgery. The use of biomimetic enhancement factors, used in combination with bone replacement grafts, is also gaining momentum and will be discussed. Success of the graft procedure is measured as it relates to implant placement, and therefore secondary outcome measures including the percentage of histologic vital bone formed as well as clinical implant survival rates are used. To date a certain threshold percentage of vital bone formed that results in implant survival is not known yet. Multiple confounding variables may also affect the observed outcomes in the research available.
2.6.2 Autogenous graft

The gold standard of bone grafting materials since the inception of modern implant dentistry has been autogenous bone as it allows bone formation by way of osteoinduction, osteoconduction, and osteogenesis. Autogenous grafts contain bone morphogenetic proteins (BMPs) which are capable of attracting osteogenic cells from the surrounding tissues. As the direct sinus lift requires a relatively large volume of graft material, donor sites were often extraoral in the past. These sites include the iliac crest, the tibia, the rib and the calvaria. Intra-oral sites include the mandibular body, the ramus as well as symphysis, the zygoma, the zygomatico-maxillary buttress, and the maxillary tuberosity. The harvested bone can be utilized either in block sections or it can be disintegrated into a particulate graft. Particularly when harvested from the iliac crest, postoperative complications such as scarring, nerve injury, chronic pain, and even fractures have been reported with an incidence of 20%. Furthermore, the increased operating costs when harvesting from an extraoral site, including the need for general anaesthesia as well as hospitalization, should be taken into consideration. The use of autogenous grafts in a delayed approach was recommended by the Academy of Osseointegration Sinus Concensus Conference of 1996. To date, long-term reports on sinus floor elevation using bone substitute materials are scarce in comparison to reports using autogenous bone, likely due to their relatively recent introduction.

2.6.3 Implant survival as per graft material

Wallace et al (2003) conducted a systematic review on the efficacy of both the direct and indirect sinus lift. 43 studies involving over 6,400 implants with a minimum follow up period of 1 year loading were included. Although the autogenous iliac block grafting technique was found to result in a significantly lower implant survival rate than all particulate grafts combined, 83.3% versus 92.3%, this lower survival rate was likely due to the overall difficulty level of the procedure, the fact that the block graft tended to resorb, and the fact that older studies tended to use machine-surfaced implants.
Del Fabbro et al (2004)\(^{39}\) carried out a systematic review on the survival rates of implants placed in the grafted maxillary sinus. 39 studies with over 6,900 implants with a minimum follow up period of 1 year loading were included. Implants placed into sinuses grafted with autogenous bone were found to have a survival of 87.70%. Survival was 94.88% when autogenous bone was combined with bone substitutes, and 95.98% when bone substitutes were used alone.

In a review of ridge augmentation techniques for implant placement Aghaloo et al (2007)\(^{41}\) found that survival was 81% for implants placed into alloplast and alloplast/xenograft combinations, 92% for implants placed into either autogenous or autogenous/composite combinations, 93.3% for implants placed into allogeneic/non-autogenous composite grafts, and 95.6% for implants placed into xenografts. 90 studies with over 5,100 implants with a minimum follow up period of 1 year were included. It was concluded that the long-term, or greater than 5 year, success and survival of implants placed into augmented bone, regardless of the grafting material used, was similar to or better than that of implants placed in straightforward sites where no grafting was required.

Pjetursson et al (2008)\(^{22}\) conducted a systematic review to assess the survival rate of grafts and implants placed using the direct sinus lift. When only studies reporting on rough surface implants were included in the analysis, 5,600 implants were included. The 3-year survival rates were similar for all types of grafting materials, and ranged from 96.3% to 99.8%.

Del Fabbro et al (2008)\(^{2}\) evaluated implant survival rates in the grafted sinus with respect to implant surface, graft material, and implant placement timing. 59 studies with more than 13,000 implants with a minimum follow up period of 1 year of loading were included. The overall implant survival rate using autogenous graft was 88.9%. Combinations of autogenous graft and either xenograft, allograft, or alloplast resulted in a survival rate of 94.7%, while grafts containing bone substitute only had an implant survival rate of 96.1%. It was concluded that implants inserted in grafts
of bone substitutes alone or in combination grafts, may achieve higher survival rates than implants inserted in autogenous bone. It is misleading however to interpret this as combined grafts or substitute grafts being able to produce better results than autogenous bone.

Nkenke et al (2009)\textsuperscript{32} conducted a systematic review comparing the advantages and disadvantages of using autogenous bone and bone substitutes in the direct sinus lift. 21 studies with implants with a minimum follow up period of 1 year loading were included. It was concluded that the current literature only provides a low level of evidence with which to guide the surgeon in favour of one graft over another. The influence of residual bone height, simultaneous or delayed implant placement, sinusitis, and graft resorption on implant survival as it relates to the graft material used cannot be identified as of yet.

Jensen et al (2009)\textsuperscript{62} performed a review of the efficacy of different grafting protocols in the augmentation of localized alveolar ridge defects. 47 studies with more than 5,300 implants with a minimum follow up period of 1 year loading were included. It was concluded that autogenous block grafts reduce implant survival as compared to particulated autogenous grafts, which might be a confounding factor in comparing the implant survival between autogenous grafts and bone substitutes. With regards to the direct sinus lift, median survival for rough surface implants was 96.8\% with the use of bone substitutes and 100\% with particulated autograft.

Esposito et al (2010)\textsuperscript{31} conducted a review to assess whether and when sinus lift procedures are necessary, and if one particular sinus lift technique is more effective. 10 studies involving 250 patients were included. It was concluded that bone substitutes are as effective as autogenous grafts, and therefore they could be used as a replacement.

Of the reviews mentioned, a consensus may be obtained such that more favourable results in terms of implant survival may be achieved with bone substitute grafts,
than with autogenous bone. Confounding variables such as implant surface texture and particulated autogenous versus block autogenous graft material should be taken into consideration when interpreting the results mentioned.\textsuperscript{37}

### 2.6.4 Xenograft, allograft, alloplast

The type of bone graft used as well as its particle size, if a particulate graft is chosen, will influence the quality of final grafted bone, the speed of osseous turnover, and the final bone density. These factors will determine the clinician’s timeline of implant placement. Particulate bone in modern clinical practice is the most popular type of graft used for sinus grafting.\textsuperscript{3}

Xenografts constitute a large proportion of bone substitutes evaluated in the comparison with autogenous graft. Xenograft success may be attributed to the fact that it is osteoconductive with the formation of approximately 25% vital bone by volume at 6 to 8 months. Furthermore, xenograft does not appear to resorb with time, which results in the addition of approximately 25% of mineral content to the future implant receptor sites, although this residual graft material is non-vital. Finally, histologic evaluation has revealed that the residual graft material is never seen in direct contact with the implant surface, and therefore it does not appear to interfere with osseointegration. Instead the residual graft particles are interconnected by segments of new vital bone, a process that has been termed “bone bridging”.\textsuperscript{37} Thus xenograft may be considered the gold standard non-autogenous sinus grafting material.\textsuperscript{63}

Testori et al (2013)\textsuperscript{64} compared histologic and histomorphometric vital bone formation and residual graft volume 6 to 8 months after bilateral direct sinus lifts were performed in 13 patients with either small particle size, 0.25-1.00mm, or large particle size, 1.00-2.00mm, Bio-Oss deproteinized bovine bone mineral xenograft in a prospective, randomized, controlled clinical trial. Large particle grafts had significantly more extensive vital bone formation compared with small particle grafts, 26.8% versus 18.8%.
In a prospective histologic, histomorphometric, radiographic and clinical study involving 113 direct sinus lifts using OsteoGraf/N deproteinized bovine bone mineral xenograft alone or in combination with autogenous bone or demineralized freeze dried allograft, Froum et al (1998)\textsuperscript{65} found that after 6-9 months, combinations of 80% xenograft and 20% autogenous bone resulted in a significantly increased amount of vital bone compared to xenograft alone. By allowing for an increased amount of vital bone formation, such a combination of xenograft and autogenous bone may accelerate the graft maturation time. At the same time, the xenograft acts as a slowly-resorbing space maintainer.\textsuperscript{66} The increased patient morbidity associated with the harvest of an autogenous graft must be taken into account, however.\textsuperscript{37}

Kolerman et al (2012)\textsuperscript{63} compared the use of Bio-Oss xenograft and Oragraft freeze dried allograft in a randomized clinical, histologic and histomorphometric study of 5 patients receiving bilateral direct sinus lifts. Allograft and xenograft were placed in contralateral sinuses. After 9 months, sinuses grafted with allograft and xenograft had achieved similar proportions of newly formed bone, 31.8% and 27.2% respectively. It was concluded that both graft materials were suitable to be used in sinus lift surgery.

Cha et al (2011)\textsuperscript{67} evaluated the 3.5-year cumulative survival rate (CSR) of 45 implants placed in conjunction with direct sinus lift surgery, in either an immediate or delayed approach in 12 patients with Osteon, an alloplast containing 70% hydroxyapatite and 30% β-tri-calcium phosphate. This case series also assessed the radiographic resorption rate of the grafted material. A CSR of 95.56% was found. There was no significant difference in the reduced height of Osteon according to simultaneous or delayed implant placement. It was concluded that Osteon may have predictable results when used as a grafting material due to its osteoconductive properties. Although promising results have been shown with allografts and alloplasts, to date these studies are fewer in number in comparison with xenografts and autogenous grafts.\textsuperscript{37}
2.6.5 Biomimetic and stem cell technology

The recent introduction of biomimetic and stem cell technology has further broadened the scope of research in implant dentistry by providing a means to achieve either more favourable or comparable outcomes to that of autogenous grafts.\(^\text{37}\) Triplett et al (2009)\(^\text{68}\) evaluated the safety and effectiveness of recombinant human morphogenetic protein-2 (rhBMP-2) in an absorbable collagen sponge (ACS) compared with autogenous graft, harvested either intraorally or extraorally, when used in two-stage direct sinus lift surgery. 160 subjects were included in this multicentre randomized, clinical, radiographic and histologic study. 6 months post-loading the induced bone formation in the rhBMP-2/ACS group was significantly denser than in the autogenous graft group, however no significant histologic differences were seen between the graft materials. Implant survival rates were also similar between groups. Drawbacks to this procedure include high cost, immature bone quality at early time intervals, a noticeable incidence of graft shrinkage\(^\text{37}\), and significant post-operative swelling.\(^\text{69}\)

Furthermore, the safety of rhBMP-2 is to be questioned. Carragee et al (2011)\(^\text{70}\) carried out a systematic review comparing the safety and efficacy of rhBMP-2 published in industry-sponsored trials on spinal fusion with follow-up publications by the Food and Drug Administration. It was revealed that the original trials did not report any rhBMP-2-associated adverse events, while in fact multiple adverse events occurred including infection, ectopic bone formation, and an increased risk of malignancy. No adverse events have been reported as of yet in the literature pertaining to sinus grafts.\(^\text{37}\) It has been recommended though that rhBMP-2 not be used in patients with an active malignancy, in those being treated for a malignancy, or in areas of existing or resected tumours.\(^\text{69}\)

Considerable research exists on the topic of platelet-rich plasma (PRP) in enhancing the outcomes of sinus lift surgery. It is produced by the centrifugation of freshly drawn venous blood from the patient, and has been proposed as a natural source for multiple growth factors including platelet-derived growth factor, insulin-like growth
factor, vascular endothelial growth factor, transforming growth factor-β, and platelet-derived angiogenic factor. Readily available centrifuge systems used in implant surgery are able to increase the concentration of platelets 3-fold, depending on the initial whole blood platelet count. Following the activation and placement of PRP, these growth factors are released. Although it may lead to enhanced soft tissue healing, PRP has not been found to significantly increase the production of vital bone or bone-implant-contact in sinus lift surgery. Overall, there is a lack of critical scientific research that shows that the addition of PRP to bone grafting material improves the outcome of sinus lift procedures. Research on PRP is ongoing, however, and it appears to show promise when used as a vehicle for mesenchymal stem cell grafting in the sinus.

Recombinant human platelet-derived growth factor ββ (rh-PDGFββ), available in combination with the osteoconductive matrix beta tricalcium phosphate (β-TCP) as Growth-factor Enhanced Matrix (GEM 21S) has been well documented for its use in enhancing periodontal regeneration. During wound healing, PDGF is both chemotactic and mitogenic for osteoblasts, and it stimulates osteoblast type I collagen synthesis. The concentration of growth factors in GEM 21S is estimated to be 3000 times that of whole blood. At present GEM 21S has not been indicated for use in sinus lift surgery. Pilot studies have shown promising results however.

Nevins et al (2009) assessed the clinical and histologic outcomes of 13 two-stage direct sinus lifts, performed in 10 patients with a combination of GEM 21S and Bio-Oss Xenograft. No serious postoperative adverse events occurred. Histologic outcomes at 6-8 months postoperative were not uniform across all grafted sites. Although many cores showed broad areas of well-formed bone, other cores did not show robust bone regeneration.

Froum et al (2013) conducted a blinded randomized controlled trial to compare the efficacy of Bio-Oss xenograft with and without rh-PDGFββ in producing vital bone at 4 to 5 months and 7 to 9 months following direct sinus lift surgery.
patients received bilateral sinus lifts. At 4 to 5 months, sinuses with xenograft and rh-PDGFββ showed significantly increased vital bone formation compared to sinuses with xenograft alone, 21.1% versus 11.8% respectively. The difference between groups disappeared in the 7 to 9 month cores. By allowing for more rapid vital bone formation, the use of rh-PDGFββ combined with xenograft could allow for earlier implant placement.

Gonshor et al (2011)75 compared bone formation following direct sinus lift surgery using Osteocel particulate cellular allograft containing native mesenchymal stem cells and osteoprogenitor cells, with conventional particulate allograft, in 18 patients in a clinical, histologic, and histomorphometric study. 26 sinuses were augmented, of which 8 were bilateral. In the bilateral cases, a split-mouth design was used comparing the grafting materials. Of the sinuses which were biopsied, an average vital bone content of 32.5% was found for Osteocel-grafted sinuses, compared with 18.3% for sinuses with conventional allograft, at an average of 3.7 months. It was concluded that the higher percentage of vital bone content provided by Osteocel after a relatively short healing phase might encourage more rapid implant placement.

2.6.6 Direct approach – without bone graft material
The tenting effect created by implant placement during a one-stage direct sinus lift surgery, combined with either the reliance on a blood clot or the insertion of centrifuged autogenous blood for wound stabilization has also been studied as an alternative to placing a bone graft. Lin et al (2011)76 measured the height of new bone formation following one-stage direct sinus lift surgery through the use of panoramic and CBCT imaging. 44 patients received 80 implants without the addition bone graft material. After 5 years, the average gained bone height was 7.44mm, and implant survival was 100%. Mazor et al (2009)58 performed 25 one-stage direct sinus lifts on 20 patients using autogenous leukocyte- and platelet-rich fibrin as the sole grafting material. 41 implants were inserted. Panoramic and CBCT imaging taken 6 months later revealed an average gained bone height of 10.1mm. At this
same time point, histologic samples showed well-organized and vital bone. An implant success rate of 100% was reported.

2.6.7 Bone grafts - summary
As multiple reviews have found implant survival rates of 95% or greater when using rough surface implants and xenografts, it is unlikely that implant survival can be significantly improved with the use of biomimetic and stem cell technology. More rapid graft maturation is possible though with this technology, thus overall treatment times may be reduced.\textsuperscript{37} The cells used in the majority of mesenchymal stem cell studies are bone marrow-derived, however cells derived from periosteum and adipose tissue are also gaining popularity. Although research to date regarding the use of biomimetic and stem cell technology in sinus lift surgery is largely comprised of either case series or case control studies, their outcomes are consistently positive when compared with conventional grafting techniques. Larger, well-designed randomized clinical trials with longer follow up periods are needed to validate their use.\textsuperscript{60}

Overall, the superiority of any one given material or technique over another must be assessed by randomized clinical trials, and the literature addressing this specific research question is still too scarce to draw definitive conclusions.\textsuperscript{2}

2.7 Sinus Lift Techniques
2.7.1 Direct approach – one/two-stage – rotary/piezoelectric access
The lateral window modified Caldwell-Luc procedure involves exposure of the lateral sinus wall. Surgical access can be performed in two different fashions. The “trap-door technique”, the more popular of the two, involves an in-fracturing of the lateral sinus wall like a trap-door and using it as the superior border of the sinus compartment while leaving it attached to the underlying Schneiderian membrane. The less-popular technique involves preparing an access hole by removing the entire lateral plate before the sinus membrane is elevated.\textsuperscript{22}
The presence of septa and the extent of their vertical height from the sinus floor will determine the shape of the lateral window access. If a trap-door is selected, then a short septum will allow a door preparation of normal shape as it will not block the door once it is luxated and turned inward and upward. If a taller septum is noticed preoperatively the clinician has three options: 1) the door can follow the contour of the septa in a scalloped W-shape, 2) two separate trap doors can be prepared, or 3) or an indirect sinus lift by means of a crestal access should be considered mesial or distal to the septum.5

When indicated, the creation of a large window allows the exposure and elevation of the sinus membrane from all bony walls, including the lateral wall of the nasal cavity, the maxillary tuberosity, the floor, and the posterior wall. When implant placement is planned in the canine and premolar regions, minimal buccal-palatal dimension can sometimes constrict access such that the implant is inclined far too palatal. A large window improves access and allows just enough fracture of the lateral wall of the nasal cavity such that it can be pushed inward in order to create space for appropriate implant angulation.55 When designing the lateral window it has been recommended however that its superior border be limited to a maximum of 18mm from the ridge in order to avoid any potential vascular damage.16 Furthermore, when extending the window in either an anterior or posterior direction, care must be taken in avoid dental neurovascular branches. Any surgical approach apical of vital neighbouring teeth might devitalize them.5

Marking of the outline of the osteotomy can be achieved using a surgical round carbide bur. The bony plate of the window is then shaved to a paper-thin plate using a fine grit round diamond bur until the bluish hue of the sinus membrane becomes visible. At this point the bony plate is either removed prior to elevation of the sinus membrane, or in-fractured to be used as the superior border of the sinus compartment. If removed, the Schneiderian membrane is elevated directly with blunt instruments. If a trap door is planned, the bony plate is gently tapped until it is
mobilized. Then, as the sinus membrane is elevated from its inferior aspect using curettes, the bony plate is rotated inwards and upwards.4

The shapes of the instruments available during the procedure play a role in the need to remove parts of the septa to facilitate membrane release. Small septa, with a height of up to 2mm, do not require resection as the membrane can be elevated as usual. Medium-sized septa, which are taller than 2mm but which do not completely divide the sinus into multiple cavities, may require resection in order to allow access to the palatal area of the sinus cavity. Large septa, which can cause partial or complete separation of the sinus cavity, may require the preparation of two separate cavities. Furthermore, septa orientation in either a sagittal, coronal, or transverse plane may limit the mobility of the instruments being used such that the access may need to be increased vestibularly, so as to avoid uncontrolled pressure on the sinus membrane.21 Second premolar sites are the most difficult areas for sinus membrane elevation due to the sharp angle formed by the medial and lateral walls of the sinus.77 Contours of dental roots in sinus floor can also make sinus membrane elevation difficult, increasing the risk of a tear.49

A separate lateral window osteotomy technique, called the lateral bone planning antrostomy, involves the use of a series of diamond-coated dome-shaped drills from the Dentium Advanced Sinus Kit (DASK), which utilize both internal and external irrigation. Bone thinning is achieved using light pressure and rotating strokes such that the bony plate is gradually eliminated and the sinus membrane is visualized. Hydraulic pressure by way of internal irrigation also assists in the separation of the sinus membrane from its cortical housing. Sinus membrane elevation is continued with curettes.78

Alternatively, the bony lateral window osteotomy and sinus membrane elevation can both be carried out using a piezoelectric hand piece (Mectron Piezosurgery System). By using bone scalpels that work with ultrasonic modulating vibrations of 25.25-30kHz, membrane perforation is avoided because the surgical action of the
scalpel ceases when it comes into contact with non-mineralized tissue. The scalpels are given a specific vibration that also allows the cut to be kept clean of bone splinters. Piezoelectric elevators, when in contact with the internal sinus bony walls, cause separation of the sinus membrane by way of both ultrasonic vibrations and hydropneumatic pressure. The bony window outline is carved to a depth of approximately 1mm or until the frame of the window is represented by the Schneiderian membrane, using a piezoelectric scalpel. The angles of the window are then rounded. Next, an overturned cone compressor is inserted into the edge of the frame, separating the borders approximately 2mm. Then, either an angled or straight piezoelectric periosteal elevator is used to separate the membrane from its mesial, distal, and crestal internal attachments to the sinus cavity. Although the bony plate of the window is not shaved, the trap-door technique is still used.79

Membrane integrity is crucial as it plays an important role in the containment of the bone graft5. Its integrity can be diagnosed either using the Valsalva maneuver, or by careful inspection that the bony window or membrane moves along with respiratory rhythm.79 If a two-stage sinus elevation is chosen, grafting material is placed into the newly made compartment. The lateral window is then covered with a resorbable or non-resorbable barrier membrane and the flap is closed. If a one-stage sinus elevation is chosen, the implant sites are prepared after sinus membrane elevation. Before placing the implant, grafting material is placed into the medial aspect of the sinus compartment. After the implants are placed, the lateral part of the compartment is also filled with grafting material.4

Soardi et al (2012)80 introduced a crestal window direct sinus lift for staged implant placement in the extremely atrophic maxillary ridge. Following exposure of the residual ridge, a piezoelectric unit is used to outline the window, whose dimensions match the width of the crest. Upon mobilization of crestal window, it is pushed inwards towards the superior aspect of the sinus while the sinus membrane is elevated from its bony walls. A new cavity is created such that its roof is the
mobilized alveolar crest. A particulate bone graft is inserted and a resorbable barrier membrane is used to cover the site.

2.7.2 Indirect approach – one-stage – rotary/osteotome/piezoelectric access

The crestal approach modified osteotome technique involves exposure of the residual ridge followed by precise location of the implant positions. The opening of the preparations are widened with round burs until a diameter is reached that is 0.5mm smaller than the implant diameter that is chosen. The distance from the crestal floor of the ridge to the floor of the maxillary sinus can be compared with preoperative measurements by using a blunt periodontal probe through soft trabecular type III or IV bone to the floor of the sinus cavity. After confirming this distance, pilot drills with diameters approximately 1.5mm less than the implant diameter are used to prepare the implant site to a distance 2mm below the sinus floor. In cases of minimal ridge height or type IV bone, pilot drills are not necessary. A small diameter tapered osteotome is inserted 1mm further than the sinus floor such that a “green stick” fracture is created in the compact bone of the sinus floor. The second, wider tapered osteotome is used to enlarge the fracture area. The third osteotome is inserted to the same depth and is straight, with a diameter 1.5mm less than the implant diameter.⁴

If grafting material will not be placed, the final osteotome is inserted. This osteotome has a form and diameter appropriate for the planned implant, 0.5mm smaller than its implant diameter, and is only inserted once, such that implant primary stability is maximized. Before implant placement the osteotomy should be checked with a depth gauge such that it is patent to the planned insertion depth.⁴

If grafting material is being placed, care is taken in avoiding osteotome insertion beyond the sinus floor. A pressure of fluid consistency is created when the combination of repositioned autogenous bone particles, grafting material, and trapped fluid are forced upward, lifting the membrane from the sinus cavity. A Valsalva maneuver is used to assess membrane integrity prior to graft insertion. 0.2-
0.3g of grafting material should be inserted into the sinus cavity. At the end of graft insertion, the osteotome tip should be able to enter 1mm into the sinus cavity and resistance should be felt. Prior to implant placement the osteotomy is checked for patency and the Valsalva maneuver is repeated. When carrying out the indirect sinus lift using an osteotome kit, in the absence of direct visualization by means of an endoscope, it has been recommended that sinus membrane elevation should not exceed 3mm in order to avoid a membrane perforation.

Trombelli et al (2010) introduced a minimally-invasive crestal approach using a combination of specially designed drills and osteotomes (Smart Lift) that incorporated adjustable stop devices that restrict the working action of burs and osteotomes to the residual ridge height. Thus the risk of sinus membrane perforation is minimized. Following ridge exposure, a locator drill perforates the cortical bone to a depth ≤3.5mm. A 1.2mm diameter end-cutting probe drill, with the adjustable stop set 1mm shorter than ridge height. Next, a 1.2mm diameter probe osteotome, also set 1mm shorter than ridge height, is inserted and gently forced in an apical direction until the cortical resistance of the sinus floor is met. Then a guide drill approximately 0.8mm narrower than the planned implant is inserted, creating a 2mm deep crestal countersink. A trephine bur is used to create a bone core up to the sinus floor. The bone core is then condensed and malleted, using an osteotome, such that it is imploded above the sinus floor. Particulate bone graft is further condensed into the sinus depending on the extent of vertical ridge augmentation required. This is followed by implant placement.

Complementary to the lateral bone planning antrostomy previously discussed, Lozada et al (2011) also described a crestal bone planning antrosomy. After preparing the implant osteotomy 1mm short of the sinus floor, a set of diamond-coated dome-shaped DASK drills with both internal and external irrigation are used to eliminate all remaining bone below the sinus membrane. Then, a set of crestal sinus curettes are used to free the membrane above the osteotomy. Following verification of membrane integrity using the Valsalva maneuver, particulate graft
material is inserted and then displaced underneath the membrane using a dome-tipped curette. This is followed by implant placement.

Domkowski et al (2011) reported on another crestal approach using both side and end-cutting drills with vertical stoppers as well as hydraulic pressure for sinus membrane elevation, the Crestal Approach Sinus (CAS) Kit from Hiossen. A 2mm diameter twist drill used to prepare an osteotomy 1-2mm below the sinus floor. Then a series of end-cutting CAS drills of increasing diameter and with vertical stoppers are used, which feature rounded peripheral edges and a conical centre. These drills create a conical bone chip that remains attached to the sinus membrane. Autogenous bone can be collected from the drill flutes. Next, a combined depth gauge and sinus probe is used to check the osteotomy and begin sinus membrane elevation. A hydraulic lifter is then used to introduce 1mL of sterile saline into the sinus cavity. Bone graft material is then condensed through the osteotomy. Next, a rotary bone spreader with a vertical stop is used to evenly distribute bone and encourage further sinus elevation. This is followed by implant placement.

Penarrocha-Diago et al (2012) reported on a crestal approach using a balloon for sinus membrane elevation in sites with minimal residual ridge height. A combination of implant drills and osteotomes are used to prepare the osteotomy within 1mm of the sinus floor. An osteotome is then used to fracture through the sinus floor. A saline-filled latex balloon is inserted through the osteotomy and slowly filled with ≤4mL of fluid. This process is repeated several times. Particulate graft material is then inserted into the subantral space, and this is followed by implant placement.

Kim et al (2012) reported on a crestal approach using hydrodynamic piezoelectric internal sinus elevation (HPISE). Upon nearing the sinus cavity, a 1.6mm wide round carbide piezoelectric insert with external irrigation is used to fracture the sinus floor and provide tactile sensation of the sinus membrane. Then a 2.8mm wide cylindrical HPISE insert with internal irrigation is used to enlarge the osteotomy site
and elevate the sinus membrane. Sinus membrane integrity is confirmed using the Valsalva maneuver as well as the backflow of saline through the osteotomy site. Following bone graft material insertion the implant is placed.

Velazquez-Cayon et al (2012) also reported on a crestal approach using a piezoelectric handpiece. Their hydrodynamic sinus lift technique involves the use of the Satelac Acteon TKW Intralift Kit and Implant Center 2 Piezotome. A higher power setting is used at the ridge crest, and as the osteotomy progresses towards the sinus incrementally less power is used. A conical diamond tip is first used as a pilot drill, followed by a cylindrical diamond tip of three increasing diameters. The final tip, non-diamond coated and non-cutting, is used to elevate the sinus by means of hydrodynamic pressure.

2.8 Complications in Sinus Lift Surgery

2.8.1 Introduction

Complications encountered in sinus lift surgery include membrane perforation, bleeding, sinusitis, cyst discovery, sinus cavity obliteration, implant dislodgement, and sequestration and infection of bone graft material. Paraesthesia and vertigo are also rare complications. The incidence and management of these complications will be discussed.

2.8.2 Incidence of perforations

Schneiderian membrane perforation is the most common complication that is encountered during sinus lift surgery. Although advanced imaging modalities are available in identifying sinus septa, and despite the fact that considerable research has been undertaken in improving the surgical technique, membrane perforations still occur, even in the hands of the experienced surgeon. Any tear in the membrane will result in a direct communication between the graft material and the contaminated sinus cavity. Especially when bone graft material is placed during the sinus lift, this perforation reduces the guarantee of initial graft stability. This
initial stability is necessary in promoting vascularization such that the graft can mature and mineralize.\textsuperscript{79} A graft exposed to the sinus cavity can also result in infection, chronic sinusitis, and the eventual loss of graft volume.\textsuperscript{47}

The incidence of reported perforations during direct sinus lift surgery has ranged from 0 to 57.5\%: 0\% in 25 sinuses\textsuperscript{58}, 0\% in 98 sinuses\textsuperscript{97}, 4.1\% in 49 sinuses\textsuperscript{3}, 11.1\% in 72 sinuses\textsuperscript{88}, 11.5\% in 52 sinuses\textsuperscript{89}, 20.0\% in 30 sinuses\textsuperscript{90}, 21.9\% in 474 sinuses\textsuperscript{91}, 23.6\% in 216 sinuses\textsuperscript{92}, 25.8\% in 182 sinuses\textsuperscript{93}, 31.8\% in 110 sinuses\textsuperscript{94}, 44.4\% in 81 sinuses\textsuperscript{95}, 57.5\% in 40 sinuses.\textsuperscript{96}

The risk of membrane perforation can be reduced by planning a direct approach by means of a lateral access.\textsuperscript{21} The risk can also be reduced by selecting cases with an increased residual ridge height.\textsuperscript{94} However, even with careful preparation and reflection, mobilization of the membrane along anatomical irregularities cannot always prevent a tear.\textsuperscript{21} When using rotary and hand instruments in a direct approach, it has been argued that the occurrence of perforations is equally attributable to the preparation of the osteotomy, the initial release of the membrane at the osteotomy margins, and the continued elevation of the membrane from the internal sinus walls.\textsuperscript{97} Aimetti et al (2008)\textsuperscript{98} obtained sinus membrane biopsy specimens and compared their thickness to the gingival thickness of the maxillary anterior teeth. It was found that increased gingival thickness could be used to reliably predict increased sinus membrane thickness. In a fresh human cadaver study, Pommer et al (2009)\textsuperscript{99} found that the membrane could be stretched up to 132.6\% of its original size in a one-dimensional elongation, and up to 124.7\% in two-dimensional elongation before tearing. Thicker membranes showed significantly higher load limits.

Evidence in the literature is variable with respect to the superiority of piezoelectric instruments over conventional rotary and hand instrumentation in avoiding sinus membrane perforations. The incidence of reported perforations during direct sinus lift surgery in studies that declared the sole use of rotary and hand instruments has
ranged from 20.0 to 44.4%: 20.0% in 30 sinuses\textsuperscript{90}, 23.6% in 216 sinuses\textsuperscript{92}, 25.8% in 182 sinuses\textsuperscript{93}, 44.4% in 81 sinuses\textsuperscript{95}. The incidence of reported perforations during direct sinus lift surgery in studies that declared the sole use of piezoelectric instruments has ranged from 0 to 11.5%: 0% in 25 sinuses\textsuperscript{58}, 4.1% in 49 sinuses\textsuperscript{3}, 7% in 100 sinuses\textsuperscript{97}, 11.5% in 52 sinuses\textsuperscript{89}. Although from this review it would seem that piezoelectric instrumentation is superior in avoiding a perforation, a randomized controlled trial by Rickert et al (2013)\textsuperscript{88} comparing the performance of piezoelectric and rotary instruments in 36 patients receiving bilateral direct sinus lifts found no significant difference with respect to the rate of membrane perforation.

The main disadvantage of the indirect sinus lift by means of osteotome access is the uncertainty of possible sinus membrane perforations\textsuperscript{4}, although this conclusion may be applied to all forms of indirect sinus lift surgery as the membrane cannot be directly visualized. The incidence of reported perforations during indirect sinus lift surgery has ranged from 0 to 21.4%: 0% in 237 patients\textsuperscript{100}, 3.3% in 30 sinuses\textsuperscript{101}, 3.7% in 54 sinuses\textsuperscript{102}, 4.0% in 250 sinuses\textsuperscript{85}, 16.7% in 6 sinuses\textsuperscript{84}, 21.4% in 14 sinuses\textsuperscript{96}. In a randomized cadaver study comparing indirect sinus lifts performed by either the modified Summer’s osteotome technique, the DASK crestal bone planning antrostomy, or the Dentium osteotome technique, Garbacea et al (2012)\textsuperscript{103} found endoscopic examination to reveal no significant difference with respect to the incidence of perforations. In another randomized cadaver study, Chan et al (2013)\textsuperscript{104} compared indirect sinus lifts performed by either the modified osteotome technique or the Sinus Lift Balloon kit. It was found that the balloon and conventional osteotome techniques were comparable in terms of the rate of perforations, and that the residual ridge height did not influence the perforation rate with respect to either technique.

2.8.3 Management of perforations
A variety of techniques have been reported in the literature to manage sinus membrane perforations, including suturing, the use of collagen membranes, fibrin
sealants, freeze-dried human lamellar bone sheets, and oxidized regenerated cellulose. Repair has been reported for perforations ranging in size from 2 to 15mm.\textsuperscript{105}

Fugazzotto and Vlassis (2003)\textsuperscript{106} devised a classification and repair system for direct sinus lift membrane perforations based on their location and severity. Class I perforations occur at any point along the most apical wall of the prepared osteotomy. Class II perforations occur along the lateral or crestal aspects of the osteotomy, and are further subdivided according to their relative position to the most mesial, distal, or crestal extension of the exposed sinus. Class III perforations occur at any location within the body of the lateral window osteotomy. In all perforations manipulation of the membrane to determine the size of the tear is to be avoided. Next, access to the lateral window osteotomy is to be increased by means of further reflection of the mucoperiosteal flap. In Class I perforations, further membrane reflection will result in the membrane folding over itself, thus sealing the perforation. Collagen tape can be placed over the area and the sinus lift can proceed as originally planned. In Class II perforations, the osteotomy can sometimes be extended further, exposing intact membrane, and collagen tape can be used to cover the perforation. If the osteotomy cannot be extended, a bioabsorbable membrane is inserted into the sinus window, with its borders extruding outside. These borders are secured with fixation tacks at all 4 external corners of the lateral window, thus creating a sinus cavity inside which bone graft material can be placed. Class III perforations are often pre-existing due to trauma or prior tooth extraction and are treated similarly as in Class II cases.

Pikos (2008)\textsuperscript{105} described a modification of the fixated membrane technique as reported by Fugazzotto and Vlassis in 2003, indicated for the repair of all perforations greater than 15mm. The lateral window osteotomy is enlarged such that remnants of the sinus membrane can be elevated from all sinus cavity walls, including the posterior wall. This allows for direct contact of the bone graft material with its bony blood supply, and it also prevents epithelial invagination in between
the graft and sinus floor. A large collagen membrane is rounded at its corners and 10mm slits are created at each corner. Contrary to Fugazzotto and Vlassis, the membrane is externally tacked only at the superior and lateral aspects of the window, allowing the membrane to drape inferiorly and internally. Particulate bone graft material is then inserted with PRP. The PRP is intended to act as an adhesive, helping to adapt the membrane with the internal sinus walls.

In a systematic review by Pjetursson et al (2008)\textsuperscript{22}, it was reported that smaller perforations less than 5mm were generally closed using tissue fibrin adhesive, suturing with Vicryl, or by covering them with a resorbable barrier membrane. With perforations greater then 5mm, larger barrier membranes, freeze-dried human lamellar bone sheets, or suturing was used either alone or in combination with tissue fibrin adhesive such that the bone graft material could still be placed and supported by a superior border. Perforations detected during an indirect sinus lift may be repaired with a collagen plug placed into the osteotomy before implant placement.\textsuperscript{47}

Although techniques for repairing large and complete perforations have been documented, surgical abandonment remains an option in cases where the risk of further membrane deterioration outweighs the benefit of an attempted repair. The incidence of reported surgical abandonment in direct sinus lift surgery has ranged from 0.5\% to 2.5\%: 0.5\% in 216 sinuses\textsuperscript{92}, 2.0\% in 201 sinuses\textsuperscript{107}, 2.5\% in 81 sinuses\textsuperscript{95}, although the vast majority of clinical studies have not reported surgical abandonment.

\textbf{2.8.4 Incidence and management of bleeding}

As mentioned previously, the maxillary sinus is perfused primarily by the maxillary artery. In particular, the PSAA and infraorbital artery anastomose in the bony lateral wall of the sinus. Although pre-operative imaging assists in locating this anastomosis, it sometimes cannot be avoided during preparation of the lateral window osteotomy during direct sinus lift surgery. Bleeding from this artery is
usually minimal, but it can sometimes occur with an intensity such that the procedure cannot be continued until the bleeding is controlled. In rare instances, completion of the sinus lift is delayed by as much as 20 minutes.\textsuperscript{97}

In a CBCT scan study by Elian et al (2005)\textsuperscript{26}, it was estimated that the PSAA, when intraosseous, has the potential to cause bleeding complications in approximately 20\% of normally positioned lateral window osteotomies. In a cadaver and CBCT scan study by Ella et al (2008)\textsuperscript{28}, it was concluded that the probability of a high risk of hemorrhage increases with PSAA diameter such that the probability is >10\% with a diameter of 0.5 to 1.0mm, and 57\% with a diameter of 1 to 2.0mm. The surgeon should expect a bilateral distribution of vessels, and thus an equal risk of hemorrhage in the contralateral sinus, when one artery is identified with a diameter of >0.5mm. The incidence of reported bleeding complications in sinus lift surgery is relatively low: 0\% in 24 sinuses\textsuperscript{108}, 1.1\% in 92 sinuses\textsuperscript{81}, and 2.0\% in 100 patients.\textsuperscript{11}

Piezoelectric surgery is reported to offer a significant advantage over conventional rotary instrumentation in that the PSAA can be safely avoided and isolated while neighbouring bone is removed\textsuperscript{37}. A randomized clinical trial would be necessary in confirming this advantage, although the feasibility of such a trial is limited owing to the fact that bleeding complications are relatively rare.

If a small vessel located in the exposed sinus membrane is ruptured, it should be left alone such that hemostasis is achieved spontaneously. Bleeding from any intra- or extra-osseous vessel can usually be stopped with slight gauze pressure.\textsuperscript{5} Direct ligation, placement of particulated bone graft into the arterial canal, and burnishing with burs may also be considered. Sitting the patient upright can decrease blood flow by 38\%, assisting in control of the bleeding.\textsuperscript{47} Electrosurgery, however, on any bleeding vessel in the sinus cavity carries with it the risk of necrotizing the sinus membrane and threatening coverage of the graft.\textsuperscript{5,11}
A post-operative nosebleed may be related to a sinus membrane perforation, as a result of the direct communication between the sinus graft and the nasal cavity. It is a rare complication and has been reported with an incidence of 2.9% in 70 patients.\textsuperscript{95} During the early healing phase vascularity within the graft increases and may cause the seeping of pooled blood such that this blood passes through the ostium and out through the nose. A combination of nasal decongestants and antibiotics along with close monitoring for infection is recommended.\textsuperscript{47}

\subsection*{2.8.5 Incidence and management of sinusitis}

As mentioned previously, patients with a history of chronic sinusitis and congestion have a higher occurrence of postoperative sinusitis associated with sinus lift surgery, and should be considered for a referral to an otolaryngologist before initiating treatment. Sinusitis usually presents as a combination of symptoms that include nasal congestion, purulent secretion, and headaches. Endoscopic examination of a patient with sinusitis would reveal mucosal redness and edema, with purulent discharge around the ostium. The pre- and postoperative use of antibiotics, steroids, and decongestants will reduce the risk of obstruction of the ostium postoperatively. Still however, the occurrence of transient sinusitis is common for up to 2 weeks. If the sinusitis persists beyond 2 weeks and becomes chronic, a referral for surgical endoscopy may be necessary.\textsuperscript{47}

The incidence of reported sinusitis in sinus lift surgery has ranged from 1.0\% to 22.2\%: 1\% in 100 patients\textsuperscript{11}, 2.9\% in 70 patients\textsuperscript{95}, 3.0\% in 99 patients\textsuperscript{93}, 5.0\% in 40 patients\textsuperscript{109}, 22.2\% in 36 patients\textsuperscript{110}. In many studies, however, the incidence of sinusitis is not reported. Raghoebar et al (2001)\textsuperscript{93} reported that cases of sinusitis lasted for 2 weeks before subsiding. All patients with postoperative sinusitis also had a history of chronic maxillary sinusitis. In the other studies the duration of sinusitis was not reported. Schwartz-Arad et al (2004)\textsuperscript{95} found that all patients with sinusitis reported a pre-operative smoking habit of at least 1 cigarette per day. Wannfors et al (2000)\textsuperscript{109} reported that the occurrence of sinusitis was not associated with an intrasurgical membrane tear. In a systematic review of sinus lift
surgery with either autogenous bone or bone substitutes, Nkenke et al (2009)\textsuperscript{32} reported that the occurrence of sinusitis is independent of the graft material used.

2.8.6 Incidence and management of wound dehiscence, infection, and necrosed graft

A tension-free flap ensures primary wound closure and undisturbed healing with a decreased chance for incision line opening. Even though the use of a barrier membrane over the lateral window may cause an increase in wound dehiscence due to the difficulty of achieving tension-free flap closure\textsuperscript{47}, multiple reviews have supported the use of barrier membrane as implant survival rates are higher in cases where a membrane was used.\textsuperscript{22,37,61} A wound dehiscence that is not deemed to result from an infection should be managed similarly to conventional guided bone regeneration procedures.

Although the infection of a grafted sinus is a rare complication, when it does occur it can have deleterious effects on both the graft and implant survival.\textsuperscript{47} A postoperative infection following sinus lift surgery is usually seen at 3 to 7 days, and the risk for infection is increased following membrane perforation\textsuperscript{22}. Purulent discharge from the wound margins usually indicates an active infection. This is accompanied by severe pain, recurrent facial swelling, elevated body temperature, or loss of bone graft material through the wound margin, or through a separate oral antral communication.\textsuperscript{111} The incidence of reported infection following sinus lift surgery has ranged from 0 to 12.5\%: 0\% in 98 sinuses\textsuperscript{87}, 1.4\% in 70 patients\textsuperscript{95}, 4.0\% in 198 patients\textsuperscript{111}, 12\% in 118 patients\textsuperscript{112}, 12.5\% in 8 patients.\textsuperscript{80} In many studies however, the incidence of infection was not reported.

In situations where an infection has contaminated the graft, complete graft removal should be considered. Amino-penicillins such as amoxicillin may be the most appropriate antibiotic in the treatment of acute sinus infections following sinus lift surgery, as the bacteria most commonly cultured in cases of acute sinusitis are \textit{H. influenza}, \textit{M. catarrhalis}, \textit{S. pneumoniae}, and methicillin-sensitive \textit{S. aureus}\textsuperscript{47}. In a
case series of 8 patients with postoperative infections, Urban et al (2012)\textsuperscript{111} reported on a technique of removal of the infected graft until a more confined, intact, immobile and healthy-looking graft zone was found. This remaining zone was curetted until all remaining loose graft particles were removed. Doxycycline in the form of putty was placed in the bone graft for 2 minutes and then washed out. The defect was curetted to re-establish bleeding. Amoxillin and clavulanic acid was prescribed. In each case the resulting five-wall defect within the original sinus graft filled in with new bone allowing for implant placement an average of 10.6 months later. Any remaining bony defect was simultaneously grafted as necessary.

2.8.7 Other complications
Implant dislodgement into the sinus cavity is a rare complication\textsuperscript{113}, and can occur in cases of minimal residual bone height such that inadequate primary stability is achieved. Firm pressure from a prosthesis worn during the immediate postoperative period may also encourage implant migration. Implant retrieval can be carried out either via a secondary lateral window access through the canine fossa, or via endoscopy. The use of a tapered implant, by way of its wedging effect during placement, may decrease the incidence of dislodgement.\textsuperscript{47}

The ostium, located 25 to 35mm superior to the maxillary sinus floor, can potentially be obliterated, or blocked, if the sinus cavity is overfilled with bone graft material during sinus lift surgery. If this occurs, patency is lost such that drainage into the nasal cavity ceases.\textsuperscript{47} Thus, in order to avoid a secondary surgery to remove the excess bone graft, preoperative measurements should be taken such that the final graft height does not exceed the height of the ostium.

Sinus lift surgery carries with it the rare risk of hypeaesthesia, paraesthesia, and/or dysaesthesia in the distribution of the maxillary nerve (Cranial Nerve V\textsubscript{2}). This distribution includes the lower eyelid, lateral nose, cheek, upper lip, maxillary teeth, and gingiva. Although it usually resolved within 6 months, this change of sensation
may be permanent. If paraesthesia occurs during the immediate postoperative period, a course of methylprednisolone therapy should be considered.\textsuperscript{69}

The indirect sinus lift by means of the osteotome approach, in rare instances, may result in benign paroxysmal positional vertigo (BPPV) when a thick layer of alveolar bone remains coronal to the sinus floor that requires extensive malleting to bypass.\textsuperscript{82} In a case series by Penarrocha-Diago et al (2008)\textsuperscript{114}, this phenomenon occurred with a frequency of 1.3\% in 320 patients. This vertigo is caused by displacement of otoliths within the semicircular canals. Days or months may pass before symptoms of BPPV appear, after which a referral to an otolaryngologist may be needed.

Cystic lesions within the maxillary sinus, identified during a routine preoperative CBCT scan for implant therapy, would rarely require removal during normal patient assessment, however they may present as obstacles during sinus lift surgery\textsuperscript{47}. Although removal of these cystic lesions almost without doubt will result in a sinus membrane perforation, Pikos (2008)\textsuperscript{105} reported on a fixated membrane technique that combines removal of a retention cyst and simultaneous grafting for future implant therapy, as described previously.

2.9 Implant Success and Survival in the Posterior Maxilla

2.9.1 Evolving definitions of implant success and survival
Albrektsson et al (1986)\textsuperscript{115} proposed criteria for the evaluation of dental implant success, as part of an assessment of the long-term efficacy of dental implants in popular use at that time. By this time, the Branemark titanium implant had already been the subject of more than 100 published papers, and more than 15,000 of these implants had been used globally. Criteria for implant success included: 1) that an individual unattached implant be immobile when tested clinically, 2) there is no evidence of peri-implant radiolucency, 3) vertical bone loss is less than 0.2mm annually following the implant’s first year of service, 4) that an individual implant’s
performance be characterized by the absence of persistent or irreversible signs and symptoms of pain, infection, neuropathy, paraesthesia, or violation of the mandibular canal, and 5) that a successful rate of 85% at the end of a 5-year observation period, and 80% at the end of a 10-year period be a minimum criterion for success.

Albrektsson and Zarb (1998)\textsuperscript{116} modified their criteria for implant success such that it became: 1) the absence of persistent pain, dysesthesia or paraesthesia in the implant area, 2) the absence of peri-implant infection with or without suppuration, 3) the absence of perceptible implant mobility, and 4) the absence of persistent peri-implant bone resorption >1.5mm during during the first year of loading and >0.2mm/year during the following years.

In 2007, the International Congress of Oral Implantologists devised the Pisa Implant Quality of Health, a modification of the James-Misch Health Scale, using 4 implant groups to describe the clinical conditions of success, survival, and failure. Implant success, or optimum health, after ≥12 months of loading, was defined as a) an absence of pain or tenderness upon function, b) a lack of mobility, c) <2mm of radiographic bone loss from initial surgery, and d) no history of exudate. Satisfactory survival was defined as a) an absence of pain on function, b) a lack of mobility, c) 2-4mm of radiographic bone loss, and d) no history of exudate. Compromised survival was defined as a) possible sensitivity on function, b) a lack of mobility, c) radiographic bone loss >4mm but less than half of the implant body, d) ≥1 probing depth of >7mm, and e) a possible history of exudate. Clinical or absolute implant failure was defined as any of the following: a) pain on function, b) mobility, c) radiographic bone loss greater than half of the implant length, d) uncontrolled exudate, or e) an already explanted implant.\textsuperscript{117}

Albrektsson et al (2012)\textsuperscript{118} published a report on a consensus meeting aimed to assess whether the high rates of peri-implantitis associated with machined implants reported in the literature to date are also valid for modern rough-surfaced implants.
It was concluded that poor, undocumented implant systems, poorly trained clinicians, and patients with drug abuse or subjected to irradiation or grafting were accountable for the vast majority of marginal bone resorption and implant failure. If controlled implants are used by properly trained clinicians who work with ordinary patients, then the overall failure rate and frequency of peri-implantitis are within 5% of all implants that have 10 years of documented follow up. Finally, when interpreting studies reporting marginal bone loss a cluster effect can be observed such that one and the same patient with marginal bone loss around one implant is likely to have problems around their other implants as well.

Furthermore, Albrektsson et al (2013)\textsuperscript{119} reported on the collective analysis of published data and evaluations of personal clinical experiences from a mini-symposium of established clinical scholars. Of note, it was concluded that implant-, clinician-, patient-, and site-related factors may all contribute to crestal bone loss. Implant factors include material, surface properties, and ease of plaque removal. Clinician factors include surgical and prosthodontic experience, skills, as well as ethics. Patient factors include systemic disease and medication, untreated or refractory periodontal disease, local infections, compliance with oral hygiene and maintenance, and smoking habits. Site-related factors include bone volume and density, soft tissue quality, foreign body reactions such as corrosion by-products, and excess cement in peri-implant soft tissues.

### 2.9.2 Implant survival in the augmented versus healed sinus

Arguments in favour of both a simultaneous sinus lift and implant placement, a one-stage surgery, as well as delayed implant placement, a two-stage surgery exist in the literature. From a biological perspective, the two-stage procedure allows for graft maturation and incorporation prior to implant placement. Thus the insertion torque is likely to be higher than with a two-stage procedure. Also, the risk of implant migration or dislodgement is eliminated. One-stage surgery, however, is less invasive, requiring only one surgical procedure. It is also more cost-effective and shortens the overall treatment time.\textsuperscript{120} The one-stage technique is now commonly
used by more experienced clinicians.\(^3\) As mentioned previously, the deciding factor in choosing the appropriate technique is the amount of residual bone available.

Wallace et al (2003)\(^6\) conducted a systematic review on the efficacy of both the direct and indirect sinus lift. 37 studies involving over 3,800 implants with a minimum follow up period of 1 year loading were included in a specific analysis of one- and two-stage techniques. Implant survival for one- and two-stage techniques were 89.7% and 89.6% respectively.

Del Fabbro et al (2004)\(^3\) carried out a systematic review on the survival rates of implants placed in the grafted maxillary sinus. 35 studies with over 5,900 implants with a minimum follow up period of 1 year loading were included in a specific analysis of one- and two-stage techniques. One- and two-stage procedures showed similar survival rates of 92.17% and 92.93% respectively. Del Fabbro et al (2008)\(^2\) evaluated implant survival rates in the grafted sinus with respect to implant surface, graft material, and implant placement timing. 47 studies with more than 10,000 implants with a minimum follow up period of 1 year loading were included in a specific analysis of one- and two-stage techniques. It was found that the implant survival rate was not dependent on the use of either a one- or two-stage protocol.

Multiple long-term follow up studies have confirmed the survival of implants placed in a one-stage technique: 97.9% survival for >2,000 implants at 9 years\(^5\), 94.2% survival for 426 implants after 9 years\(^4\), and 94.8% for 588 implants at 12 years\(^4\). In a review of the literature, Wallace et al (2012)\(^3\) concluded that both one- and two-stage techniques have similar survival rates assuming primary stability is achieved at placement and maintained throughout the early graft maturation period.

Tan et al (2008)\(^3\) conducted a systematic review on the survival of implants inserted in combination with an indirect sinus lift. 19 studies involving over 4,300 implants were included. It was found that the failure rate of implants increased and
correlated with reduced residual bone height as well as reduced implant length. In a multicentre retrospective study of implants placed via an indirect osteotome approach, Rosen et al (1999)\textsuperscript{50} found that the implant survival rate was 96\% or greater when the pre-treatment ridge height was 5mm or more. However, when the ridge height was 4mm or less, survival dropped to 85.7%.

2.9.3 Implant survival in the augmented sinus without graft material
It has been argued that the placement of bone graft material during a one-stage direct or indirect sinus lift is not necessary. The formation of new bone beneath the raised sinus membrane may not require the presence of graft as a scaffold. Instead, the maintenance of sufficient space for blood clot formation, followed by osteoblastic and osteoclastic activity derived from either the sinus periosteum or the peripheral cancellous marrow in the maxilla may be sufficient for implant regenerative purposes.\textsuperscript{52}

Multiple clinical trials have reported on implant survival following one-stage direct sinus lifts without graft material: 100\% survival for 47 implants at 2 years\textsuperscript{52}, 97.7\% survival for 44 implants after a mean follow up of 2 years\textsuperscript{57}, 100\% survival for 80 implants after 5 years\textsuperscript{76}, and minimum 88.7\% survival for 262 implants after 5 years.\textsuperscript{56} Similar successful results have also been reported following one-stage indirect sinus lifts without graft material: 97.3\% survival for 75 implants after a mean follow up of 2 years\textsuperscript{102}, and 98.6\% survival for 71 implants after a mean follow up of 1.6 years.\textsuperscript{121}

2.9.4 Implant survival after perforations
It is important to evaluate implant survival following sinus membrane perforations during sinus lift surgery, as they are the most common intrasurgical complication. Khoury et al (1999)\textsuperscript{92} reported on a prospective study of 216 one-stage direct sinus lifts using autogenous block grafts. Perforations occurred in 23.6\% of cases and were repaired either with fibrin adhesive or by suturing. During a 6-year follow up period 28 out of 467 implants failed, leading to an implant survival rate of 94.0\%. 14
failed implants, or 50%, belonged to sinuses in which perforations were
documented.

Proussaefs et al (2004)\textsuperscript{108} carried out a retrospective study of 12 patients who
received bilateral two-stage direct sinus lifts with allograft and/or xenograft. In each
patient, 1 sinus had accidently been perforated and repaired with a resorbable
collagen membrane, however both sinuses received the same graft material. 43
implants were placed 6 to 16 months later. Implant failure was assessed at the time
of surgical uncovering. Implants placed in perforated sinuses had a significantly
decreased survival rate compared with implants placed in non-perforated sinuses,
69.56\% versus 100\%. Postoperative panoramic radiographs confirmed that
perforated sinuses showed dislodgement of the graft beyond the sinus membrane as
well as a generally more radiolucent appearance of the graft relative to the
contralateral sinus.

Hernandez-Alfaro et al (2008)\textsuperscript{91} reported on a prospective study of 474 one-stage
direct sinus lifts using autogenous block grafts. Perforations occurred in 21.9\% of
cases and were repaired with a combination of either suturing, resorbable collagen
membrane, the use of the lamellar bone from the sinus window, or a pedicled buccal
fat pad. 6 months after loading, the overall implant survival rate was 90.81\% for 272
implants placed underneath perforated sinuses. Implant survival was significantly
higher in perforations <5mm compared with perforations >10mm, 97.14\% versus
74.14\%.

Despite these studies, numerous other studies have found no significant association
between the incidence of perforations and implant success or survival.\textsuperscript{93-95,107,109} A
systematic review by Pjetursson et al (2008)\textsuperscript{22} also confirmed the lack of such an
association as of yet.
2.9.5 Implant survival after infection

Although the incidence of infection after sinus lift surgery is low, when it does occur it has the potential to negatively affect both graft and implant survival. Schwartz-Arad et al (2004)95 followed 212 implants over 7 years, placed either during a one- or two-stage direct sinus lift in 70 patients. Although 9 implants failed, an overall failure rate of 4.2%, none occurred in patients with a postoperative infection. 1 patient experienced a persistent infection around 1 implant, which resolved after treatment by curettage.

Peleg et al (2006)55 followed over 2,100 implants for up to 9 years, placed during one-stage direct sinus lift surgery in 731 patients. Although only 44 implants failed, an overall failure rate of 2.1%, 27 or 61.4% of these failed implants belonged to patients who experienced postoperative infection. Overall, most implant failures occur 3 to 6 months post-placement, and these failures are usually not associated with a postoperative infection.107

2.9.6 Implant survival in smokers

Cigarette smoking is frequently recognized as a statistically significant risk factor for implant failure. The pathogenesis of periodontitis and peri-implantitis in smokers is complex, but the impairment of both one’s innate and adaptive immunity is thought to be central to these processes. Smoking also interferes with normal wound healing.122 In heavy smokers who are also positive for the IL-1 genotype, a significantly increased risk exists for both per-implant mucositis and peri-implantitis.123

Mayfield et al (2001)124 followed 15 patients who received 39 implants via one- or two-stage direct sinus lifts for a minimum of 4 years post-loading. 7 implants, or 17.9%, failed and all belonged to smokers. In a multicenter retrospective study, Geurs et al (2001)125 followed 100 patients who received 329 implants via one- or two-stage direct sinus lifts for 3 years post-placement. 62 implants were placed in current smokers, and 267 implants were placed in non-smokers. Implant failure was
significantly greater for smokers compared with non-smokers, 12.7% versus 4.8% respectively. In this study implant surface characteristics were not listed.

Kan et al (2002)\textsuperscript{126} reported on a retrospective study of 60 patients who received 228 implants via one- or two-stage direct sinus lift surgery, which were loaded for a mean of 3.5 years. 70 implants were placed in smokers, while 158 implants were placed in non-smokers. Corresponding failure rates between smokers and non-smokers were 17.1% and 7.0%, respectively. In this study over 80% of the implants used were hydroxyapatite coated.

Barone et al (2006)\textsuperscript{127} reported on the occurrence of complications following two-stage direct sinus lift surgery in 70 patients, 54 of which received bilateral sinus lifts. 21 patients, or 30% were smokers. 7 patients experienced suppuration of the surgical site 3 to 5 weeks following the sinus lift. Of these patients, 5 were smokers.

Despite these studies, others have found no significant increased risk for postoperative complications or implant failure in smokers compared with non-smokers in conjunction with sinus lift surgery.\textsuperscript{55,128,129} As peri-implantitis and implant failure are both problems of multifactorial etiology, the isolation of smoking as a risk factor alone has proven to be difficult. Still, smoking cessation protocols are recommended when planning implant-driven therapy.\textsuperscript{122,130}

2.9.7 Implant survival in patients with diabetes

Uncontrolled diabetes is a contraindication to performing any elective surgery as it increases one’s chances of becoming susceptible to a postoperative infection, as a result of a compromised immune response. Polymorphonuclear leukocytes typically show decreased chemotaxis and phagocytosis.\textsuperscript{47} Furthermore, due to the abnormal growth and impaired regeneration of blood vessels\textsuperscript{131} those with uncontrolled diabetes may be more prone to decreased graft turnover and wound dehiscence following sinus lift and implant surgery.
In a multicentre retrospective study of 40 patients with controlled Type I and Type II diabetes who received 215 implants placed in both the maxilla and mandible, Fiorellini et al (2000)\(^\text{132}\) reported a cumulative survival rate of 85.7% after 6.5 years of loading. In a retrospective study of 25 patients with controlled Type I and Type II diabetes who received 136 implants in both the maxilla and mandible, Farzad et al (2002)\(^\text{133}\) reported a survival rate of 94.1% at 1 year post-placement.

No studies to date have assessed the outcome of diabetic control on sinus lift surgery and implant placement. Although there is a slight tendency for increased implant failures in diabetics compared to non-diabetics, this increased risk is not significant as long as the patient maintains strict control of their plasma glucose level.\(^\text{122,133,134}\)

### 2.9.8 Implant survival in patients with osteoporosis

Osteoporosis is a term encompassing a group of systemic skeletal conditions that involve low bone mass as well as structural deterioration of bone tissue. In untreated patients, bone typically is fragile and at an increased risk of fracturing. A bone mineral density test will aid in the diagnosis of osteoporosis.\(^\text{122}\) Implants placed in patients with osteoporosis however appear to successfully integrate, as the potential for bone regeneration around the implant is not altered in patients with osteoporosis.\(^\text{47,122}\)

Bisphosphonates, commonly prescribed for the treatment of osteoporosis, inhibit osteoclast activity and have anti-angiogenic properties such that normal bone remodelling processes are inhibited. A rare complication related to the chronic use of oral bisphosphonates is the development of osteonecrosis of the jaws (ONJ) after implant placement.\(^\text{122}\) Marx et al (2005)\(^\text{135}\) reported on a case series of 119 patients with ONJ who were receiving either pamidronate, zoledronate, or alendronate therapy. In a review of the apparent events that resulted in the development of ONJ, 25.2% of cases occurred spontaneously without any dental treatment, while 3.4% of cases resulted after implant placement. Implant therapy is contraindicated in cancer
patients receiving intravenous bisphosphonates. It may be considered safe however in patients receiving oral bisphosphonates for less than 5 years.\textsuperscript{136}

No studies to date have assessed the outcome of osteoporotic control on sinus lift surgery and implant placement. It has been recommended though that when planning a two-stage direct sinus lift the graft maturation period be extended to 8 months before implant placement. Accordingly, it has been recommended that the time period before loading also be extended.\textsuperscript{47}

\textbf{2.9.9 Implant survival in patients with periodontal disease}

Levin et al (2011)\textsuperscript{137} reported on a prospective cohort study of over 700 patients who received over 2300 implants, and who were followed up for a mean period of 54 months. The cumulative survival rate at 108 months was 96\% and 95\% for implants inserted into healthy and moderate chronic periodontitis patients, and 88\% for implants in patients with severe periodontitis. It was concluded that periodontal status is a significant risk factor for late implant failure, particularly 50 months post-implant placement.

Swierkot et al (2012)\textsuperscript{138} reported on a prospective cohort study of 35 patients treated for generalized aggressive periodontitis and 18 periodontally healthy patients who received 149 implants and who were followed up for a mean period of 8 years. Implant survival rates were 100\% in periodontally healthy patients and 96\% in treated generalized aggressive periodontitis patients. Treated generalized aggressive periodontitis patients however had a five fold greater risk of implant failure, a three fold greater risk of mucositis, and 14 fold greater risk of peri-implantitis.

\textbf{2.9.10 Implant survival related to implant surface type}

Two implant systems prevailed during the development phase of modern implants. These included implants with a turned, minimally rough titanium surface, and implants with a coated, rough titanium plasma sprayed surface. Alternative implant
surfaces were then produced through combinations of sandblasting, acid etching, or gritblasting. These newer surfaces, all sharing a moderately rough surface topography, make up the majority of commercially available implants today. Modern implants have shown significantly improved clinical results in comparison to the older turned surfaces in multiple demanding scenarios, including implants placed in irradiated or grafted beds, maxillary implants, rapidly loaded implants, the use of short implants, and in patients who smoke.\textsuperscript{118}

Several reviews will be mentioned that were discussed previously with respect to implant survival as per graft material. Del Fabbro et al (2004)\textsuperscript{39} carried out a systematic review on the survival rates of implants placed in the grafted maxillary sinus. 19 studies were reviewed that included over 1,800 smooth surface implants and over 1,300 rough surface implants. The 3-year survival rates for rough and smooth surface implants were 93.61% and 85.24%, respectively.

Del Fabbro et al (2008)\textsuperscript{2} evaluated implant survival rates in the grafted sinus with respect to implant surface, graft material, and implant placement timing. In an analysis of over 2,000 machined surface implants and over 1,800 textured surface implants, independent of graft material, the 3-year implant survival rate for machined surface implants ranged between 83.60% to 90.97%, while that for textured surface implants ranged between 90.57% to 95.49%.

Pjetturson et al (2008)\textsuperscript{22} conducted a systematic review to assess the survival rate of grafts and implants placed using the direct sinus lift. In an analysis of implant survival as per implant surface type, 43 studies were reviewed that included over 2,300 machined surface implants and over 6,300 rough surface implants. The 3-year survival rate for rough surface implants was significantly higher than that for machined surface implants, 96.5% versus 81.4%.

In a review of augmentation procedures of the maxillary sinus, Esposito et al (2010)\textsuperscript{31} mentioned that as of yet, there is a lack of reliable evidence for the
superiority of any one particular implant surface modification or design over another. However, regardless of the specific surface modification, in a review of the evolution of the direct sinus lift technique, it was argued that implant survival rates of more than 98% could be reliably achieved using a combination of rough surfaced implants, xenograft material, and the placement of a membrane over the lateral window osteotomy.37

2.9.11 Short implants and implant survival
Earlier studies have found decreased implant survival for short implants relative to more current research. A confounding factor is that these earlier studies also reported on machined surface implants. In a retrospective study of over 4,600 Branemark machined surface implants placed in both the maxillae and mandibles of 889 patients, Friberg et al (1991)139 found that the shortest implants used, 7mm in length, experienced the highest relative failure rate, 7.1% and 3.1% respectively. In a 5-year retrospective study of over 800 Branemark machined surface implants placed in the maxillae of 150 patients, Jemt et al (1995)140 concluded that implant failure correlated significantly with bone quality and the ratio of 7mm implants.

Later studies revealed that implant surface topography with respect to short implants is a major determinant of their success. Hagi et al (2004)141 conducted a review of study outcomes with short implants (≤7mm) placed in partially edentulous patients. 12 studies involving over 4100 implants were included. It was discovered that while machined surface implants showed higher failure rates in short versus longer lengths, sintered porous-surfaced implants displayed increased relative survival in short lengths.

Domingues das Neves (2006)142 performed a review of 33 longitudinal studies that included over 16,000 implants placed in both the maxilla and mandible. It was found that 7mm implants had a failure rate of 9.7%, compared to 6.3% for 10mm implants. Poor bone quality was highly associated with the failure of short implants. Renouard et al (2006)143 conducted a review of 12 studies on machined surface implants and
22 studies on rough surface implants. The survival and success rates of implants <10mm were comparable to that of longer implants, provided that the implant osteotomies were prepared in accordance with the existing bone density, rough surface implants were used, and implant placements were performed by experienced surgeons.

In a prospective study, Ferrigno et al (2006)\textsuperscript{10} followed 588 maxillary implants placed in 323 patients via an osteotome indirect sinus lift, for a mean observation period of 6 years. It was discovered that 8mm implants did not have a significantly increased failure rate compared to 10 or 12mm implants. An increasing amount of evidence on the success of short rough surface implants in the posterior maxilla should alert the implant clinician that these implants may be considered in sites previously thought to be unfavourable for implant placement. These sites include those with ridge resorption, previous injury, or trauma where implant placement may not have been though possible without a direct sinus lift.

In a review of the literature on the use of short implants, Morand & Irinakis (2007)\textsuperscript{144} described crucial decision-making factors that should be considered when treatment planning the placement of short implants. These include the splinting of adjacent short implants to distribute occlusal forces, maximizing implant width where possible, allowing longer periods for osseointegration and avoiding immediate loading, and the consideration of temporarily maintaining teeth that are planned for extraction to provide support for a potential fixed provisional prosthesis that would avoid transmucosal loading of the implants.

In a review of augmentation procedures of the maxillary sinus, Esposito et al (2010)\textsuperscript{31} concluded that implants 5mm long and 6mm wide could be successfully loaded in posterior maxillary sites with residual ridge heights of 4-6mm without the necessity of any augmentation procedure. The long-term prognosis of this treatment approach is uncertain as of yet. Furthermore, in sites with residual ridge heights of 3-6mm, the placement of 8mm implants in conjunction with an indirect sinus lift
may lead to fewer complications than the placement of 10mm implants in conjunction with a direct sinus lift.

2.9.12 Implant success and survival – summary

Overall, implant therapy in the posterior maxilla can be considered a safe and predictable procedure, provided that fair consideration is given to the ideal prosthetic location of the implants as well as the need for ridge augmentation, patient risk factors for implant failure are taken into account, rough surface implants are used, and the surgeon and restorative dentist are both experienced.

Implant survival rates in the augmented sinus compare favourably to reported survival rates for implants placed in the non-grafted posterior maxilla\(^6\). At the implant level, the estimated annual implant failure rate for implants inserted in combination with a direct sinus lift is 3.5%, leading to a 3-year implant survival of 90.1%. The percentage of implant failure is usually highest during the first year post-placement. There is a current lack of longitudinal studies with observation periods of 10 years or more.\(^2\)

The restorative aspect of implant therapy in the posterior maxilla should also be taken into consideration. The survival rates of single crowns, splinted crowns, and fixed partial dentures have ranged between 96.4% and 100% after a minimum 12 month follow up, therefore the prognosis of implant therapy does not seem to be influenced by the type of restoration placed. To date there is a lack of controlled studies using split mouth designs that compare the outcomes of implant therapy with single versus splinted crowns. Furthermore, it has been argued that the adjacent dentition plays an influential role in force distribution and protection of the implant such that implant-supported single crowns in a full surrounding natural dentition may be exposed to less occlusal load than multi-unit implant fixed partial dentures in partially edentulous patients, or full arch restorations in edentulous patients.\(^1\)

120
3. OBJECTIVES

A retrospective chart review was performed to assess the prevalence and severity of sinus membrane tear complications as they relate to the presence of sinus septa, both intraoperative as well as postoperative. Secondary objectives included the evaluation of other clinical, implant- or patient-related factors, which may impact marginal bone loss, as measured on intraoral radiographs.

The following hypotheses were tested:

1. Radiographic septum and sinus lift boundaries are related to sinus membrane tears.
2. Sinus membrane tears are not related to major postoperative complications.
3. Patient-related factors such as age, gender, medical history, and smoking status are not related to implant survival, marginal bone loss, sinus membrane tears, or major postoperative complications.
4. Implant placement at the time of sinus lift surgery is related to operating time but not sinus membrane tears or major postoperative complications.
4. MATERIALS AND METHODS

A chart review was performed of 79 sinus lift surgeries and 107 implants placed in 67 patients from May of 2008 to August of 2012, at two centres, one in Vancouver, British Columbia, and the other in Calgary, Alberta. Human ethics approval was obtained from the Clinical Research Ethics Board, University of British Columbia Office of Research Services (approval number H10-00464). Sinus lift and implant surgeries were performed in partially dentate and edentulous patients, in the posterior maxillary arch, utilizing either a one- or two-stage sinus lift approach. All partially dentate patients had either been previously treated for periodontal disease and were receiving maintenance therapy, or they did not show any signs or symptoms of periodontal disease. 11 Nobel Replace Straight Groovy, 47 Nobel Replace Tapered Groovy, one Nobel Replace Select Straight, seven Nobel Replace Select Tapered, six Nobel Replace Conical Connection, six Nobel Active, nine Straumann Bone Level Sand-blasted, Large grit, Acid-etched (SLA), 18 Astra OsseoSpeed TX Straight, and two MIS SEVEN implants were placed in sites that had previously or simultaneously received sinus augmentation. These implants were evaluated for a period of up to 37 months following integration check, with an average post-integration check period of 12.8 months. Both restored and unrestored implants were included in the follow-up period post-integration check.

Inclusion criteria:

1. Patients who had at least one direct sinus lift surgery performed in private periodontal practice by one operator, Dr. Anastasios (Tassos) Irinakis (T.I.)
2. In patients who also received implant therapy, the availability of periapical radiographs representing implants with clearly discernible threads during placement as well as during follow-up appointments.

Preoperative Cone Beam Computed Tomography (CBCT) images were evaluated using Kodak 3D Imaging v2.4 software and the distribution of interfering septa according to Class I (buccal-lingual direction), Class II (mesial-distal direction), Class III (horizontal
orientation), and Class IV (combinations of Class I, II, or III) was assessed (Appendix A, B, C). Pre-operative ridge heights were also measured at the planned implant sites.

The primary sinus outcome variable was the occurrence of a sinus membrane tear. The secondary sinus outcome variable was the occurrence of major postoperative complications, including an infected graft, the development of persistent sinusitis ≥2 months postoperative, extraoral facial collapse, soft tissue numbness, and severe pain at the ipsilateral ear.

The primary implant outcome variable was implant failure. An implant was considered to have failed if it had been removed from the oral cavity due to implant mobility, peri-implant radiolucency, if the patient experienced clinical symptoms that were not resolvable, if there were mechanical problems that prevented prosthodontic restoration, or if there was progressive marginal bone loss or infection that required implant removal.

The secondary implant outcome variable was marginal bone loss as measured in millimetres on conventional and digital radiographs at baseline and follow up appointments. Periapical radiographs were used. Intraoral radiographs were taken at implant placement and during follow up appointments with a long-cone parallel technique using a paralleling device (Dentsply International, USA).

Conventional radiographs were scanned using an Epson Expression 10000XL Photo scanner and all digital images were measured using Image J v1.46 software (National Institutes of Health, Maryland, USA). The coronal margin of the implant collar as well as the most coronal aspect of the bone-to-implant contact were used as reference points for linear measurements of marginal bone loss (Appendix F). Measurements of mesial and distal marginal bone levels adjacent to each implant were performed. In order to compensate for angulation and magnification distortion in the radiographs, the diameter of the implant collar was used for calibration of implant dimensions (Appendix F), adapted from Piao et al. in 2009. The amount of true bone resorption, the difference between the initial bone level and the bone level at the latest follow-up examination, was calculated. For implants
that were intentionally placed in a supracrestal position, the height of the implant collar above the alveolar crest during placement was subtracted from follow up radiograph measurements. Mesial and distal marginal bone loss values were recorded for each implant. In order to reduce measurement error and bias in the radiographic assessments performed, one “blinded” examiner who was not involved in the treatment of patients, evaluated all intraoral radiographs. 25 periapical radiographs were measured twice, once at baseline and again after 3 months to assess intra-examiner reliability.

 Thresholds of 1.5mm and 1.0mm of averaged marginal bone loss were selected for comparisons during the latest follow-up. The 1.5mm threshold of marginal bone loss, particularly during the first year of loading, was reported as a criteria for implant success by Albrektsson & Zarb in 1998.116 Although the 1.0mm threshold has been reported in multiple clinical trials as outcome criteria for implant success146,147, evidence in the literature is not conclusive as to whether one threshold is more effective than the other. As previously mentioned, Albrektsson et al (1986)115 proposed criteria for successful implants that included the absence of peri-implant radiolucency as well as the absence of mobility, pain, infection and neuropathy. In this study, the use of success as an outcome variable was not possible due to the limited follow up data available as well as the fact that implants cemented into multiunit prostheses could not be assessed on an individual basis for mobility. Postoperative complications following sinus lift and implant surgery were evaluated based on existing chart records. Patients were not re-examined prior to this report. Due to these limitations, conclusions regarding implant success could not be made in this study.

 Patient clinical and demographic data was recorded using Microsoft Excel 2011 v14.3.6 software (Washington, USA). All implant-related information pertaining to osseointegration, including infection, pain, neuropathy, mobility, and radiographic signs of peri-implant radiolucency was evaluated at follow up appointments. Patient-related factors including age, gender, medical and smoking status, anatomic site-related factors including implant location, pre-operative ridge height, sinus lift boundaries, radiographic septum
presence and orientation, intra- and post-operative notes including operating time, graft type, the occurrence of a membrane tear, the occurrence of postoperative complications, implant properties including brand, model, dimensions, insertion torque, and Osstell value or reverse torque test result at integration check, and timing variables including one- or two-stage sinus lift, and one- or two-stage implant placement protocol were recorded. Prosthetic restorations included single unit crowns, splinted crowns, fixed partial dentures, as well as complete-arch fixed prostheses. A reverse torque test was used to verify implant stability at integration check when the Osstell Implant Stability Quotient (ISQ) device was not available.

IBM SPSS Statistics v21.0 software (New York, USA) was used for the statistical analyses. Descriptive statistics were used for all evaluated parameters. Baseline implant, patient, sinus characteristics were summarized in terms of frequencies and percentages for all variables assessed. Predictor variables were analyzed at the implant, sinus and patient levels. The average of the mesial and distal bone loss measurements was used during analyses to identify risk factors associated with marginal bone loss. The independent samples t-test, one-way analyses of variance with Bonferroni post Hoc adjustment, and Fisher’s exact test were used to assess relationships between patient-, implant design-, bone grafting-, implant placement timing-, and intrasurgical-related factors and outcome variables including marginal bone loss, the occurrence of sinus membrane tears, major postoperative complications, and operating time. The P-value of <0.05 was considered to be statistically significant.

Box plots were used to display certain results so that the distribution of data could be visualized. The central rectangle, the interquartile range (IQR), represents the middle 50% of the data. The median, located at a mid-point within the IQR, separates the higher half of the data sample from the lower half. Data points that lie significantly outside the IQR by >3 standard deviations are referred to as outliers (Illustration 2).
**Figure 2.** Box plot representation
5. RESULTS

5.1 Population, Sinus, Bone Graft and Implant Distribution

The patient population included 67 patients, comprised of 37.3% males and 62.7% females, aged 55 ± 12.6 years. Patients were treated at two private periodontal practices: one in Vancouver, British Columbia (n=45) and one in Calgary, Alberta (n=22). A total of 79 sinus lifts were performed by one operator (T.I.), a periodontist. 12 patients received bilateral sinus lifts. Sinus septal classes were identified using Cone Beam Computed Tomography. The distribution of interfering septa according to Class I (buccal-lingual direction), Class II (mesial-distal direction), Class III (horizontal shelf orientation), and Class IV (combinations of Class I, II, or III) is presented in Figure 3. Interfering septa were identified in 48.1% of sinuses. Of sinuses with septa, 71.1% of these contained a Class I septum.

![Pie chart showing septal classes](image)

**Figure 3.** Radiographic septal classes identified as per CBCT imaging

Simultaneous sinus lift and dental implant placement was performed in 31 sinuses, while delayed implant placement was performed in 48 sinuses. 107 implants were placed. Of these, 101 were placed by T.I. The distribution of implants is presented in Figure 4.
One patient did not return for treatment following implant placement, therefore only 105 implants received an integration check. All implants that received an integration check had successfully osseointegrated, resulting in an overall survival rate of 100%.

Osseointegration was verified radiographically and by either an Osstell ISQ (n=73) or a manual reverse torque test (n=32). For one-stage implants, integration check was done at a pre-determined time point after implant placement. For two-stage implants, integration check was done at the time of second stage surgery. Of these 105 implants, records existed for 61 that reached a time point defined as the latest follow-up, which is any radiographic follow up 1-37 months beyond the date of integration check. These 61 implants, which had a mean follow-up period of 12.8 months, were related to 37 sinuses. Records existed for 32 restored implants within 13 months of integration check. This group of 32 implants was considered to have been loaded for up to one year. Four types of bone graft material were used during sinus lifts: injectable paste allograft, particulate allograft, BioOss particulate

**Figure 4. Distribution of implants**
xenograft, and particulate alloplast. The distribution of bone graft materials is presented in Figure 5.

![Distribution of graft materials](image)

**Figure 5.** Distribution of graft material at the sinus level

### 5.1.1 Marginal bone loss and intra-examiner reliability

At the latest follow-up, the mean mesial implant marginal bone loss was 0.7±0.8mm, with a minimum of 0.0mm and a maximum of 2.9mm. The mean distal implant marginal bone loss was 0.7±0.9mm, with a minimum of 0.0mm and a maximum of 3.5mm. As the mean mesial and distal marginal bone loss measurements were strongly correlated (Pearson correlation coefficient = 0.813, P<0.001), the average mean marginal bone loss (0.7±0.8mm) was used for statistical analysis (min. 0.0mm, max. 3.2mm). Outliers in the distal aspect readings with the highest marginal bone loss correspond to a patient with a non-contributory medical history. This data is presented in Figure 6. Intra-examiner reliability was assessed in a sample of 25 randomly selected double recordings of marginal bone loss at the latest follow up. These duplicate recordings were highly correlated, with Pearson correlation coefficients of 0.988 (P<0.001) and 0.993 (<0.001) at the mesial and distal measurements, respectively.
Figure 6. Box plot of marginal bone loss for the mesial, distal, and average of the mesial and distal measurements at the latest follow-up

5.2 Patient-Related Factors

5.2.1 Patient age and marginal bone loss

It was hypothesized that increasing age was not associated with implant marginal bone loss. To enable these comparisons, the study population was divided into three age groups: those younger 45 years (n=12), those aged 45-64 (n=37), and those aged 65 years or older (n=18). This data is presented in Figure 7. At the latest follow-up, records existed for five patients younger than 45 years, 22 patients aged 45-64 years, and 4 patients aged 65 years or older. For age group comparison, the data was evaluated at the patient level. At the 1.5mm threshold, the 45-64 year age group showed the lowest proportion of average marginal bone loss, but this association was not statistically significant (Table 1) (p=0.327). At the 1.0mm threshold the oldest age group showed the highest proportion of average marginal bone loss, however this association was also not statistically significant.
The mean implant marginal bone loss for the youngest age group was 0.6±0.7mm, compared with 0.6±0.8mm for the middle age group, and 1.0±0.6 for the oldest age group. The mean difference between the youngest age group and middle age group was only 0.1mm (p=1.000). The mean difference between the youngest and oldest age groups was 0.4mm (p=1.000), and that between the middle and oldest age groups was 0.5mm (p=0.817). Outliers with the highest marginal bone loss were found in both the youngest and middle age groups (Figure 8). These patients both had a non-contributory medical history.

Figure 7. Sample distribution according to age groups
**Figure 8.** Average implant marginal bone loss according to age group

**Table 1.** Overall averaged marginal bone loss and bone loss at the 1.5 and 1.0mm thresholds in 3 age groups

<table>
<thead>
<tr>
<th>Age Groups</th>
<th>Bone loss &lt;1.5mm</th>
<th>Bone loss ≥1.5mm</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;45 years</td>
<td>4 (80.0%)</td>
<td>1 (20.0%)</td>
<td>Fisher’s Exact test P=0.327</td>
</tr>
<tr>
<td>45-64 years</td>
<td>20 (90.9%)</td>
<td>2 (9.1%)</td>
<td></td>
</tr>
<tr>
<td>&gt;64 years</td>
<td>3 (75.0%)</td>
<td>1 (25.0%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age Groups</th>
<th>Bone loss &lt;1.0mm</th>
<th>Bone loss ≥1.0mm</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;45 years</td>
<td>4 (80.0%)</td>
<td>1 (20.0%)</td>
<td>Fisher’s Exact test P=0.569</td>
</tr>
<tr>
<td>45-64 years</td>
<td>17 (77.3%)</td>
<td>5 (22.7%)</td>
<td></td>
</tr>
<tr>
<td>&gt;64 years</td>
<td>2 (50.0%)</td>
<td>2 (50.0%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean Difference (mm)</th>
<th>One Way ANOVA with Bonferroni post Hoc adjustment: Significance (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;45 years</td>
<td>0.07</td>
</tr>
<tr>
<td>&gt;64 years</td>
<td>-0.38</td>
</tr>
<tr>
<td>45-64 years</td>
<td>-0.07</td>
</tr>
<tr>
<td>&lt;45 years</td>
<td>-0.45</td>
</tr>
<tr>
<td>&gt;64 years</td>
<td>0.38</td>
</tr>
<tr>
<td>45-64 years</td>
<td>0.45</td>
</tr>
</tbody>
</table>
5.2.2 Patient age and membrane tears

The association between patient age and membrane tears was another factor that was analyzed in this study. The study population was divided again into the same three age groups. 12 patients received bilateral sinus lifts. If a tear occurred in one or both sinuses, that patient was documented as having had a tear. For age group comparison, the data was evaluated at the patient level. Although the oldest age group experienced the highest proportion of small and large tears, this difference was not statistically significant (p=0.422). These results are presented in Figure 9.

![Figure 9](attachment:image.png)

**Figure 9.** The occurrence of membrane tears according to age group

5.2.3 Patient age and major complications

It was hypothesized that increasing age was not associated with an increased occurrence of major postoperative complications. In patients who received bilateral sinus lifts, if a postoperative complication occurred following one or both surgeries, that patient was documented as having had a complication. For age group comparison, the data was evaluated at the patient level. Although the youngest age group experienced the smallest
proportion of complications, this difference was only minimal and not statistically significant (p=1.000). These results are presented in Figure 10.

![Figure 10](image)

**Figure 10.** The occurrence of major postoperative complications according to age group

### 5.2.4 Gender and marginal bone loss

The association between gender and marginal bone loss was another factor that was analyzed in this study. Of the 67 patients, 42 were women (62.7%) and 25 were men (37.3%). Women received 65 implants (60.7%) and men 42 implants (39.3%). For gender comparison, the data was evaluated at the patient level. This data is presented in Figures 11, 12, and 13. At the latest follow-up, records existed for 21 females and for 10 males. At the 1.5mm threshold, females accounted for a higher proportion of patients with an average marginal bone loss of ≥1.5mm per patient. This association was not statistically significant (Table 2) (p=1.000). Similarly, at the 1.0mm threshold, the association was also not statistically significant (p=1.000). The mean implant marginal bone loss for females was 0.63±0.81mm, compared with 0.64±0.58mm for males. The mean difference between genders was negligible (0.01mm) (p=0.971). The outlier visible in Figure 13 corresponds to
a patient with a non-contributory medical history, who also did not experience any major postoperative complications.

**Figure 11.** Distribution of patients according to gender

<table>
<thead>
<tr>
<th></th>
<th>Females</th>
<th>Males</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Females</strong></td>
<td>65 (60.7%)</td>
<td>42 (39.3%)</td>
</tr>
<tr>
<td><strong>Males</strong></td>
<td>42 (62.7%)</td>
<td>25 (37.3%)</td>
</tr>
</tbody>
</table>

**Figure 12.** Distribution of implants according to gender
**Figure 13.** Average implant marginal bone loss per patient according to gender

**Table 2.** Overall averaged marginal bone loss and bone loss at the 1.5 and 1.0mm thresholds for gender

<table>
<thead>
<tr>
<th>Gender Groups</th>
<th>Bone loss &lt;1.5mm</th>
<th>Bone loss ≥1.5mm</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number (%)</td>
<td>Number (%)</td>
<td></td>
</tr>
<tr>
<td>Females</td>
<td>18 (85.7%)</td>
<td>3 (14.3%)</td>
<td>Fisher's Exact test</td>
</tr>
<tr>
<td>Males</td>
<td>9 (90.0%)</td>
<td>1 (10.0%)</td>
<td>P=1.000</td>
</tr>
<tr>
<td><strong>Bone loss &lt;1.0mm</strong></td>
<td><strong>Number (%)</strong></td>
<td><strong>Number (%)</strong></td>
<td></td>
</tr>
<tr>
<td>Females</td>
<td>15 (71.4%)</td>
<td>6 (28.6%)</td>
<td>Fisher's Exact test</td>
</tr>
<tr>
<td>Males</td>
<td>8 (80.0%)</td>
<td>2 (20.0%)</td>
<td>P=1.000</td>
</tr>
</tbody>
</table>

**Independent Samples T-Test**

<table>
<thead>
<tr>
<th></th>
<th>Females</th>
<th>Males</th>
<th>P values (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Averaged Bone Loss (mm)</td>
<td>Number</td>
<td>Mean±SD</td>
<td>Number</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>0.63±0.81</td>
<td>10</td>
</tr>
</tbody>
</table>
5.2.5 Gender and membrane tears

It was hypothesized that gender was not associated with the occurrence of sinus membrane tears. In all, 67 patients received 79 sinus lifts and 12 of these patients received bilateral sinus lifts. If a tear occurred in one or both sinuses, that patient was documented as having had a tear. For gender comparison, the data was evaluated at the patient level. No gender difference was discovered with respect to the occurrence of membrane tears (p=1.000). These results are presented in Figure 14.

![Figure 14](image)

**Figure 14.** The occurrence of membrane tears according to age group

5.2.6 Gender and major complications

The association between gender and major postoperative complications was another factor that was analyzed in this study. In patients who received bilateral sinus lifts, if a postoperative complication occurred following one or both surgeries, that patient was documented as having had a complication. For gender comparison, the data was evaluated at the patient level. Although females showed a larger proportion of major complications, this difference was not statistically significant (p=0.700). These results are presented in Figure 15.
Figure 15. The occurrence of major postoperative complications according to gender

5.2.7 Pertinent medical history and marginal bone loss

It was hypothesized that pertinent medical history was not associated with implant marginal bone loss. The study population was divided into six groups according to their medical history: those without any medical or lifestyle risks (n=48), those with Type I or II Diabetes Mellitus (n=2), those who were current smokers (n=8), those with osteoporosis and currently taking bisphosphonate medication (n=3), those with sinusitis (n=5), and those with both sinusitis and obstructive sleep apnea (n=1). This data is presented in Figure 16. At the latest follow-up, records existed for three patients who were current smokers, one patient with osteoporosis, two patients with sinusitis, and 25 patients without any medical or lifestyle risks. For comparison of pertinent medical history, the data was evaluated at the patient level. Due to the small sample size, all medical history categories were combined and compared with those without any medical or lifestyle risks. At both the 1.5mm and 1.0mm thresholds, those without any medical or lifestyle risks showed a higher proportion of average marginal bone loss per patient, although these associations were not statistically significant (p=0.561, p=1.000 respectively). The mean
implant marginal bone loss for those without any medical or lifestyle risks was 0.7±0.8mm, compared with 0.5±0.4mm for those with at least one medical or lifestyle risk (p=0.416). These results are presented in Figure 17 and Table 3.

**Figure 16.** Distribution of patients according to pertinent medical history
**Medical or lifestyle risk per patient**

**Figure 17.** Average implant marginal bone loss per patient according to pertinent medical history

**Table 3.** Overall averaged marginal bone loss and bone loss at the 1.5 and 1.0mm thresholds for pertinent medical history

<table>
<thead>
<tr>
<th>Pertinent medical history</th>
<th>Bone loss &lt;1.5mm</th>
<th>Bone loss ≥1.5mm</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>No medical or lifestyle risks</td>
<td>21 (84.0%)</td>
<td>4 (16.0%)</td>
<td>Fisher’s Exact test P=0.561</td>
</tr>
<tr>
<td>≥1 medical or lifestyle risk</td>
<td>6 (100.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pertinent medical history</th>
<th>Bone loss &lt;1.0mm</th>
<th>Bone loss ≥1.0mm</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>No medical or lifestyle risks</td>
<td>18 (72.0%)</td>
<td>7 (28.0%)</td>
<td>Fisher’s Exact test P=1.000</td>
</tr>
<tr>
<td>≥1 medical or lifestyle risk</td>
<td>5 (83.3%)</td>
<td>1 (16.7%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Independent Samples T-Test</th>
<th>P values (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No medical or lifestyle risks</td>
<td>≥1 medical or lifestyle risk</td>
</tr>
<tr>
<td>Number</td>
<td>Mean±SD</td>
</tr>
<tr>
<td>------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>25</td>
<td>0.67±0.80</td>
</tr>
</tbody>
</table>
5.2.8 Pertinent medical history and membrane tears

The association between pertinent medical history and membrane tears was another factor that was analyzed in this study. For comparison of pertinent medical history, the data was evaluated at the patient level. All medical history categories were combined and compared with those without any medical or lifestyle risks. 12 patients received bilateral sinus lifts. If a tear occurred in one or both sinuses, that patient was documented as having had a tear. Patients with at least one medical or lifestyle risk had a slightly higher occurrence of membrane tears but this difference was not statistically significant (p=0.760). These results are presented in Figure 18.

![Figure 18](image)

**Figure 18.** The occurrence of membrane tears according to pertinent medical history

5.2.9 Pertinent medical history and major complications

It was hypothesized that patients’ pertinent medical history was not associated with an increased occurrence of major postoperative complications. In patients who received bilateral sinus lifts, if a postoperative complication occurred following one or both surgeries, that patient was documented as having had a complication. For medical history comparison, the data was evaluated at the patient level. Patients without any medical or
lifestyle risks experienced a higher occurrence of postoperative complications, although this difference was not statistically significant (p=0.424). These results are presented in Figure 19.

Figure 19. The occurrence of major postoperative complications according to pertinent medical history

5.2.10 Smoking status and marginal bone loss

The association between smoking status and marginal bone loss was another factor that was analyzed in this study. The study population was divided into two groups: non-smokers (n=59) and smokers (n=8). At the latest follow-up, records existed for three patients who were current smokers and 28 patients who were non-smokers. For comparison of smoking status, the data was evaluated at the patient level. At both the 1.5mm and 1.0mm thresholds, non-smokers showed a higher proportion of average marginal bone loss per patient, although these associations were both not statistically significant (Table 4) (p=1.000, p=0.550 respectively). The mean implant marginal bone loss for non-smokers was 0.7±0.8mm, compared with 0.4±0.4mm for smokers (p=0.326). The
outlier visible in Figure 20 corresponds to a patient with a non-contributory medical history. These results are presented in Figure 20.

**Figure 20.** Average implant marginal bone loss per patient according to smoking status

**Table 4.** Overall averaged marginal bone loss and bone loss at the 1.5 and 1.0mm thresholds for smoking status

<table>
<thead>
<tr>
<th>Smoking status</th>
<th>Bone loss &lt;1.5mm</th>
<th>Bone loss ≥1.5mm</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number (%)</td>
<td>Number (%)</td>
<td></td>
</tr>
<tr>
<td>Non-smoker</td>
<td>24 (85.7%)</td>
<td>4 (14.3%)</td>
<td>Fisher's Exact test P = 1.000</td>
</tr>
<tr>
<td>Smoker</td>
<td>3 (100.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bone loss &lt;1.0mm</th>
<th>Bone loss ≥1.0mm</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number (%)</td>
<td>Number (%)</td>
<td></td>
</tr>
<tr>
<td>Non-smoker</td>
<td>20 (71.4%)</td>
<td>8 (28.6%)</td>
</tr>
<tr>
<td>Smoker</td>
<td>3 (100.0%)</td>
<td>0 (0.0%)</td>
</tr>
</tbody>
</table>

**Independent Samples T-Test**

<table>
<thead>
<tr>
<th>Non-s它们er</th>
<th>Smoker</th>
<th>P values (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>Mean±SD</td>
<td>Number</td>
</tr>
<tr>
<td>28</td>
<td>0.66±0.77</td>
<td>3</td>
</tr>
</tbody>
</table>
5.2.11 Smoking status and membrane tears

It was hypothesized that patients’ smoking status was not associated with an increased occurrence of sinus membrane tears. For comparison of smoking status, the data was evaluated at the patient level. 12 patients received bilateral sinus lifts. If a tear occurred in one or both sinuses, that patient was documented as having had a tear. Smokers had a higher occurrence of membrane tears, however this difference was not statistically significant (p=0.672). These results are presented in Figure 21.

![Figure 21](image)

**Figure 21.** The occurrence of membrane tears according to smoking status

5.2.12 Smoking status and major complications

The association between smoking status and major complications was another factor that was analyzed in this study. In patients who received bilateral sinus lifts, if a postoperative complication occurred following one or both surgeries, that patient was documented as having had a complication. For smoking status comparison, the data was evaluated at the patient level. Non-smokers experienced a higher occurrence of postoperative
complications, although this difference was not statistically significant (p=0.582). These results are presented in Figure 22.

![Figure 22. The occurrence of major postoperative complications according to smoking status](image)

### 5.3 Implant Design-Related Factors

#### 5.3.1 Implant brand surface and marginal bone loss

Of the 105 implants placed, records existed for 61 that reached a time point defined as the latest follow-up, which is any radiographic follow up 1-37 months beyond the date of integration check. These 61 implants were related to 37 sinuses. As all implant brands in this study featured their own respective “rough” micro-surface technology, it was hypothesized that the implant brand itself should not have been a factor affecting crestal bone loss at the latest follow-up. For implant brand surface comparison, the data was evaluated at the implant level. At the 1.5mm threshold, the Nobel TiUnite surface was close to being significantly associated with increased crestal bone loss as compared to the other brands (Table 5) (P=0.054). At the 1.0mm threshold, this association reached statistical significance (P=0.001). When comparing mean marginal bone loss without any threshold,
the association was significant (P=0.000). The mean implant marginal bone loss for the Nobel TiUnite series was 1.0±0.8mm, compared with 0.1±0.3mm for the Straumann SLA series, and 0.1±0.2mm for the Astra OsseoSpeed series. The Nobel implants (n=41) accounted for 67.2% of implants that reached the latest follow-up. The outliers visible in Figure 23 correspond to patients with non-contributory medical histories. These results are presented in Figure 23 and Table 5.

![Box plot showing average marginal bone loss by implant brand surface](image)

Figure 23. Average implant marginal bone loss according to implant brand surface
**Table 5.** Overall averaged marginal bone loss and bone loss at the 1.5 and 1.0mm thresholds for implant surface

<table>
<thead>
<tr>
<th>Implant brand surface</th>
<th>Bone loss &lt;1.5mm</th>
<th>Bone loss ≥1.5mm</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number (%)</td>
<td>Number (%)</td>
<td></td>
</tr>
<tr>
<td>Nobel TiUnite</td>
<td>31 (75.6%)</td>
<td>10 (24.4%)</td>
<td>Fisher’s Exact test P=0.054</td>
</tr>
<tr>
<td>Straumann SLA</td>
<td>8 (100.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>Astra OsseoSpeed</td>
<td>12 (100.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Bone loss &lt;1.0mm</th>
<th>Bone loss ≥1.0mm</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number (%)</td>
<td>Number (%)</td>
<td></td>
</tr>
<tr>
<td>Nobel TiUnite</td>
<td>23 (56.1%)</td>
<td>18 (43.9%)</td>
<td>Fisher’s Exact test P=0.001</td>
</tr>
<tr>
<td>Straumann SLA</td>
<td>8 (100.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>Astra OsseoSpeed</td>
<td>12 (100.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Mean Difference (mm)</th>
<th>One Way ANOVA with Bonferroni post Hoc adjustment: Significance (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nobel TiUnite</td>
<td>Straumann SLA</td>
<td>0.86 0.007 (0.2;1.5)</td>
</tr>
<tr>
<td></td>
<td>Astra OsseoSpeed</td>
<td>0.95 0.000 (0.4;1.5)</td>
</tr>
<tr>
<td>Straumann SLA</td>
<td>Nobel TiUnite</td>
<td>-0.86 0.007 (-1.5;-0.2)</td>
</tr>
<tr>
<td></td>
<td>Astra OsseoSpeed</td>
<td>0.09 1.000 (-0.7;0.9)</td>
</tr>
<tr>
<td>Astra OsseoSpeed</td>
<td>Nobel TiUnite</td>
<td>-0.95 0.000 (-1.5;0.4)</td>
</tr>
<tr>
<td></td>
<td>Straumann SLA</td>
<td>-0.09 1.000 (-0.9;0.7)</td>
</tr>
</tbody>
</table>

### 5.3.2 Implant shape and marginal bone loss

It was hypothesized that the implant shape should not have been a factor affecting marginal bone loss at the latest follow-up. For implant shape comparison, the data was evaluated at the implant level. At the 1.5mm threshold, the Nobel Replace series was close to being significantly associated with increased marginal bone loss as compared to the other brands (Table 6) (P=0.067). At the 1.0mm threshold, this association reached statistical significance (P<0.001). When comparing mean marginal bone loss without any threshold, the association was significant (P<0.001). The mean implant marginal bone loss for the Nobel Replace series was 1.1±0.8mm, compared with 0.3±0.4mm for the Nobel Active series, 0.1±0.3mm for the Straumann Bone Level series, and 0.1±0.2mm for the Astra Straight series. The outliers visible in Figure 24 correspond to patients with non-contributory medical histories. These results are presented in Figure 24 and Table 6.
Figure 24. Average implant marginal bone loss according to implant shape
**Table 6.** Overall averaged marginal bone loss and bone loss at the 1.5 and 1.0mm thresholds for implant shape

<table>
<thead>
<tr>
<th>Implant shape</th>
<th>Bone loss &lt;1.5mm</th>
<th>Bone loss ≥ 1.5mm</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number (%)</td>
<td>Number (%)</td>
<td></td>
</tr>
<tr>
<td>Nobel Replace</td>
<td>27 (73.0%)</td>
<td>10 (27.0%)</td>
<td>Fisher’s Exact test</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>P=0.067</td>
</tr>
<tr>
<td>Nobel Active</td>
<td>4 (100.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>Straumann Bone Level</td>
<td>8 (100.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>Astra Straight</td>
<td>12 (100.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bone loss &lt;1.0mm</td>
<td>Bone loss ≥ 1.0mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Number (%)</td>
<td>Number (%)</td>
<td></td>
</tr>
<tr>
<td>Nobel Replace</td>
<td>19 (51.4%)</td>
<td>18 (48.6%)</td>
<td>Fisher’s Exact test</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>P=0.000</td>
</tr>
<tr>
<td>Nobel Active</td>
<td>4 (100.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>Straumann Bone Level</td>
<td>8 (100.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>Astra Straight</td>
<td>12 (100.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean Difference (mm)</td>
<td>One Way ANOVA with Bonferroni post Hoc adjustment: Significance (95% CI)</td>
<td></td>
</tr>
<tr>
<td>Nobel Replace</td>
<td>Nobel Active</td>
<td>0.74</td>
<td>0.266 (-0.2; 1.7)</td>
</tr>
<tr>
<td></td>
<td>Straumann Bone Level</td>
<td>0.93</td>
<td>0.005 (0.2; 1.7)</td>
</tr>
<tr>
<td></td>
<td>Astra Straight</td>
<td>1.02</td>
<td>0.000 (0.4; 1.6)</td>
</tr>
<tr>
<td>Nobel Active</td>
<td>Nobel Replace</td>
<td>-0.74</td>
<td>0.266 (-1.7; 0.2)</td>
</tr>
<tr>
<td></td>
<td>Straumann Bone Level</td>
<td>0.19</td>
<td>1.000 (-0.9; 1.3)</td>
</tr>
<tr>
<td></td>
<td>Astra Straight</td>
<td>0.28</td>
<td>1.000 (-0.8; 1.4)</td>
</tr>
<tr>
<td>Straumann Bone Level</td>
<td>Nobel Replace</td>
<td>-0.93</td>
<td>0.005 (-1.7; 0.2)</td>
</tr>
<tr>
<td></td>
<td>Nobel Active</td>
<td>-0.19</td>
<td>1.000 (-1.3; 0.9)</td>
</tr>
<tr>
<td></td>
<td>Astra Straight</td>
<td>0.09</td>
<td>1.000 (-0.8; 0.9)</td>
</tr>
<tr>
<td>Astra Straight</td>
<td>Nobel Replace</td>
<td>-1.02</td>
<td>0.000 (-1.6; 0.4)</td>
</tr>
<tr>
<td></td>
<td>Nobel Active</td>
<td>-0.28</td>
<td>1.000 (-1.4; 0.8)</td>
</tr>
<tr>
<td></td>
<td>Straumann Bone Level</td>
<td>-0.09</td>
<td>1.000 (-0.9; 0.8)</td>
</tr>
</tbody>
</table>

### 5.3.3 Nobel Replace series and marginal bone loss

The association between implants within the Nobel Replace series and marginal bone loss was another factor that was analyzed in this study. For Nobel replace series comparison, the data was evaluated at the implant level. At the 1.5mm threshold, the Nobel Replace Tapered Groovy model experienced the largest but non-significant proportion of increased marginal bone loss as compared to the other brands (Table 7) (P=0.350). At the 1.0mm threshold, the Nobel Replace Straight Groovy model experienced the largest but non-significant proportion of increased marginal bone loss (P=0.402). A comparison of mean marginal bone loss without any threshold across the Nobel Replace series was not possible due to the fact that this study sample contained fewer than 2 implants from the Nobel Replace Select Straight series. The mean implant marginal bone loss for the Nobel Replace...
Straight Groovy model was 1.0±0.7mm, compared with 1.2±1.0mm for the Nobel Replace Tapered Groovy model, 1.2 ±0.4mm for the Nobel Replace Select Tapered model, and 0.5±0.2mm for the Nobel Replace Conical Connection model. The outlier visible in Figure 25 corresponds to a patient with a non-contributory medical history. These results are presented in Figure 25 and Table 7.

Figure 25. Average implant marginal bone loss according to Nobel Replace model

Table 7. Marginal bone loss at the 1.5 and 1.0mm thresholds for the Nobel Replace series

<table>
<thead>
<tr>
<th>Nobel Replace series</th>
<th>Bone loss &lt;1.5mm</th>
<th>Bone loss ≥1.5mm</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number (%)</td>
<td>Number (%)</td>
<td></td>
</tr>
<tr>
<td>Nobel Replace Straight Groovy</td>
<td>9 (90.0%)</td>
<td>1 (10.0%)</td>
<td>Fisher’s Exact test P=0.350</td>
</tr>
<tr>
<td>Nobel Replace Tapered Groovy</td>
<td>12 (60.0%)</td>
<td>8 (40.0%)</td>
<td></td>
</tr>
<tr>
<td>Nobel Replace Select Straight</td>
<td>1 (100.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>Nobel Replace Select Tapered</td>
<td>2 (66.7%)</td>
<td>1 (33.3%)</td>
<td></td>
</tr>
<tr>
<td>Nobel Replace Conical Connection</td>
<td>3 (100.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bone loss &lt;1.0mm</td>
<td>Bone loss ≥1.0mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Number (%)</td>
<td>Number (%)</td>
<td></td>
</tr>
<tr>
<td>Nobel Replace Straight Groovy</td>
<td>4 (40.0%)</td>
<td>6 (60.0%)</td>
<td>Fisher’s Exact test P=0.402</td>
</tr>
<tr>
<td>Nobel Replace Tapered Groovy</td>
<td>10 (50.0%)</td>
<td>10 (50.0%)</td>
<td></td>
</tr>
<tr>
<td>Nobel Replace Select Straight</td>
<td>1 (100.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
<tr>
<td>Nobel Replace Select Tapered</td>
<td>1 (33.3%)</td>
<td>2 (66.7%)</td>
<td></td>
</tr>
<tr>
<td>Nobel Replace Conical Connection</td>
<td>3 (100.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
</tbody>
</table>
5.3.4 All implants, platform-switching and marginal bone loss

It was hypothesized that implant platform-switching would be a factor affecting marginal bone loss at the latest follow-up. For implant platform-switching comparison, the data was evaluated at the implant level. Non-platform-switched models included the Nobel Replace Straight Groovy, Nobel Replace Tapered Groovy, Nobel Replace Select Straight, and Nobel Replace Select Tapered. Platform-switched models included the Nobel Replace Conical Connection, Nobel Active, Straumann Bone Level, Astra Osseospeed TX Straight, and MIS Seven. At both the 1.5mm and 1.0mm thresholds, non-platform-switched implants displayed a significantly greater proportion of marginal bone loss as compared to platform-switched implants (Table 8) (P=0.002, P<0.001 respectively). The mean implant marginal bone loss for platform-switched implants was 0.2±0.3mm, compared with 1.1±0.9mm for non-platform-switched implants. These results are presented in Figure 26 and Table 8.

![Figure 26. Average implant marginal bone loss according to implant platform-switching](image-url)
Table 8. Overall averaged marginal bone loss and bone loss at the 1.5 and 1.0mm thresholds for implant platform-switching

<table>
<thead>
<tr>
<th>All implants and platform-switching</th>
<th>Bone loss &lt;1.5mm</th>
<th>Bone loss ≥1.5mm</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Platform-Switched</td>
<td>24 (70.6%)</td>
<td>10 (29.4%)</td>
<td>Fisher’s Exact test P=0.002</td>
</tr>
<tr>
<td>Platform Switched</td>
<td>27 (100.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bone loss &lt;1.0mm</th>
<th>Bone loss ≥1.0mm</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number (%)</td>
<td>Number (%)</td>
<td></td>
</tr>
<tr>
<td>Not Platform-Switched</td>
<td>16 (47.1%)</td>
<td>18 (52.9%)</td>
</tr>
<tr>
<td>Platform Switched</td>
<td>27 (100.0%)</td>
<td>0 (0.0%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Independent Samples T-Test</th>
<th>P values (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>Mean±SD</td>
</tr>
<tr>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>Averaged Bone Loss (mm)</td>
<td>27</td>
</tr>
</tbody>
</table>

5.3.5 Nobel implants, platform-switching and marginal bone loss

The association between implant platform-switching within the Nobel implants and marginal bone loss at the latest follow-up was another factor that was analyzed in this study. For Nobel implant platform-switching comparison, the data was evaluated at the implant level. Non-platform-switched models included the Nobel Replace Straight Groovy, Nobel Replace Tapered Groovy, Nobel Replace Select Straight, and Nobel Replace Select Tapered. Platform-switched models included the Nobel Replace Conical Connection and Nobel Active. At the 1.5mm threshold, platform-switched Nobel implants displayed a greater proportion of marginal bone loss compared to the non-platform-switched Nobel implants, however this difference was not statistically significant (Table 9) (P=0.164). At the 1.0mm threshold, non-platform-switched implants displayed a significantly greater proportion of marginal bone loss as compared to platform-switched implants (P=0.012). The mean implant marginal bone loss for Nobel platform-switched implants was 0.4±0.3mm, compared with 1.1±0.9mm for non-platform-switched Nobel implants. These results are presented in Figure 27 and Table 9.
**Figure 27.** Average implant marginal bone loss according to Nobel implant platform-switching

**Table 9.** Overall averaged marginal bone loss and bone loss at the 1.5 and 1.0mm thresholds for Nobel implant platform-switching

<table>
<thead>
<tr>
<th>Nobel implants and platform-switching</th>
<th>Bone loss &lt;1.5mm</th>
<th>Bone loss ≥1.5mm</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Platform-Switched Nobel</td>
<td>24 (70.6%)</td>
<td>10 (29.4%)</td>
<td>Fisher’s Exact test, P=0.164</td>
</tr>
<tr>
<td>Platform Switched Nobel</td>
<td>7 (100.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nobel implants and platform-switching</th>
<th>Bone loss &lt;1.0mm</th>
<th>Bone loss ≥1.0mm</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Platform-Switched Nobel</td>
<td>16 (47.1%)</td>
<td>18 (52.9%)</td>
<td>Fisher’s Exact test, P=0.012</td>
</tr>
<tr>
<td>Platform Switched</td>
<td>7 (100.0%)</td>
<td>0 (0.0%)</td>
<td></td>
</tr>
</tbody>
</table>

**Independent Samples T-Test**

<table>
<thead>
<tr>
<th></th>
<th>Platform-Switched Nobel</th>
<th>Not Platform-Switched Nobel</th>
<th>P values (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Averaged Bone Loss (mm)</td>
<td>7 (0.39±0.32)</td>
<td>34 (1.12±0.85)</td>
<td>0.001 (0.33;1.11)</td>
</tr>
</tbody>
</table>
5.3.6 Platform-switched Nobel versus platform-switched non-Nobel implants and marginal bone loss

It was hypothesized that platform-switched Nobel implants and platform-switched non-Nobel implants would have similar levels of marginal bone loss at the latest follow-up. For platform-switching comparison, the data was evaluated at the implant level. Platform-switched Nobel models included the Nobel Replace Conical Connection and Nobel Active. All non-Nobel implants were platform-switched, and these included the Straumann Bone Level, Astra OsseoSpeed TX Straight, and MIS Seven. All implants displayed less than 1.0mm of marginal bone loss and thus comparisons at the 1.5mm and 1.0mm thresholds were not possible. Nobel platform-switched implants displayed a significantly greater mean marginal bone loss than non-Nobel implants, 0.4±0.3mm versus 0.1±0.2mm (P=0.044). Outlying values for Non-Nobel implants correspond to patients with a non-contributory medical histories. These results are presented in Figure 28 and Table 10.
**Figure 28.** Average implant marginal bone loss according to Nobel platform-switched and Non-Nobel implants

**Table 10.** Overall averaged marginal bone loss for Nobel platform-switched and Non-Nobel implants

<table>
<thead>
<tr>
<th></th>
<th>Platform-Switched Nobel</th>
<th>Non-Nobel</th>
<th>Independent Samples T-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Mean±SD</td>
<td>Number</td>
</tr>
<tr>
<td>Averaged Bone Loss (mm)</td>
<td>7</td>
<td>0.39±0.32</td>
<td>20</td>
</tr>
</tbody>
</table>
5.4 Bone Grafting-Related Factors

5.4.1 Graft material and marginal bone loss

The association between the graft material used and implant marginal bone loss in sites with ≥3mm of initial ridge height was another factor that was analyzed in this study. It was expected that any marginal bone loss that would occur would happen on autogenous bone. For graft material comparison, the data was evaluated at the implant level. At the 1.5mm threshold all bone graft materials except for BioOss xenograft included implants that had averaged marginal bone loss ≥1.5mm. This association was not found to be statistically significant (Table 9) (P=0.307). At the 1.0mm threshold, all graft materials included implants that had averaged marginal bone loss ≥1.0mm, with injectable paste allograft contributing the largest proportion of implants (n=9). This association was not found to be statistically significant (P=0.205). When comparing average marginal bone loss without any threshold (Table 2), the lack of an association was confirmed. Interestingly, outlying implants were found that corresponded to the same patient. The mean implant marginal bone loss for implants grafted with injectable paste allograft was 1.0±0.9mm, compared with 0.7±1.0mm for particulate allograft, 0.5±0.6mm for BioOss xenograft, and 0.5±0.8mm for particulate alloplast. These results are presented in Figure 29 and Table 11.
Figure 29. Averaged marginal bone loss and graft material at the implant level.
Table 11. Overall averaged marginal bone loss and bone loss at the 1.5 and 1.0mm thresholds for graft material

5.4.2 Graft consistency and operating time
It was hypothesized that in single implant cases where a sinus lift and simultaneous implant placement were performed, that the operating time was longer if particulate graft was used instead of injectable graft. 12 simultaneous single implant cases were on record, where operating time was recorded. For graft consistency comparison, the data was evaluated at the implant level. Although the mean operating time when particulate graft was used, 64.0±5.7 minutes, was on average 2.4 minutes longer than when injectable paste graft was used, 61.6±16.3, this difference was not statistically significant (P=0.727). These results are presented in Figure 30 and Table 12.
Figure 30. Operating time and the effect of graft consistency

Table 12. Operating time and the effect of graft consistency

<table>
<thead>
<tr>
<th>Single Cases with Simultaneous Placement</th>
<th>Injectable Paste Graft</th>
<th>Particulate Graft</th>
<th>Independent Samples T-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>Mean±SD</td>
<td>Number</td>
<td>Mean±SD</td>
</tr>
<tr>
<td>Mean Operating Time (min)</td>
<td>10</td>
<td>61.6±16.3</td>
<td>2</td>
</tr>
</tbody>
</table>

5.4.3 Graft consistency and major complications

The occurrence of postoperative complications at the sinus level is presented in Figure 31. All major complications occurred in different patients. It was hypothesized that injectable paste grafts and particulate grafts were equally associated with postoperative complications. It was discovered that injectable paste grafts were significantly associated with a higher occurrence of complications (P=0.014). These results are presented in Figure 32.
Figure 31. Major Postoperative Complications at the sinus level

Figure 32. Graft consistency as it relates to postoperative complications
5.5 Factors Related to Timing of Implant Placement

5.5.1 Implant placement timing and operating time

In single implant cases where a sinus lift and simultaneous implant placement were performed, it was expected that the operating time would be significantly longer than if just a sinus lift was performed. Operating time was recorded for 16 single implant cases. For implant placement timing comparison, the data was evaluated at the implant level. Although the mean operating time during sinus lift and implant placement, 62.0±14.9 minutes, was on average 10.0 minutes longer than during the sinus lift alone, 52.0±13.3 minutes, this difference was not statistically significant (Table 13) (P=0.256). These results are presented in Figure 33. An outlier can be observed in the sinus lift and implant placement group. During this particular procedure a membrane tear ≥5mm was encountered.

![Operating time and implant placement timing](image)

**Figure 33.** Operating time and implant placement timing
Table 13. Operating time and implant placement timing

<table>
<thead>
<tr>
<th>Implant placement timing</th>
<th>Sinus lift alone</th>
<th>Sinus lift &amp; implant</th>
<th>Independent Samples T-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Mean±SD</td>
<td>Number</td>
</tr>
<tr>
<td>Mean Operating Time</td>
<td>4</td>
<td>52.0±13.3</td>
<td>12</td>
</tr>
</tbody>
</table>
(min)                     |        |           |           |           |                  |

5.5.2 Implant placement timing and sinus membrane tears

It was hypothesized that in all sinus lift cases, single and multiple implant combined, that the sinus lift alone and the sinus lift and implant groups were associated with similar occurrences of sinus membrane tears. For implant placement timing comparison, the data was evaluated at the sinus level. The sinus lift and implant group was found to be associated with an increased proportion of sinus membrane tears, although the results were not statistically significant (P=0.410). These results are presented in Figure 34.

![Figure 34](image_url)

Figure 34. Implant placement timing as it relates to membrane tears
5.5.3 Implant placement timing and major postoperative complications

In all sinus lift cases, single and multiple implant combined, it was expected that the sinus lift alone and sinus lift and implant groups would be associated with similar occurrences of major postoperative complications. For implant placement timing comparison, the data was evaluated at the sinus level. Both groups were in fact found to be associated with equal proportions of sinus membrane tears, 9.7% and 10.4% respectively. These results are presented in Figure 35.

![Figure 35](image)

**Figure 35.** Implant placement timing as it relates to postoperative complications

5.6 Intrasurgical-Related Factors

5.6.1 Sinus membrane tears and marginal bone loss

It was hypothesized that the occurrence of sinus membrane tears was not associated with implant marginal bone loss during the latest follow-up. For sinus membrane tear comparison, the data was evaluated at the sinus level. At both the 1.5mm and 1.0mm thresholds, the occurrence of a sinus membrane tear was associated with an increased occurrence of marginal bone loss, however both results were not statistically significant.
(Table 14) (P=0.410, P=0.215 respectively). The mean implant marginal bone loss for sinuses which did not experience a membrane tear was 0.6±0.8mm, compared with 0.9±0.9 mm for sinuses that did experience a tear (P=0.325). The outlier visible in Figure 36 corresponds to a patient with a non-contributory medical history. These results are presented in Figure 36 and Table 13.

![Figure 36. Average implant marginal bone loss according to sinus membrane tears](image)

Table 14. Overall averaged marginal bone loss and bone loss at the 1.5 and 1.0mm thresholds for sinus membrane tears

<table>
<thead>
<tr>
<th>Sinus membrane tear</th>
<th>Bone loss &lt;1.5mm</th>
<th>Bone loss ≥1.5mm</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number (%)</td>
<td>Number (%)</td>
<td></td>
</tr>
<tr>
<td>No tear</td>
<td>25 (89.3%)</td>
<td>3 (10.7%)</td>
<td>Fisher’s Exact test P=0.410</td>
</tr>
<tr>
<td>Tear</td>
<td>6 (66.7%)</td>
<td>3 (33.3%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bone loss &lt;1.0mm</th>
<th>Bone loss ≥1.0mm</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number (%)</td>
<td>Number (%)</td>
<td></td>
</tr>
<tr>
<td>No tear</td>
<td>22 (78.6%)</td>
<td>6 (21.4%)</td>
</tr>
<tr>
<td>Tear</td>
<td>5 (55.6%)</td>
<td>4 (44.4%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Independent Samples T-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>No membrane tear</td>
</tr>
<tr>
<td>Number</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>Averaged bone loss</td>
</tr>
</tbody>
</table>
5.6.2 Radiographic septum and sinus membrane tears

The occurrence of sinus membrane tears overall was 22.8%, regardless of whether or not an interfering septum was visualized on the pre-operative CBCT scan. An interfering septum was defined as a septum lying directly above the alveolar ridge where sinus lift surgery was planned. Small and large membrane tears, 1-4mm and ≥5mm respectively, occurred with an occurrence of 12.7% and 10.1%, respectively. In sinuses where an interfering septum was visualized radiographically, small and large tears occurred with an occurrence of 26.3% and 18.4%, respectively. In sinuses where an interfering septum was not visualized radiographically, only 1 tear occurred, leading to an occurrence of 2.4%. These results are presented in Figures 37, 38, and 39. Due to the relatively small occurrence of radiographic Class II, III, and IV septum (Figure 1, Table 15), a separate analysis of septal classes and the occurrence of sinus membrane tears was not possible. Owing to the small sample size of this study, it was hypothesized that a small or large sinus membrane tear (all tears combined) was associated with the radiographic presence of an interfering septum (all classes combined). For radiographic septum comparison, the data was evaluated at the sinus level. The presence of an interfering radiographic septum on the pre-operative CBCT scan was found to be significantly associated with the occurrence of a sinus membrane tear (P<0.001). Thus the association was proven. These results are presented in Figure 40.

![Pie chart showing frequency of sinus membrane tears](image)

**Figure 37.** The frequency of all sinus membrane tears
Figure 38. The frequency of small and large tears in sinuses with septa

Figure 39. The frequency of small and large tears in sinuses without septa

Table 15. The distribution of all tears, both small and large, according to septal class

<table>
<thead>
<tr>
<th>Membrane Tears</th>
<th>No Tear</th>
<th>Tear</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Septum</td>
<td>40 (97.6%)</td>
<td>1 (2.4%)</td>
<td>41</td>
</tr>
<tr>
<td>Class I (B-L)</td>
<td>16 (59.3%)</td>
<td>11 (40.7%)</td>
<td>27</td>
</tr>
<tr>
<td>Class II (M-D)</td>
<td>2 (50.0%)</td>
<td>2 (50.0%)</td>
<td>4</td>
</tr>
<tr>
<td>Class III (Shelf)</td>
<td>3 (100.0%)</td>
<td>0 (0.0%)</td>
<td>3</td>
</tr>
<tr>
<td>Class IV (Combo of I, II, or III)</td>
<td>0 (0.0%)</td>
<td>4 (100.0%)</td>
<td>4</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>61 (77.2%)</td>
<td>18 (22.8%)</td>
<td>79</td>
</tr>
</tbody>
</table>
Figure 40. Septum identified by CBCT analysis as they relate to membrane tears

5.6.3 Sinus lift boundaries and sinus membrane tears

It was hypothesized that surgical sites that were tooth-bound on both their mesial and distal aspects would be more prone to experiencing an intraoperative membrane tear than sites where there was no distal tooth (free end situation), due to the increased difficulty of performing the sinus lift. For sinus lift boundary comparison, the data was evaluated at the sinus level. A trend was found in an opposite direction than was expected, with free-end sinus lifts showing an increased occurrence of membrane tears, although this difference was not statistically significant (P=0.790). These results are presented in Figure 41.
Figure 41. Sinus lift boundaries as they relate to membrane tears

5.6.4 Sinus location and sinus membrane tears

It was expected that the right and left maxillary sinuses would be equally prone to experiencing a membrane tear during surgery, and that the surgeon being right-handed was not a factor that influenced this occurrence. For sinus lift location comparison, the data was evaluated at the sinus level. This trend was confirmed, such that right and left sinuses were equally prone to experiencing a membrane tear (P=1.000). These results are presented in Figure 42.
Figure 42. Sinus location as it relates to membrane tears

5.6.5 Sinus membrane tears and major postoperative complications

The distribution of major postoperative complications is presented in Figure 31. It was hypothesized that the occurrence of any major postoperative complication (all types combined) was not associated with the occurrence of a sinus membrane tear (small and large tears combined). For sinus membrane tear comparison, the data was evaluated at the sinus level. It was found that the occurrence of an intrasurgical membrane tear was not associated with the occurrence of major postoperative complications ($P=1.000$). These results are presented in Figure 43.
5.7 Osstell-Related Factors

5.7.1 Osstell reading versus marginal bone loss at integration check and at latest follow-up

The predictive value of Osstell readings at integration check in terms of their ability to signal marginal bone loss both at integration check and during the latest follow-up was assessed. Osstell readings existed for 73 implants at integration check. Of the 61 implants which reached the latest follow-up, Osstell readings existed for 52 implants. It was hypothesized that increased average Osstell readings at integration check would be correlated with decreased average marginal bone loss at integration check. A small, statistically significant correlation was found ($R=-0.286$, $P<0.05$). An even smaller, non-statistically significant correlation was found when comparing Osstell readings at integration check and average marginal bone loss during the latest follow-up ($R=-0.035$, $P>0.05$). These results are presented in Figures 44 and 45.
Figure 44. Average marginal bone loss at integration check compared with average ISQ value at integration check

Figure 45. Average marginal bone loss at latest follow-up compared with average ISQ value at integration check
5.8 Effect of Implant Loading

5.8.1 Marginal bone loss during the first year of loading

Records existed for 32 implants which were loaded (restored) within 13 months of integration check. Of these 32 implants, two (6.3%) showed an average marginal bone loss of ≥1.5mm. Seven (21.9%) showed an average marginal bone loss ≥1.0mm. These results are presented in Figures 44 and 45. Two restored implants with an average marginal bone loss <1.5mm belonged to patients who experienced soft tissue numbness in the region following sinus lift surgery that was improving over time.

Figure 46. Average marginal bone loss ≥1.5mm after one year of loading

Figure 47. Average marginal bone loss ≥1.0mm after one year of loading
6. DISCUSSION

Advancement of the implant surgeon’s knowledge regarding sinus septa morphology is imperative to safe and effective treatment with dental implants in the posterior maxilla. The versatility of direct sinus lift surgery over the indirect technique has been discussed with respect to its potential of regenerating both severely atrophied maxillary sinuses as well as sinuses without an even floor anatomy. However, choosing to proceed with the direct technique does not reduce one’s risk of encountering a sinus membrane tear. Postoperative complications following a sinus membrane tear include graft dislodgement beyond the sinus membrane as well as infection. Reduced implant survival following sinus membrane tears has also been reported. Although a variety of techniques have been discussed with respect to the intrasurgical management of perforations, surgical abandonment has also been documented, particularly in cases of large perforations. For these reasons, an increased understanding of the risks posed by interfering sinus septa is of high value to both the surgeon and patient.

6.1 Sinus Septa Prevalence and Orientation

The prevalence of interfering septa at the sinus level within this study was 48.1%. As previously discussed the overall prevalence of septa reported in the literature at the sinus level is between 16% and 48%. The majority of sinuses in this study with interfering septa contained Class I septa, or septa with a medial-lateral orientation that divided the sinus cavity into anterior and posterior compartments. The remaining sinuses contained septa either oriented in a mesial-distal orientation (Class II), in horizontal shelf orientation (Class III), or they contained combinations of Class I and II or Class II and III septa. Van Zyl et al (2009) reported on a retrospective CBCT study of 400 maxillary sinuses. It was found that most septa also had a medial-lateral orientation. Velasques-Plata et al (2002) reported on a retrospective CBCT study of 312 maxillary sinuses. All septa that were identified exhibited a medial-lateral orientation. Kim et al (2006) reported on a retrospective CBCT study of 200 maxillary sinuses. It was found that most septa also had a medial-lateral orientation. Zijderveld et al (2008) reported on a prospective study.
involving 118 direct sinus lift surgeries. When septa were encountered, their orientation was also largely medial-lateral.

6.2 Patient-Related Factors

6.2.1 Patient age

The distribution of average implant marginal bone loss at the latest follow-up across the three age groups did not reveal significant differences between groups, however a trend of increased bone loss was seen in the older age groups. Patient-related factors contributing to marginal bone loss including systemic disease and medication, untreated or refractory periodontal disease, local infections, compliance with oral hygiene and maintenance, and smoking habits\textsuperscript{119} may well accumulate with age. Evidence in the literature however points to the lack of a significant relationship between age and implant failure.\textsuperscript{122} Trends were also observed such that the oldest age group experienced the highest proportion of membrane tears and the youngest age group experienced the smallest proportion of major postoperative complications, however neither of these associations reached statistical significance. Relationships between age and the occurrence of tears or major postoperative complications following sinus lift surgery have not been reported in the literature as of yet. One of the main limitations of this study is its small sample size, and thus true differences that might exist in the population may have been masked.

6.2.2 Gender

No trend was observed between genders with respect to average implant marginal bone loss at the latest follow-up or the occurrence of membrane tears. Gender should not have been a factor affecting the occurrence of membrane tears following sinus lift surgery in the general population, as all surgeries were performed by the same operator using the same technique, and there is no biological explanation favouring tears in one gender over another. A trend was observed such that females experienced a larger proportion of major postoperative complications, however this difference was not statistically significant. Lee et al (2010)\textsuperscript{148} followed 120 implants placed in 50 patients in both the maxilla and mandible, both rough and smooth surface, for 3 years of loading either as single or 2-3 unit splinted
crowns in a prospective radiographic study. A significantly increased amount of bone resorption was observed around implants in females. Relationships between gender and the occurrence of tears or major postoperative complications following sinus lift surgery have not been reported in the literature as of yet however.

6.2.3 Pertinent medical history

The presence of at least one medical or lifestyle risk factor was associated with decreased implant marginal bone loss at the latest follow-up, an increased occurrence of membrane tears, and a decreased occurrence of major postoperative complications, however these associations were not statistically significant. Evidence in the literature points towards a slightly increased risk for implant failure in diabetic patients compared to non-diabetics, however this should not affect implant treatment planning with respect to those with well-controlled diabetes.122,133,134 No studies to date have assessed the outcomes of osteoporotic control, sinusitis, or obstructive sleep apnea on sinus lift surgery and implant placement.

6.2.4 Smoking

A trend towards decreased implant marginal bone loss at the latest follow-up was found for smokers, however this association was not statistically significant. As previously discussed, while some studies have found decreased implant survival in smokers124-127, others have found no significant difference.55,128 Only 11.9% of this study's population were smokers, and smoking status was self-reported. Furthermore, as peri-implantitis and implant failure are both problems of multifactorial etiology the isolation of smoking as a risk factor alone is difficult.122 In this study smokers experienced an increased occurrence of membrane tears as well as a decreased incidence of postoperative complications compared to non-smokers, although both associations were not statistically significant. While an increased occurrence of postoperative infection following sinus lift surgery has been reported in smokers versus non-smokers127, other studies have not found any difference with respect to the occurrence of intraoperative and postoperative complications.55,129 Overall, the trends of decreased implant marginal bone loss and decreased occurrence of postoperative complications among smokers is in the opposite direction of what was expected. As the sample size in this
study was small and inter-individual variation in the general population is relatively large, there is the possibility that the relationships observed were skewed.

6.3 Implant Design-Related Factors

6.3.1 Implant surface and shape

The Nobel implants, all featuring the TiUnite surface, experienced a significantly larger amount of marginal bone loss at the latest follow-up compared to the Straumann and Astra Tech implants. The Nobel implants accounted for 67.2% of implants that reached the latest follow-up. Laurell et al (2011)\textsuperscript{149} performed a systematic review on 40 prospective studies with five-year loading follow-up on over 1,100 Astra, 3,700 Brånemark, and 1,300 Straumann implants. The weighted mean radiographic marginal bone level changes were -0.27, -0.72, and -0.56mm respectively, with significant differences between brands such that the Astra Tech implants performed much better than presently accepted thresholds for success. In this study the Nobel Replace series implant shape experienced a significantly larger amount of marginal bone loss at the latest follow-up compared to the Nobel Active, Straumann Bone Level, or Astra Straight series. Again, the Nobel Replace Series accounted for 60.1% of implants that reached the latest follow-up. No studies to date on root form dental implants have assessed the effect of implant shape variations on marginal bone loss.

6.3.2 Nobel Replace series

Of the five models within the Nobel Replace series, the Nobel Replace Tapered Groovy and Straight Groovy models experienced the largest proportions of marginal bone loss at the latest follow-up, although these differences were not statistically significant. Specific comparisons of average marginal bone loss between the Nobel Replace Straight Groovy, Tapered Groovy, Select Straight, Select Tapered, and Conical Connection models could not be found in the literature. These results must be interpreted with caution as the sample size in this study was small, limiting our ability to perform a reasonable comparison. This study sample contained fewer than 2 implants from the Nobel Replace Select Straight model. Therefore, if this model was removed from the evaluation, a specific comparison of mean marginal bone loss without any threshold across the Nobel Replace series would
have been possible. In addition, the Nobel Replace Tapered Groovy and Straight Groovy models contributed the largest proportions of Nobel Replace implants, possibly skewing the trends observed.

### 6.3.3 Platform-switching

It was suspected that platform-switching might play a more prominent role in affecting marginal bone loss than implant surface or shape. By having the implant-abutment junction positioned inwardly, an additional horizontal surface area is created for soft tissue attachment, allowing the biologic width to be established horizontally.\textsuperscript{150} Also, as this design increases the distance between the inflammatory cell infiltrate at the microgap and the crestal bone, it has the potential to minimize the effect of inflammation on marginal bone resorption\textsuperscript{151}. In our study it was found that platform-switched implants experienced a significantly reduced amount of marginal bone loss at the latest follow-up compared with non-platform-switched implants. Tellem et al (2012)\textsuperscript{152} reported on the one-year post-loading results of a randomized clinical trial in which 80 patients receive 113 implants, both non-platform-switched and platform-switched. Significantly reduced interproximal bone loss was observed around platform-switched implants. Al-Nsour et al (2012)\textsuperscript{153} conducted a systematic review on the effect of platform-switching that included nine studies and over 1,100 implants. Seven studies reported marginal bone preservation as a result of platform-switching. In our study it was found that Nobel platform-switched implants experienced a significantly reduced amount of marginal bone loss at the latest follow-up compared with Nobel non-platform-switched implants. Wagenberg & Froum (2010)\textsuperscript{154} reported on a prospective study of 94 Nobel platform-switched implants with external connections. It was found that platform-switching preserved marginal bone levels. Furthermore, in our study Nobel platform-switched implants experienced a significantly increased amount of marginal bone loss compared to implants from other brands, which included Straumann, Astra, and MIS. No studies to date on platform-switched implants have assessed the effect of implant brand variations on marginal bone loss.
6.4 Bone Grafting-Related Factors

6.4.1 Graft material and marginal bone loss

A trend was seen such that sinuses grafted with injectable paste allograft were related to implants that experienced increased marginal bone loss at the latest follow-up, however this association was not statically significant. Although studies comparing marginal bone loss on implants following placement in sinuses grafted with allograft, xenograft, or alloplast have not been reported, multiple reviews of the literature have found implant survival rates of 95% or greater when sinuses were grafted with bone substitutes as opposed to autogenous bone, regardless of their composition.\textsuperscript{22,39,62} Urban and Lozada (2010)\textsuperscript{155} reported on a prospective study of 79 patients who received 100 direct sinus lifts and 245 implants in a two-stage sequence. The success and survival of implants placed in sites with pre-treatment residual ridge heights of ≤3.5mm and >3.5mm were comparable.

6.4.2 Graft consistency and operating time

In single implant cases where a sinus lift and simultaneous implant placement were performed, a trend was seen such that the operating time when injectable paste allografts were used was decreased compared with particulate allograft, however this difference was not statistically significant. Irinakis (2011)\textsuperscript{3} compared the operating time in 49 patients who received a direct sinus lift and simultaneous single implant placement with either particulate allograft or injectable paste allograft. It was found that the use of injectable paste allowed for a significantly decreased operating time. Any reduction in surgical operating time may provide a benefit to the patient in terms of decreased morbidity, specifically the occurrence of postoperative infection. Peleg et al (2004)\textsuperscript{156} reported on a study including 156 sinus floor augmentation surgeries involving intraoral autogenous bone harvests. Autogenous bone harvesting added a minimum of 10 minutes to the overall operating time.
6.4.3 Graft consistency and major complications

A statistically significant association was seen such that the use of injectable paste allograft was related to an increased proportion of major postoperative complications compared to the use of particulate allograft. Irinakis (2011)$^3$ compared the efficacy of injectable paste allograft with particulate allograft during direct sinus lift surgery and simultaneous implant placement. No patients receiving either graft material experienced postoperative complications requiring surgical re-entry. As of yet, an association between the type of bone graft material used during sinus lift surgery and the occurrence of postoperative complications has not been found.$^{32}$

6.5 Factors Related to the Timing of Implant Placement

A trend was seen such that the operating time during single implant cases was increased where a sinus lift and simultaneous implant placement were performed, compared to cases in which only a sinus lift was performed, although the difference was not statistically significant. Also, a lack of an association was seen between the staging of implant placement and the development of major postoperative complications. Furthermore, a trend was seen such that sinus lift surgery and simultaneous implant placement, including both single and multiple implant cases, was associated with an increased proportion of sinus membrane tears, although the results were not statistically significant. As of yet such comparisons have not been reported in the literature.

6.6 Intrasurgical-Related Factors

6.6.1 Sinus membrane tears and marginal bone loss

The occurrence of a sinus membrane tear was related to implant marginal bone loss at the latest follow-up, however this association was not found to be statistically significant. Karabuda et al (2006)$^{157}$ assessed the effect of sinus membrane perforation on the success of implants placed in augmented sinuses, after both one- and two-stage direct sinus lifts, in a study involving 91 patients and 259 implants. A statistically significant difference was not seen in the peri-implant resorption rate between implants placed in sinuses with or
without membrane perforations. As previously discussed, although some evidence in the literature points to a relationship between sinus membrane tears and reduced implant survival\textsuperscript{91,92,108}, the majority of research on this topic points to the lack of such an association.\textsuperscript{22,93-95,107,109} The trend of sinus membrane tears causing increased marginal bone loss following implant placement, even if clinically relevant, may never prove to be statistically significant because the actual increase in marginal bone loss caused by a tear is likely very small relative to the overall success of implant therapy in the posterior maxilla.

### 6.6.2 Radiographic septum and sinus membrane tears

In this study the presence of an interfering radiographic septum on the preoperative CBCT scan was significantly associated with the occurrence of a sinus membrane tear. As previously mentioned, the incidence of reported perforations during direct sinus lift surgery has ranged from 0 to 57.5\%.\textsuperscript{3,87-96} Of these studies, only Malkinson and Irinakis (2009)\textsuperscript{89} in a retrospective study involving 52 direct sinus lifts, assessed for the presence of interfering septa on preoperative CBCT scans. An association between the presence of interfering septa and membrane perforations was not found.

### 6.6.3 Sinus lift boundaries, sinus location, and sinus membrane tears

Free-end sinus lifts showed a trend for an increased occurrence of membrane tears, although this difference was not statistically significant. This contradicts our hypothesis that surgical sites that were tooth-bound on both their mesial and distal aspects would be more prone to experiencing an intraoperative membrane tear than sites where there was no distal tooth, due to the increased difficulty of performing the sinus lift. As of yet such a comparison has not been reported in the literature. Krennmair et al (2007)\textsuperscript{96} reported on a retrospective study of 37 patients who received single implants in combination with one- or two-stage direct sinus lift surgery. Sinus membrane tears occurred with an incidence of 58\%. This relatively high incidence was attributed to the restricted access of a tooth-bound maxillary osteotomy. Also, in this study right and left sinuses were found to be equally prone to experiencing a membrane tear. As of yet such a comparison has not been reported in the literature.
6.6.4 Sinus membrane tears and major postoperative complications

The occurrence of an intrasurgical membrane tear in this study was not associated with the occurrence of any major postoperative complications. These complications included an infected graft, persistent sinusitis ≥2 months postoperative, extraoral facial collapse, severe pain at the ipsilateral ear, and soft tissue numbness. As previously discussed, the incidence of reported infection following sinus lift surgery has ranged from 0 to 12.5%. Of these studies, only Schwartz-Arad et al (2004) reported that membrane perforations were strongly associated with the occurrence of postoperative complications, including infection. It has been argued that the occurrence of sinusitis is not associated with the occurrence of membrane tears.

6.7 Osstell-Related Factors

A small, statistically significant correlation was found such that increased Osstell readings at integration check were related to decreased average radiographic marginal bone loss at integration check. The use of resonance frequency analysis does provide some assurance that an installed implant is clinically stable, however its relationship with marginal bone levels is questionable. Furthermore, it has been reported that implants placed in the mandible have both higher insertion torques and implant stability quotient readings compared with those placed in the maxilla, thus potentially refuting an association between Osstell readings at integration check and marginal bone loss.

6.8 Implant Success During the First Year of Loading

As previously discussed, Albrektsson and Zarb (1998) reported on criteria for implant success that it included 1) the absence of persistent pain, dysesthesia or paraesthesia in the implant area, 2) the absence of peri-implant infection with or without suppuration, 3) the absence of perceptible implant mobility, and 4) the absence of persistent peri-implant bone resorption >1.5mm during during the first year of loading and >0.2mm/year during the following years. Two, or 6.3%, of the 32 implants in this study showed an average marginal bone loss of ≥1.5mm during their first year of loading. None of the remaining 30 implants
were related to signs of infection. Due to the fact that implants cemented into multiunit prostheses could not be assessed on an individual basis for mobility, the calculation of true implant success was not possible in this study. However, setting aside the absence of mobility as a criteria for success a tentative overall success rate of 93.8% can be reported during the first year of loading, although 2 implants were associated with soft tissue numbness that was improving over time. Implant survival in the posterior maxilla following a one- or two-stage sinus lift technique after a minimum 1 year of loading has been reported within the range of 89.6% to 97.9%.\textsuperscript{39,40,54,55,61} Due to the limited follow-up data further calculation of implant success was not possible. Postoperative complications following sinus lift and implant surgery were evaluated based on existing chart records. Patients were not re-examined prior to this report.

6.9 Limitations of the Study

This retrospective study had a small sample size in general. As inter-individual variation in the general population is relatively large, there is the possibility that several relationships observed were skewed in a direction opposite to that which was expected, particularly with respect to smoking. Smoking frequency was not documented. Data for this study was collected from two different centres. Patient-related risk factors had to be grouped together to accommodate for our small sample size. Although all sinus lift surgeries as well as the vast majority of implant placements were performed by the same operator, radiographic records following integration check existed for only just over one half of the original implants. Due to the relatively short follow up period following integration check, the detection of significant differences or correlations between contributing factors and marginal bone loss was made difficult, even if true differences exist. The restoration of dental of implants plays a significant role in their overall success. Factors such as the creation of hygienic implant restoration contours as well as proper occlusal adjustment are critical to their long-term success. The majority of patients in this study returned to their referring dentists for implant restoration, and thus the confounding variable of multiple operators with different skill levels may also have affected the results observed. Other limitations include the lack of randomization and blinding, as well as the lack of
standardization of radiographs. Statistical analyses were completed at the implant, sinus, and patient level to maximize the validity of comparisons depending on the specific variables assessed. Particularly, an attempt was made to evaluate systemic factors at the patient level, to reduce the effect of patients with multiple implants in multiple sinuses. Averaging marginal bone loss values for this patient population diluted extreme results, however box plots were used to highlight the range of results, as well as demonstrate the presence of outliers. Being a retrospective study, the results presented rely on the accuracy of existing chart records.

6.10 Clinical Considerations and Suggestions for Future Research

Direct sinus lift surgery in preparation for implant therapy requires considerable preoperative planning. Due to the fact that the prevalence of interfering sinus septa within the region of proposed surgery is relatively high, and both the success of the sinus lift procedure as well as the occurrence of complications may be related to their presence, CBCT imaging is highly recommended as part of the preoperative protocol. Sinus membrane tears were managed by a very experienced surgeon and this may have contributed to the lack of a significant association between tears, postoperative complications, and marginal bone loss. Rough surfaced platform-switched implants are recommended in implant therapy both in the posterior maxilla as well as in all other sites. The findings of the present study clarify the need for a longitudinal investigation including a larger sample size to examine the effect of patient-related risk factors such as diabetes and smoking on the occurrence of membrane tears, postoperative complications, and long-term implant marginal bone loss. Anatomic factors such as sinus membrane thickness should also be considered.
7. CONCLUSIONS

Based on the results from this study, the following conclusions can be drawn:

- The prevalence of interfering maxillary sinus septa on preoperative CBCT scans in the region directly superior to the premolar and molar sites was 48.1%.
- When identified, these septa were most likely to be oriented in a buccal-lingual or medial-lateral orientation.
- Patient-related risk factors were not found to be significantly associated with marginal bone loss, the occurrence of sinus membrane tears, or any major postoperative complications.
- Implant platform-switching was significantly associated with marginal bone preservation.
- The identification of interfering septa on preoperative CBCT scans was significantly associated with the occurrence of intrasurgical sinus membrane tears.
- Sinus membrane tears were not significantly associated with major postoperative complications or implant marginal bone loss.
BIBLIOGRAPHY


16. Gündüz GN, Yıldırım YD, L WH, Tözüm TF. Location of posterior superior alveolar artery and evaluation of


2008 Sep;17:339–49.


89. Malkinson S, Irinakis T. The influence of interfering septa on the incidence of Schneiderian membrane...


APPENDICES

Appendix A. CBCT scan depicting a Class I sinus septum

Appendix B. CBCT scan depicting a Class II sinus septum

Appendix C. CBCT scan depicting a Class III sinus septum
Appendix D. Radiographs depicting no marginal bone loss

Appendix E. Radiographs depicting marginal bone loss

Appendix F. Example of measurements taken using Image J v1.46 software