A retrospective analysis of grafting and adjunctive procedures performed to facilitate dental implant therapy in private practice.

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Abstract

Purpose:

To retrospectively describe and analyse, with reference to the published literature, the augmentation profiles and any associated complications of grafting for dental implants that were placed and/or restored in private practice in the state of Victoria, Australia.

Materials and Methods:

Specialist and general dentists, and oral and maxillofacial surgeons who were placing and/or restoring implants during the period January 2005 to December 2009 were invited to participate in the study. Data were extracted by trained and calibrated research assistants from anonymised patient histories. Information was collected on augmentation techniques of onlay and particulate grafting, open and closed sinus lifting, socket preservation and soft tissue procedures. Complications were categorised as surgical (technical): neuro-sensory disturbance, pain, bleeding, swelling, bone perforation, insufficient bone quantity or quality or inadequate primary stability; and biological: Infection, bone loss, failure to osseointegrate, loss of integration, and peri-implantitis.

Cross tabulation was carried out in IBM SPSS™ to provide statistics on frequency, timing of procedures, materials and complications. Uni- and multi-
variate analysis was performed to assess independent risk factors of augmentation complications using GenStat®. Complications at implants sites that were augmented were compared to the sites that were not augmented.

Results:

During the period January 2005 to December 2009, 8486 implants were placed in 4116 patients. Nearly one third (26.9%) underwent at least one augmentation procedure either before or at the same time as placement. Particulate grafting was the most common hard-tissue procedure (21.4% of implants) and 63.1% of these were simultaneous, single-stage implants. In 35.9% of grafts, barrier membranes were used. 5.5% of implants had a soft tissue procedure recorded. The most popular materials overall were Bio-Oss® (Geistlich Biomaterials: Pharma North America Inc.) and autogenous bone. 92.9% of onlay grafts and 83.7% of open sinus lifts had a healing period before implant placement (mean overall healing period 6.7 months). The anterior maxilla was the most common site for all augmentation procedures.

There was a significant difference in the overall complication rate between the augmented implant sites and the sites that were not augmented (17.3% versus 12.6%; p=<0.001). The hard tissue augmented group had significantly more cases of insufficient bone and/or more dehiscences (2.10% v 0.58%; p<0.001) and bone loss (0.61% v 0.19%; p=0.0014) at implant placement than the non-augmented group. In these cases, implants were placed and grafted simultaneously (p<0.05) with particulate autogenous bone and/or Bio-Oss (p<0.05) in combination with resorbable xenograft membrane (p<0.001). There
was significantly more bone loss in open sinus lifted cases than in cases where implants were placed in native bone (1.90% v 0.30%; p=0.009). Other factors such as augmentation technique or material used, healing period length or timing of implant placement, were not found to significantly contribute to the complications, on multi-variate analysis.

Conclusions:

Augmentation procedures were required for nearly one third of implants placed, highlighting their importance in routine dental implant treatment and potential for complications to influence implant outcomes.

The study demonstrated no relationship between graft complication and any specific augmentation technique or material. This suggested that routine grafting procedures used in private practice were safe and appropriate despite a recent drive to avoid augmentation by using angulated, narrow or wide implants, in addition to zygomatic implants, as alternatives, when native bone might be lacking. A small (5%) but statistically significant increase in complication rate in the augmentation group did not preclude implant placement or aberrantly affect implant outcome in the short-term.

Whilst there are no guidelines with respect to the best materials to use for augmentation, the use of membrane, healing periods, and timing of procedures, this study demonstrated practices and complication rates largely in keeping with the published literature.
Declaration

This thesis comprises only my own original work towards the Master of Philosophy in Dental Science except where acknowledged in the text.
Acknowledgements

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Periodontology (Victorian Branch), Australian Prosthodontic Society (Victorian Branch) and the Australian Society of Implant Dentistry.

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Thank you whole-heartedly to my supervisors, Associate Professors Roy judge and Arun Chandu and Dr Denise Bailey for their tireless support and feedback. They have had major on-going involvement in the initiation, design, data collection and analysis phases of the overall study.
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List of abbreviations

BMP: Bone Morphogenic Protein
CBCT: Cone Beam Computerised Tomography
CI: Confidence Interval
DO: Distraction Osteogenesis
ePTFE: expanded-PolyTetraFluoroEthene
GBR: Guided Bone Regeneration
IAN: Inferior Alveolar Nerve
ID: Identification
PRP: Platelet Rich Plasma
RCT: Randomised-Controlled Trial
1. CHAPTER 1: INTRODUCTION

1.1 Background

Dental implants are a contemporary method of tooth replacement, and they represent the gold-standard for treatment of people with missing teeth. A prerequisite for their placement is sufficient bone volume of adequate quality in the alveolus to enable primary stability upon placement, osseo-integration and long-term maintenance of osseo-integration and stability. Osseointegration implies a direct structural and functional connection between living bone and an implant surface and was first described by Branemark in 1969 (Branemark et al. 1977). A stable soft tissue seal around the implant abutment is also essential for long-term success (Hammerle et al. 2002). Augmentation of hard and soft tissues may be performed in the context of implant dentistry where either one is deficient.

Bone loss most commonly occurs as a result of post-extractional alveolar resorption. Other reasons for bone deficiency are congenital: including congenital alveolar deficiency, hypodontia/anodontia, ectodermal dysplasia; and acquired: infection, iatrogenic (post- surgical), traumatic and pathologic. The resultant bony defect may be classified by the number of walls present (Seibert 1983) or according to the degree of loss of the ridge (Cawood and Howell 1988).

After extraction of a tooth, there is a predictable pattern of bone resorption in the first six months, due to bone disuse atrophy, reduced vascularization and inflammatory response. If such resorption is extensive, there may not be enough bone to enable successful placement of an implant in a satisfactory position or
inclination. However, a functional implant rapidly reduces disuse atrophy and slows down the resorptive process (Verhoeven et al. 2000). Bone resorption has been shown to take place bucco-lingually (mean 3.8mm or 29-63%) first and to the greatest extent, causing a lingual or palatal shift in the crest of the ridge (Pietrokovski 1975), followed by a reduction of ridge height (mean 1.24mm or 11-22%) at six months post extraction (Tan et al. 2012). It occurs more rapidly in the mandible than the maxilla (Atwood 1971). Over time, with such resorption, there may not be enough bone to enable successful osseointegration and/or there may be inadequate “orthoalveolar form,” or inter-arch relationship, resulting in a functionally and/or aesthetically unfavourable prosthetic result.

1.1.1 Basic bony requirements for successful implant placement

A key determinant of the long-term functional and aesthetic success of a dental implant is the available bone in three dimensions. The basic dimensions (diameter and length) of the implant and surrounding bone required for placement prescribe the necessary volume of the alveolus. These are dictated biologically by the necessity to achieve osseo-integration by maximising surface area contact between the titanium surface and living bone and to provide enough bony support for over-lying soft tissues to produce an adequate implant biologic width. Without adequate bone volume, vertical bone loss of the buccal plate may ensue, resulting in labial gingival recession. 1.5mm to 2mm facially (Buser et al. 2004) and 1mm lingually to an implant, with 3mm between implants (Tarnow et
al. 2000) or 1.5mm from native tooth root to implant (Buser et al. 2004) in the mesio-distal dimension, is considered the minimum quantity of bone required around an implant for placement. This is certainly the absolute minimum, and, ideally the labial thickness would be 2mm or greater for optimal aesthetics and soft tissue support. Indeed, one study indicated that as the facial thickness of bone associated with implants approached 1.8 to 2mm, bone loss reduced significantly and there was even some evidence of bone gain (Spray et al. 2000). The thickness of the buccal plate of bone may also guide the clinician with respect to the timing of implant placement following tooth extraction. Preservation of a thick buccal plate (a rare event) may facilitate immediate implant placement, which in turn, may help to preserve local bone and soft tissues (Levine et al. 2014). The height of bone available is dictated by local anatomy including the level of the inferior alveolar nerve (IAN), maxillary antrum, and the adjacent unaffected or tooth-bearing alveolus (and level of cemento-enamel junction of the adjacent teeth), which can be used as a vertical guide for implant positioning. The implant platform may be placed at tissue level, but for simplicity, when referring to implant height in the context of bone augmentation for this thesis, the level embedded in bone will dictate the height of the implant. Prosthodontic factors influencing bone requirements include the positioning in the arch, inclination and emergence profile, direction of implant loading, the inter-arch height and sagittal relationship. If these minimum requirements for bone are not met, one or more hard tissue augmentation procedures is required before or at the same time as implant placement.
Bone quality can be classified or rated according to density: D1 to D4; with reducing quality from D1 to D4 (Lekholm and Zarb 1985). High density bone is considered to be high quality for the purpose of implant placement. This is because higher density has been shown to positively correlate with improved primary stability (Marquezan et al. 2012). It may be measured pre-operatively by the radiographic opacity or Hounsfield units of bony substrate, as illustrated in table 1, or intra-operatively by tactile feedback when cutting the implant osteotomy (subjective) or by measuring the torque at which the implant being placed ceases to turn (objective). Thus, adequate bone density is that which provides sufficient implant primary stability. Although it is not possible to control density in native bone, when bone augmentation is planned, it is useful to consider the factors that might improve this feature such as type of graft, its micro-architecture (form), and harvest site.
Table 1: Comparison of bone density and quality by site; adapted from Misch, E.C. Contemporary Implant Dentistry Mosby Elsevier 3rd ed. (Misch 2008).

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<th>Description of bone</th>
<th>Typical location</th>
<th>Radiographic appearance</th>
<th>Hounsfield Units</th>
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<td>D1</td>
<td>Dense cortical</td>
<td>Anterior mandible</td>
<td><img src="image1.png" alt="Radiograph" /></td>
<td>&gt;1250</td>
</tr>
<tr>
<td>D2</td>
<td>Porous cortical;</td>
<td>Anterior and</td>
<td><img src="image2.png" alt="Radiograph" /></td>
<td>850-1250</td>
</tr>
<tr>
<td></td>
<td>dense trabecular</td>
<td>posterior mandible, anterior maxilla</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D3</td>
<td>Porous thin cortical; fine trabecular</td>
<td>Anterior and posterior maxilla, posterior mandible</td>
<td><img src="image3.png" alt="Radiograph" /></td>
<td>350-850</td>
</tr>
<tr>
<td>D4</td>
<td>Fine/soft trabecular</td>
<td>Posterior maxilla</td>
<td><img src="image4.png" alt="Radiograph" /></td>
<td>150-350</td>
</tr>
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1.1.1.1 Bone augmentation by defect type

The simplest procedures, and those that are performed in routine practice include particulate grafting or guided bone regeneration (GBR), cortico-cancellous block grafting, and open and closed sinus lifting. The type of alveolar defect may help to guide the extent or complexity of bone augmentation required to fulfil the alveolar bone requirements described for implant placement. Table 2 summarises the potential augmentation modalities according to the defect type, although, as later described, there are numerous variations on techniques and materials that may be used. Bone augmentation procedures may be performed in advance of implant placement (delayed) with a variable period of healing, or at the same time as implant placement (simultaneous) in order to increase the ridge width and/or height depending on the pattern of resorption that has taken place and restorative requirements. Additionally there are multiple ‘biologically active’ agents and biomaterials currently used to augment native bone. The more technically involved surgical procedures of distraction osteogenesis (DO), ridge splitting and Le Fort I osteotomies are usually reserved for more complex cases with severe, more generalised atrophy or bone loss.
Table 2: Indications for bone augmentation according to defect type. The number of walls corresponds to the number of bony walls that are present at the defect site.

<table>
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<th>Defect type</th>
<th>Suggested bone graft</th>
<th>Diagram</th>
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<td>Particulate bone and membrane</td>
<td><img src="image1.png" alt="Diagram" /></td>
</tr>
<tr>
<td></td>
<td>Or Autogenous cortico-cancellous block graft with particulate bone +/- membrane</td>
<td><img src="image2.png" alt="Diagram" /></td>
</tr>
<tr>
<td>2-walled horizontal defect</td>
<td>Particulate bone and membrane</td>
<td><img src="image3.png" alt="Diagram" /></td>
</tr>
<tr>
<td></td>
<td>Or Autogenous cortico-cancellous block graft with particulate bone +/- membrane</td>
<td><img src="image4.png" alt="Diagram" /></td>
</tr>
<tr>
<td>1-walled horizontal defect and Vertical or combined vertical and horizontal defect</td>
<td>Autogenous cortico-cancellous block graft with particulate bone +/- membrane Or Particulate autogenous bone and rigid/titanium</td>
<td><img src="image5.png" alt="Diagram" /></td>
</tr>
<tr>
<td>defect</td>
<td>membrane</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>----------</td>
<td></td>
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</table>
| Maxillary sinus pneumatisation | Autogenous cortico-cancellous block graft with particulate bone +/- membrane  
Or  
Particulate bone +/- membrane |

Socket preservation may be carried out at time of dental extraction with a variable period of healing before further augmentation or implant placement. The purpose of this augmentation procedure is to reduce the post-extractional bony ridge changes that may occur in order to preserve bone for future implant placement (Hammerle et al. 2012). Indications for this might be if the buccal wall of the extraction socket were thin or damaged, or in sites with a high aesthetic demand such as the anterior maxilla in patients with a high smile line. It might also be useful in sites where anatomical limitations are predicted to be a problem, such as proximity to the IAN or in cases where multiple extractions are being performed, after which the alveolus might be more prone to resorption.
1.1.2 Basic soft tissue requirements for successful implant placement

Soft tissues are important in the functional and aesthetic outcome of dental implants. Functionally, healthy cleansable peri-implant tissues and an adequate biologic width are essential for long-term implant maintenance. Positive patient outcomes are also dependent on creating an illusion that the implant is a real tooth, in harmony with the rest of the dentition. As well as deriving support from the underlying bone, soft tissues may be augmented by way of grafting. In particular connective tissue transfer from the hard palate with different flap designs, free gingival grafts or xenograft materials may be employed to increase gingival thickness in thin bio-types, or width of peri-implant keratinised gingiva. The different techniques of augmentation that may be employed to treat different types of soft tissue defect are described in table 3. There is a greater degree of subjectivity in assessing these defects and measuring the outcomes than in bone augmentation.
Table 3: Indications for soft tissue augmentation according to defect type; as described in a recent systematic review of the literature (Levine et al. 2014).

<table>
<thead>
<tr>
<th>Defect type</th>
<th>Suggested soft tissue procedure</th>
<th>Potential results</th>
</tr>
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<td>Facial surface implant up to recession 3mm Or Thin cuff of tissue at implant-abutment interface causing undesirable grey colour</td>
<td>Sub-epithelial connective tissue graft with coronally advanced flap Or Sub-epithelial connective tissue graft with envelope flap or pouch</td>
<td>• Increased width of peri-implant keratinised tissue • Reduced recession • Desired soft-tissue prominence around implant • Loss of peri-implant discolouration</td>
</tr>
<tr>
<td>&lt;1.5mm keratinised tissue at implant-abutment interface</td>
<td>Free gingival graft Or Vestibuloplasty Or Subepithelial placement of acellular dermal matrix</td>
<td>• Increased width of attached mucosa • Increased thickness of facial tissue</td>
</tr>
<tr>
<td>4mm marginal gingival defect Or</td>
<td>Pedicled connective tissue graft (the transposed soft tissue</td>
<td>• Improvement of the peri-implant soft tissue defect and aesthetics</td>
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Deficient interproximal area
Or
Failure of other augmentation techniques

maintains its connection to the donor site for its blood supply

Implant literature regarding augmentation practices, including ridge preservation, is mainly derived from small studies with limited numbers or individual academic or teaching centres, where the data is at risk of bias. The specific complications of augmentation procedures are seldom quoted, because the main outcome measures used are usually implant outcome or implant success rate. Thus augmentation procedures themselves are difficult to analyse with respect to the subsequent optimal timing of implant placement, and the most appropriate materials that should be used, including the use of barrier membrane. The rationale for this study was to provide an insight into the augmentation choices in private practice and to attempt to deliver some guidance on optimal augmentation protocols, based on documented complication rates.

1.2 Aims and objectives

This aim of this thesis is to describe contemporary augmentation techniques that are used to facilitate implant treatment and to explore the evidence for them.
Published techniques are compared to those that are employed by private practitioners in Australia, Victoria, using data that was collected retrospectively, from implants that were placed and/or restored over a 5 year period. Two journal articles in turn pose the research questions:

1. What are the techniques employed, materials and timings of augmentation and adjunctive procedures in the setting of implant treatment? How do these compare to the published literature?

2. What are the complications of these procedures and how do they compare to the published literature?

The advantage of a retrospective assay such as this is that no relationships or factors contributing to success or complication have been assumed; all data has been collected and possible relationships explored. As such, data collection has been comprehensive and involving a large and diverse group of patients and independent practitioners. No patients have been excluded on the basis of their medical background or other adverse characteristics such as age, tobacco use, diabetes or other immune-suppressive condition, radiotherapy to the head and neck or previous pre-prosthetic surgery, allowing analysis of all possible relationships and correlations with minimal sampling bias. The drawbacks of this study also mostly relate to the fact that it is retrospective. It carries risk of bias due to limitations of documentation and under-reporting. However, in highlighting these limitations, future prospective work will be better-informed.
This thesis is part of a larger project which involved the collection of data from 8486 implants that were placed from January 2005 to December 2009 in private practice in the state of Victoria, Australia. It is a joint study with the University of Melbourne Dental School and the Evident Foundation. Evident is a Dental Practice Based Research Network (an initiative of the Australian Dental Association Victoria Branch and the Oral Health Cooperative Research Centre at the University of Melbourne) that facilities practice-based dental research by supporting relationships between dental practitioners and academic researchers. Ultimately the aim of the project is to document contemporary implant treatment protocols in private practice, and to use the information to 1. Document trends over time; 2. Correlate practices with surgical, restorative and implant complications and outcomes; 3. Contribute to the design of a prospective data collection tool and/or assist with record keeping of practitioners; 4. Support the recruitment of practitioners for future studies; 5. Assist in the design of a future similar prospective study and in the formulation of evidence-based guidelines for treatment planning. This small aspect of the overall project may help to inform the treatment planning and case management of patients requiring grafting in conjunction with dental implant rehabilitation and help predict and/or avert complications in the more complex cases that require grafting. This may be achieved by analysis of complications of grafted implant sites in order to make recommendations on best practice. The specific outcomes of the implants are beyond the scope of this thesis.
2. CHAPTER 2: REVIEW OF THE LITERATURE

There are multiple options for augmentation in the context of dental implant treatment where native bone is lacking or soft tissue is deficient. Graft success has been defined as “Creation of an alveolar ridge of adequate dimensions to facilitate placement of dental implants that were eventually osseointegrated into the host and regenerated bone, and were functionally loaded under a restorative driven protocol for at least 6 months,” (Donos et al. 2008).

Contemporary augmentation techniques vary in their definition and nomenclature; clinicians also vary in their interpretation of each procedure, use of materials and timing of procedures. Techniques may also be classified in the context of the intention to augment specific ridge defects or either horizontal or vertical deficiencies, which each carry different challenges and potential for complications. Increasingly alternatives to augmentation are being developed such as angulated and zygomatic implants or shortened or narrow implants to fit the residual native bone whilst maximising surface area. Whilst these also carry risks, it is important to compare the outcomes of implants that are placed using these techniques with conventional and time-tested augmentation protocols. The potential for complications using different augmentation techniques and implant alternatives are described in turn with reference to the published literature.
2.1 Techniques of augmentation

Some hard tissue augmentation procedures are more technically challenging than others. The more commonly employed procedures are usually the least complex. More than one technique however may be used at any one hard-tissue deficient site. Each procedure will be described briefly in turn with some details of the clinical situations in which it may be employed.

1. Particulate grafting/guided bone regeneration (GBR)
2. Onlay bone grafting
3. Open sinus lifting
4. Closed sinus lifting
5. Ridge-splitting and interpositional grafting
6. Le Fort I osteotomy
7. Distraction osteogenesis (DO)
8. Socket preservation

1. Particulate graft/guided bone regeneration is an augmentation strategy where, conventionally, a barrier membrane is used to maintain the space in which filler material is placed and bone is intended to form. It can be used to augment or recontour the alveolar ridge or to fill peri-implant bone defects, as illustrated in figure 1. There have been interpretations of this technique documented, and, in some instances, the filler may be omitted (Simion et al. 2001). Strictly, GBR should include the use of a barrier membrane, and when it was first conceived as a technique for restoring periodontal tissues (Guided Tissue Regeneration), the
membrane was deemed essential to prevent migration of junctional epithelium in to the site intended for bony augmentation (Sculean et al. 2008, Rakhmatia et al. 2013). However, barrier membranes are increasingly less likely to be used for space maintenance as newer manufactured materials such as BondBone® (MIS Corporation, Israel) are better able to maintain their structural integrity. Thus, in this thesis, the terms particulate graft and GBR are used interchangeably and the presence or absence of a membrane is specified.
Figure 1: GBR to enhance the horizontal contour of the mandibular alveolar ridge with simultaneous implant placement: a. packing of particulate bone into the defect; b. measuring up the resorbable membrane; c. tucking the membrane under the mucosa to cover the graft; d. mucosal closure.

2. **Onlay** bone grafting involves placement and immobilization of graft material, frequently autogenous cortico-cancellous block, over the deficient area to increase horizontal or vertical dimension or both. The bone may be immobilised with resorbable screws consisting of poly (D,L-lactide) acid (PDLLA) or non-resorbable titanium screws, with or without plates, or with self-tapping dental implants when the graft is placed at the crest of the ridge (Kahnberg et al. 1989).
Whilst it may be difficult to adapt the onlay to the recipient site, this type of grafting has the advantage of maintaining its position and rigidity in order to achieve changes in ridge dimension outside of the pre-existing skeletal envelope. Figure 2 is an example of a large cortico-cancellous onlay bone graft.

Figure 2: a. Cortico-cancellous onlay bone graft to the right maxilla secured with three bicortical screws, providing increased width of the facial plate of bone; b. Cone-Beam Computerised Tomography (CBCT) of an onlay graft in the maxilla demonstrating screw retention of the graft.

3. *Open/lateral approach sinus lift* conventionally involves the creation of a window into the sinus laterally and elevating the sinus membrane, without perforation, to create a pocket in to which to place a graft material. The window may be a trap-door, where by the superior border of the cortical bony plate remains attached to the underlying Schneiderian membrane, or an access hole, where the entire bony plate is removed (Pjetursson et al. 2008). Graft material
may be condensed in to the sinus cavity or blocks can be secured with screws or with self tapping implants (Wannfors et al. 2000). Figure 3 is an example of particulate bone open sinus elevation. This procedure may be used to achieve bony height for osseointegration to compensate the for pneumatisation of the maxilla that follows edentulism. However, this does not compensate for the loss in height that gives rise to increased free-way space due to maxillary resorption. Thus it does not assist in improving unfavourable inter-arch relationships that occur as a result of alveolar atrophy. It is notable that, provided implants have primary stability, they can be successfully augmented simultaneously, where they protrude in to the sinus cavity, as demonstrated in figure 3. An additional concept is the finding that even if the protruding implants are not grafted, the coagulum that forms between the implant surface and the tented sinus lining may, on its own, give rise to new bone formation (Lundgren et al. 2004).
Figure 3: Open sinus elevation left maxilla: a. Delineation of the lateral window; b. Elevation of the window (trap-door) and placement of two dental implants under direct vision; c. Packed particulate bone around the implants within the sinus, with particulate bone visible at the window; d. Post-operative radiograph demonstrating packed particulate bone at apices of two dental implants.

4. Closed sinus lift also involves lifting the sinus lining apically to create space for an implant, but is less invasive than open sinus lifting. A 'green-stick fracture' of the ridge of bone apical to an implant (sinus floor) is created blindly via a crestal approach with a series of concave-tipped osteotomes, ideally without perforation. Usually an implant is placed simultaneously. Summers, who first described this trans-alveolar procedure using osteotomes, considered that at
least 6mm of residual bone was necessary to ensure primary stability of the implant (Summers 1994). However the technique has since been described with as little as 2 to 4mm of residual bone (Cosci and Luccioli 2000). Tenting up the Schneiderian membrane in this way creates a space for coagulum, from which new bone forms.

Other methods of elevating the sinus membrane have included a series of atraumatic drills (Cosci and Luccioli 2000) and injection of particulate graft material in to the osteotomy site; the hydraulic pressure from its injection gently elevating the sinus lining to create a pocket. Additionally, the rounded apex of a self-drilling implant may be used to lift the cortical lining of the sinus as it is placed. Summers also described a less conventional two-staged closed sinus lift whereby an osteotomy would allow a lifting of the sinus lining and injection of material followed by a delay to enable bone healing before implant placement (Summers 1995). Such an adaptation of the conventional closed sinus lift procedure obscures the boundaries of closed versus open sinus lifting techniques.

5. Inlay or interpositional grafting involves the surgical separation of a section of bone and placement of a graft material which is sandwiched between the two sections. Depending on the technique, the ridge can be segmentally augmented in width or height. Ridge expansion requires a longitudinal osteotomy along its crest to sagittally separate two cortices of bone with vertical stop cuts to define the length of alveolus being augmented. An example of this ridge-splitting
technique is shown in figure 4, where the defect is filled with particulate bone. Implants may also be simultaneously placed in the defect, if primary stability can be achieved. Ridge height can be increased by creating an osteotomy parallel to the crest, curving it superiorly at each end whilst maintaining crestal and lingual soft tissue attachments. This is demonstrated radiographically in figure 5. The inter-posed bone may be a cortico-cancellous block, particulate or a combination. The success of this procedure is in part due to the maintenance of periosteal blood supply of the native bone, and the endosteal incorporation of the graft from the adjacent bone marrow (Jensen et al. 2006a). Due to the complexity of this technique, its use in routine clinical practice is uncommon, and it was not documented in the studied cohort.
Figure 4: Ridge splitting and interpositional particulate grafting of atrophic anterior maxilla. Stages of the surgical procedure and post-operative CBCT are shown.
Figure 5: Radiograph of vertically augmented posterior mandibular alveolus by ridge-splitting technique. Bone has been sandwiched between the cortices and secured with titanium mini-plates.

6. Le Fort I osteotomy is a complex pre-prosthetic augmentation procedure that can be used in the severely atrophic maxilla, in conjunction with interpositional and/or onlay bone grafting. The sinus membrane may also be simultaneously lifted and the maxillary antra grafted in a form of open sinus lift. The Le Fort I osteotomy enables control of the vertical and antero-posterior dimension of the entire maxilla relative to the mandible, and as such has the advantage of correcting a reversed inter-arch antero-posterior relationship, and increased vertical inter-maxillary relationship (Nystrom et al. 2009). This improved relationship or optimal “ortho-alveolar form” may result in a biomechanically more favourable prosthesis and thus, as postulated, it may reduce peri-implant bone resorption (Ribeiro-Junior et al. 2009). There are also aesthetic benefits such as improved lip and soft-tissue support, although rarely does the procedure realistically produce enough projection to obviate the need for an acrylic or pink
porcelain flange on an implant-supported fixed bridge. The osteotomy, demonstrated in figure 6, is technically difficult, particularly in “egg-shell” thin bone, which poses problems for internal fixation and carries an increased risk of bone fragmentation and sinusitis as a complication. For this reason, it is not commonly undertaken. However, some authors have suggested an implant success rate of up to 85%, and a 100% prosthetic success rate, at mean 13 year follow-up in such cases (Nystrom et al. 2009). As this procedure was not performed in the studied cohort, it will not specifically be discussed further.

Figure 6: Intra-operative photograph of Le Fort I osteotomy with antero-posterior advancement, interpositional grafting and packing of particulate bone in to the antra, as can be seen in the third photograph.

7. Distraction osteogenesis (DO) is the gradual controlled displacement of a surgically prepared osteotomy to increase interpositional bone volume, with immature woven then mature lamellar bone. This has the advantage of producing vascularised bone without donor site morbidity, and simultaneously expanded soft tissues with no tension or reduction in sulcus depth, resulting in
complete bone coverage at the site. Having been developed in the 1980s (Bianchi et al. 2008), the technique of tissue histiogenesis has been described in cranio-maxillofacial surgery by various authors to correct basal bone length as well as alveolar bone deficits. Like the Le Fort I osteotomy, DO can be used to achieve ortho-alveolar form as well as bone for osseointegration, using extra- or intra-oral devices. Indeed, this technique may allow for greater (more successful) vertical bone augmentation than other techniques (Bianchi et al. 2008, Esposito et al. 2009b) and as such may be useful if large increases of bone height are required such as in the severely resorbed posterior mandible. A successful example of this is illustrated in figure 7, showing advancement of the atrophic maxilla. However, it is minimally used in routine dental private practice due to the specific technical expertise that is required. As such, it will not be addressed further in this review. Technical difficulties include vector control, transport segment displacement or tipping, occlusal disturbance, mucosal dehiscence or infection and device fracture (Soon-Jung Hwang 2004).
Figure 7: Internal Le Fort I level distraction of the atrophic maxilla enabling implant placement and prosthodontic rehabilitation; pre- and post-distraction radiographs and clinical photographs.

8. **Socket (ridge) preservation** is carried out at time of dental extraction, followed by a variable period of healing, in order to help preserve ridge volume by reducing rate of post-extraction changes. Particulate material is usually placed in the extraction socket, with or without coverage by barrier membrane and/or primary socket closure. One systematic review reported a pooled small statistically significant gain in bone height (0.91mm: range 0.49 to 1.32mm) and
width (2.97mm: range 2.33 to 3.60mm) following socket preservation suggesting that future augmentation or implant procedures might therefore be simplified or reduced in magnitude. However, the clinical benefit of such a small difference on implant outcome was unclear (Hammerle et al. 2012, Vittorini Orgeas et al. 2013). The use of a barrier membrane without graft material has been suggested to be sufficient, or even preferred, for optimisation of wound healing in extraction sites (Vittorini Orgeas et al. 2013), giving rise to the greatest dimensional gains. The reason for this improved outcome, as compared to graft and barrier together, is difficult to explain, but may be related to difficulty with primary closure when a graft filler material is used.

*Connective tissue grafting*, where autogenous grafts are harvested from the hard palate, may be used to augment peri-implant keratinised tissue. Connective tissue grafting has been suggested to improve aesthetics, thickness and seal of peri-implant tissues in addition to helping to re-build lost inter-dental papillae (Esposito M 2012). This is particularly useful in patients with a thin biotype, where thinning of peri-implant tissues may compromise aesthetics and cleansibility. This may also help to reduce soft tissue and grafting complications such as wound dehiscence by improving tension-free coverage (Misch 2011). Some authors have advocated the use of xenograft collagen matrix to increase peri-implant keratinised tissue, on the basis of the reduced invasiveness of this technique, as they have shown this method of augmentation to be equally as effective as grafting (Lorenzo et al. 2012), although other authors disagree (Levine et al. 2014).
2.2 Materials

Materials used in augmentation procedures can be categorised based on their osteogenic, osteoinductive and osteoconductive properties, their source, and their form or microstructure.

Osteogenicity describes the laying down of new bone in the process of resorption and remodelling by osteo-competent cells (osteocytes and osteoblasts). Osteoinductivity is the process of new bone formation by local undifferentiated mesenchymal cells stimulated to become osteoprogenitor cells. Induction of new bone is a pharmacokinetic occurrence and is thought to be directly proportional to the concentration of bone-inductive proteins such as bone morphogenic protein (BMP) preserved in the grafted material (Jensen et al. 1998). Osteoconductivity is the ability of a graft to provide a scaffold for formation of new bone. The bone is derived from the host/recipient site’s osteocompetent cells.

Materials can also be categorised according to their source. Osteogenicity is a property unique to autogenous bone- bone that has the same human donor and recipient. Allograft is bone derived from another human; xenograft is derived from another species; and allograft is synthetic bone. All have potential for osteoconduction and osteoinduction, particularly when combined with BMPs. Further sub-categorisation of materials is the form in which they are used: Particulate bone is granular in nature. It may form a putty like consistency when manipulated or remain fragmented; Block bone is a solid sheet of bone that is
rigid and stable in form but may not necessarily have any tensile or compressive strength.

2.2.1  Autogenous bone

The use of autogenous bone is currently considered the gold-standard in implant dentistry (Esposito et al. 2009b). Sources of autogenous bone are summarised in Table 4. Block bone, which is usually used as an onlay graft, needs to be harvested via an osteotomy so that it does not fragment. This requires some technical expertise as it involves use of a drill or saw and osteotomes in close proximity to vital structures. The onlay may be corticated or non-corticated. Figure 8 is an example of cortico-cancellous graft being harvested from the chin. The mental nerves and tooth roots are in close proximity. Autogenous bone may also be particulate in form and is usually cancellous, although cortical bone can be particulated. This requires slightly less expertise to harvest, by way of curettage, scraping or using a bone trap in the surgical suction tubing for opportunistic gathering. These methods are illustrated in figure 9.

![Figure 8: Harvest of onlay bone graft from the chin.](image-url)
Advantages of the use of autogenous bone are biological compatibility, osteogenicity, osteoinductivity by endogenous BMPs and osteoconductivity. Indeed in one study that used histopathology to directly compare bone defects grafted with particulate autogenous bone, xenograft and alloplast over time, autogenous bone demonstrated the fastest bone regeneration and increased osseous maturity at all observation periods (Jensen et al. 2006b). Another study looking at open sinus lifts also suggested that autogenous bone was more beneficial than alloplast and xenograft materials when treating large pneumatised sinuses with minimal native bone (Aghaloo and Moy 2007).

Drawbacks of use of autogenous bone include donor-site morbidity, limited availability and possible contamination with saliva, which has a large bacterial load and therefore possible increased risk of infection. Intra-oral harvest sites
carry the risk of IAN or mental nerve injury. However the material risk of donor site complication may be greater in extra-oral harvest sites such as the iliac crest, as it includes risk of altered gait and sensori-neural change to a large area of the upper lateral thigh. However, the advantage of iliac crest is that large volumes of bone may be harvested for extensive augmentation of atrophic or defective ridges and the risk of bacterial contamination is lower than oral sites.
Table 4: Potential sources of autogenous bone used for implant dentistry.

<table>
<thead>
<tr>
<th>Source of bone</th>
<th>Site</th>
<th>Form</th>
<th>Harvest technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intra-oral source</td>
<td>Local Extraction socket</td>
<td>Particulate cancellous</td>
<td>Bone trap/filter/bone scraper</td>
</tr>
<tr>
<td></td>
<td>Implant osteotomy</td>
<td>Particulate cancellous</td>
<td>Bone trap/filter/bone scraper</td>
</tr>
<tr>
<td>Distant</td>
<td>Ramus</td>
<td>Particulate cancellous and/or cortical Block cortico-cancellous</td>
<td>Bone trap/filter/bone scraper/curettage Osteotomy</td>
</tr>
<tr>
<td></td>
<td>Symphysis</td>
<td>Particulate cancellous mostly Block cortico-cancellous</td>
<td>Bone trap/filter/scaper Osteotomy</td>
</tr>
<tr>
<td>Maxillary tuberosity</td>
<td></td>
<td>Particulate cancellous mostly Block</td>
<td>Bone trap/filter/scaper Osteotomy and curettage</td>
</tr>
<tr>
<td>Source</td>
<td>Bone Type</td>
<td>Preparation</td>
<td>Method</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------------------------------</td>
<td>-------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Oral bony exostoses</td>
<td>Particulate cancellous mostly</td>
<td>Block cortico-cancellous</td>
<td>Bone trap/filter/scaper Osteotomy</td>
</tr>
<tr>
<td>Zygomatico-maxillary buttress or zygoma</td>
<td>Particulate cancellous and/or cortical Block</td>
<td>Bone trap/filter/scaper Osteotomy</td>
<td></td>
</tr>
<tr>
<td>Extra-oral source</td>
<td>Tibial plateau</td>
<td>Particulate cancellous</td>
<td>Curettage</td>
</tr>
<tr>
<td></td>
<td>Iliac crest</td>
<td>Block and particulate as required</td>
<td>Osteotomy and curettage</td>
</tr>
<tr>
<td></td>
<td>Calvarium</td>
<td>Block cortico-cancellous</td>
<td>Osteotomy</td>
</tr>
<tr>
<td></td>
<td>Rib</td>
<td>Block cortico-cancellous</td>
<td>Osteotomy</td>
</tr>
</tbody>
</table>

The density or quality of autogenous bone and its resorption characteristics can be variable, which is another drawback. Autogenous cortico-cancellous grafts that are harvested from intra-oral sites are usually graded D1 to D2 and are thus denser than iliac crest, which is D3 to D4. Mandibular ramus bone is, in turn,
denser than symphyseal bone (Misch 1997). Once incorporated, it is suggested that the quality of block-grafted autogenous bone may exceed that of native maxillary bone, and that this enhanced quality may improve implant stability (Misch 2011). The form or osseous micro-architecture of grafted bone may also be important in rate of graft resorption (Ozaki and Buchman 1998). Mandibular ramus bone, which has a thicker cortex, has shown less resorption than iliac crest, which is mostly porous cancellous bone, despite the more rapid revascularisation potential of cancellous bone (Kusiak et al. 1985). Thus, ramus block grafts may be more successful than other modalities of autogenous augmentation (Misch 2011).

2.2.2 Xenografts

Xenograft materials are commonly derived from animals and take the form of demineralised bone matrix or collagen. Bovine, porcine and coral-derived materials are processed in order to remove the organic component. These graft materials are osseo-conductive and may retain their osseoinductive properties and as such activate the host’s mesenchymal cells to differentiate into osteoblasts. They may additionally have BMPs added to them.

There is no overall consensus regarding the efficacy of these materials. There has been concern regarding the absolute non-infectivity of bovine-derived materials with respect to risk of Creutzfeldt-Jakob disease, although this has been disputed (Wenz et al. 2001, Esposito et al. 2009b). Other precluding factors in the use of such substitutes are cultural and religious factors and cost. One example of a
commonly used xenograft is Bio-Oss® (Geistlich Biomaterials: Pharma North America Inc.). The obvious advantage of the use of non-autogenous bone is the lack of donor-site morbidity. As such, in one split-mouth trial comparing Bio-Oss® (Geistlich Biomaterials: Pharma North America Inc.) to iliac crest harvest, naturally, there was a statistically significantly patient preference for the xenograft. In this trial there was no difference in implant outcome, questioning the need for such a high-risk operation as that of the iliac crest graft harvest, when large quantities of bone were required (Felice et al. 2008). One trial, documented in a review of the literature on bone augmentation procedures (Esposito et al. 2009b), suggested that horizontal bone augmentation for rehabilitation with single implants could be successfully achieved using Biooss® (Geistlich Biomaterials: Pharma North America Inc.). Whilst augmentation with Bio-oss® (Geistlich Biomaterials: Pharma North America Inc.) showed a trend of increased healing time and more failures, failed implants could be removed and replaced successfully without a need for further augmentation (Meijndert et al. 2007). Furthermore, the use of xenograft in particulate form has been suggested to resorb less that the autogenous equivalent or other bone substitutes, as demonstrated in histopathological studies (Piattelli et al. 1999, Jensen et al. 2006b). However, another systematic review suggested that xenograft augmentation was inferior to autogenous bone in terms of implant outcome (Aghaloo and Moy 2007). As suggested in a comprehensive review of the literature, there is no evidence to suggest superiority or inferiority of xenograft grafting materials (Esposito et al. 2009b). Their use appears to be
mostly influenced by the volume required, cost and patient and practitioner preference. Bio-Oss® (Geistlich Biomaterials: Pharma North America Inc.) in particular is recognised for its biocompatibility, versatility and osteoconductive properties, and its use has been extensively documented (Jensen et al. 2006b).

2.2.3 Alloplasts

These synthetic bone substitutes include ceramics such as calcium phosphates/sulphates/hydroxyapatite and bioactive glasses. Alloplasts provide a physical framework for bone ingrowth (osteo-conductivity) and may have osteoinductive factors added to them. The greater the porosity, the greater the likelihood of rapid vascularisation and bony ingrowth (Giannoudis et al. 2005). They may or may not resorb completely or partially with time, and the resorption pattern can be unpredictable (Giannoudis et al. 2005). Examples of commonly used alloplasts are BondBone® (MIS Corporation, Israel) (biphasic calcium sulphate), beta-tricalcium phosphate and synthetically-derived calcium hydroxyapatite. Bioactive glasses are hard, conferring mechanical strength and resistance to drilling and shaping, but are brittle and prone to fracture with cyclic loading (Giannoudis et al. 2005). The main use of bone substitutes is to reduce the volume of autogenous bone required, particularly in large bony defects such as in atrophic or very pneumatised maxillary sinuses.

Similarly to the xenograft materials, there are advantages and disadvantages to the use of alloplasts. One histologic and histomorphometric study suggested that beta-tricalcium phosphate was advantageous due to its increased resorptive
capacity than the equivalent volume of xenograft or autogenous bone. At eight weeks after augmentation, this bone substitute resulted in deposition of the greatest volume of new bone (Jensen et al. 2006b). However a systematic review of the literature demonstrated a lower success rate overall in implants placed in alloplast versus autogenous, allograft and xenograft (Aghaloo and Moy 2007).

2.2.4 Allografts

Allograft is bone harvested from human cadavers and processed by methods such as freezing or demineralising and freezing followed by sterilization. It may contain osteo-inductive molecules but these have been shown to be of no clinical advantage due to processing (Buser et al. 1998). There is concern regarding the absolute non-infectivity of this material as a human product (Esposito et al. 2009b). Its high cost and the availability of multiple viable alternatives currently negate its widespread use in implant dentistry within Australia, although it does account for a large proportion of bone grafts in North America (Boyce et al. 1999).

2.2.5 Combinations of materials

Practitioners often use materials in combination for various reasons including cost, practicality and limited availability of autogenous bone. As there is no one ideal graft material, combining them may also confer the potential benefits of more than one material. For example, autogenous bone, which has unique osteogenic properties may be combined with a long-lasting xenograft such as Bio-Oss® (Geistlich Biomaterials: Pharma North America Inc.) to ‘bulk out’ the
graft, providing increased support and long-lasting osteoconductivity. Indeed, this appears to be a commonly used graft combination (Jensen and Terheyden 2009). Trials used in a review of bone augmentation techniques suggested that, despite the reputation of autogenous bone for being the gold-standard of bone replacement, it was not always consistently more successful than bone substitutes (Esposito et al. 2009b).

2.2.6 Barrier Membranes

Membranes are commonly used in the technique of GBR. They may also be used in open sinus lifts, where they serve a similar purpose (Li et al. 2012), or may be used to isolate the graft in cases where the sinus membrane has been inadvertently perforated. The features of a membrane that make it successful are: 1. biocompatibility; 2. occlusivity: helping to maintain the position of the graft material, preventing ingress of soft tissue into the graft that may disturb osteogenesis (Esposito et al. 2009b) and allowing isolation from the oral cavity particularly where tension-free primary closure is not possible; 3. space maintenance: maintenance of rigidity where appropriate to help preserve the shape of the alveolar ridge; and 4. easy handling characteristics. The ideal membrane has not yet been established. Indeed, there is no consensus regarding when membrane should and should not be used in conjunction with augmentation and the benefits remain debated. Membranes may be resorbable, non-resorbable; synthetic or organic (xenograft). Examples of membranes are Bio-Gide® (Geistlich Biomaterials: Pharma North America Inc.) (porcine,
resorbable), expanded polytetrafluoroethylene (e-PTFE) (synthetic, non-resorbable).

GBR was shown in one study to be successful when resorbable and non-resorbable membranes were used to manage bony fenestrations and dehiscences (Christensen et al. 2003). The advantages of a sub-periosteal barrier membrane have been shown to be retention of a graft and bone graft factors, thus yielding more bone and/or reducing resorption (Antoun et al. 2001, Gielkens et al. 2007, Li et al. 2012). It has also been suggested that the membrane may ‘protect’ the grafted bone from resorption prior to implant placement (Antoun et al. 2001, von Arx et al. 2001), although the necessity for this in cortico-cancellous onlay grafts harvested from the mandible, which have lower resorption rates than iliac crest or particulate bone, has been questioned (Misch 2011). However, meta-analyses have demonstrated similar immediate and long-term success of augmentation with or without the use of resorbable and non-resorbable membranes (Gielkens et al. 2007). Very similar percentage defect fill in dehiscences, of 75.7%, 87% and 75.5% fill, has been documented in cases where non-resorbable membrane, resorbable membrane and no membrane have been used respectively, in a review of pooled data (Jensen and Terheyden 2009). Another meta-analysis of four animal studies suggested that the amount of vertically augmented bone was just 0.32 mm more in membrane-covered groups than in the non-membrane groups (p=0.006), and the clinical importance of this amount of augmentation was unclear (Khojasteh et al. 2013). The published evidence for membrane in the enhancement of the physiologic healing process
has been more convincing in the context of socket preservation (Vittorini Orgeas et al. 2013), where data has suggested greater reduction in ridge resorption following extraction where membrane was used without a filler material.

Non-resorbable barrier membranes such as e-PTFE and titanium mesh have been suggested to be more advantageous than resorbable when managing large defects, in particular vertical deficiencies (Chiapasco et al. 2006). However, although highly advocated by some due to their rigidity and imperviousness to soft tissue ingrowth and bacteria (Buser et al. 1996, Rakhmatia et al. 2013) non-resorbable membranes may be difficult to handle (Antoun et al. 2001) and may carry increased morbidity (Rakhmatia et al. 2013). Bio-gide® (Geistlich Biomaterials: Pharma North America Inc.) however, whilst lacking rigidity for space maintenance, has been shown to be relatively biocompatible (Liu et al. 2011, Naujoks et al. 2013) and to have favourable handling and resorption characteristics compared to other membranes (Rothamel et al. 2005). The obvious advantage of a resorbable membrane is that second surgery is not required for its removal.

2.2.7 Adjuncts and other new ‘bio-active agents’

Bio-active agents are constantly being investigated and introduced with the aim of improving overall implant success rates by enhancing osseo-inductivity within native bone and grafted sites. Clinicians and researchers alike are always in search of methods of improving the outcome of dental implants, particularly in unfavourable circumstances such as where bone defects are large or ridges
severely atrophic. However, they have not yet gained widespread popularity in everyday practice, and this may be due to cost in addition to lack of evidence for their absolute benefit. The efficacy of BMPs and platelet rich plasma (PRP) remains under investigation and there is currently no conclusive evidence that they significantly improve the clinical outcome of augmentation procedures with autogenous bone or bone substitutes.

BMPs are a family of proteins (cytokines), naturally present in bone, responsible for activation of bone development by stimulating the differentiation of mesenchymal stem cells and osteoprogenitor cells in to osteoblasts (Esposito et al. 2009b). It has been hypothesized that recombinant BMPs incorporated in augmentation materials may encourage bone formation (Jung et al. 2009). BMP-2 and BMP-7 in particular have been used since the 1990s in combination with different augmentation techniques. When used with a carrier such as absorbable collagen, they have been suggested to themselves induce a complete sequence of bone formation and have been shown to be successful in the reconstruction of large mandibular continuity defects without graft material (Herford and Boyne 2008). Similar successes of de-novo bone formation have been demonstrated in the maxillary sinus with the purpose if implant placement (Boyne et al. 2005), although it should be noted that de-novo bone formation is also possible with graft-less lifting of the sinus membrane (Boyne 1993). A consensus report has suggested that BMP-2 may be an adjunctive agent for the future, although results are still preliminary and research is in its early phase (Tonetti et al. 2008). In one split-mouth randomised-controlled trial (RCT) performing GBR with xenograft
and barrier membrane in one group and recombinant BMP-2 with membrane in
the other, no significant difference was demonstrated in bone volume between
the sites (Jung et al. 2009).

Platelet Rich Plasma (PRP), which is synthesised from centrifusion of fresh
autogenous whole blood with thrombin and calcium chloride, contains a BMP
that may promote bone formation, in addition to peripheral stem cells, growth
promoters and cytokines that are known for their antibacterial, growth
promoting, angiogenic and wound healing properties (Weibrich et al. 2002)
These include platelet-derived growth factor, transforming growth factors,
vascular endothelial growth factor, platelet-derived endothelial cell growth
factor, interleukin-1, basic fibroblast growth factor, and platelet activating factor
(Weibrich et al. 2002). Results from PRP studies are conflicting, methods of
synthesis varied and treatment numbers in trials are low. A 1998 study claimed
a 1.62 to 2.16-fold increase in bone density when PRP was added to an
autogenous bone graft (Marx et al. 1998). Another more recent RCT
corroborated this finding of significantly increased bone density at six months
with the use of PRP following open sinus lifting with autogenous bone (Khairy et
al. 2013). However, a split-mouth trial mixing PRP with autogenous bone to
 sinus lift a severely atrophic (Class V to VI (Cawood and Howell 1991)) maxilla
with poor quality bone (Class D4 (Lekholm and Zarb 1985)) demonstrated no
clinical or histological value in its use compared with the same material with no
PRP (Raghoebhar et al. 2005). It has been postulated that PRPs may have added
value in situations of large bony defects with poor vascularity or post-
radiotherapy (Raghoebar et al. 2005) but no trial has been devised to investigate these indications specifically to date. Other reasons for differences in conclusions between trials include: 1. Inconsistencies or inaccuracies of the investigative tool, such as microradiology versus plain radiographic imaging to analyse bone maturation (Raghoebar et al. 2005); 2. Timing of analysis: whilst this particular trial showed no benefit in outcome when an implant was placed at 3 months in the sinus-lifted maxilla, the authors suggested that PRPs might have had a role at an earlier stage of healing. They suggested that PRPs may have improved the outcome of implants placed at a shorter interval following augmentation (Raghoebear et al. 2005); 3. technique of synthesis: it has been suggested that different techniques used to harvest PRP such as ‘test-tube’ separation versus a centrifuge have provided different concentrations of platelets and some growth factors in trials and therefore a variable quality of product (Weibrich et al. 2003). It is therefore probably not ideal to compare studies that have employed different harvesting techniques.

2.3 Timing of procedures

Timing is relevant in private practice because of the pressures of outcome-driven protocols that patients demand, balanced against the need for practitioners to minimise risk of failure or complication due to poor planning or inadequate healing. Implants may be placed at the time of extraction (immediate implant), at the time of augmentation, or after a period of healing after augmentation.
Implants may also be placed as a single-stage procedure, where a trans-mucosal healing abutment is used, or two-stage, where the implant is buried for a period of time prior to exposure to the oral cavity. The timing of soft tissue surgery may also be of relevance with respect to the complication rate.

2.3.1 Simultaneous versus delayed implant placement following hard tissue augmentation

Implants may be placed after a period of healing following augmentation (delayed) and they may also be successfully placed at the same time as augmentation (simultaneous) (Vermeeren et al. 1996, Nystrom et al. 2004, Rapani and Rapani 2012). The current evidence-base does not present a clear indication or ‘cut-off’ for simultaneous versus delayed implant placement and both methods are advocated in the literature.

The conventional approach to implant placement in alveolar augmented and sinus lifted sites has been to wait for a period of four to six months for healing of the graft prior to implant placement (Chiapasco et al. 2009). Four months is generally the recommended healing period for onlay bone grafts (Misch 2011). Following alveolar augmentation, enough time needs to elapse to ensure healing and graft incorporation but implants need to be placed early enough to ensure bony maintenance and stimulation of regenerated bone (Nystrom et al. 1996). Authors who have advocated a delayed approach have done so on the basis that a re-vascularised graft has a greater regenerative and healing capacity (Shirota et al. 1991) in addition to the fact that diminished bone contact has been found
around dental implants placed simultaneously with grafting (Nystrom et al. 1993). One prospective cohort study of GBR at implant sites attempted to analyse and compare outcomes of implants placed at the same time as GBR versus implants placed after a healing period. There was a suggestion that a staged approach might have a lower risk of crestal bone resorption than simultaneous implant placement, although the clinical significance of this in terms of implant outcome was negligible (Christensen et al. 2003). Another recent retrospective study of implants placed in grafted bone found on multivariate analysis that significantly more implants failures occurred when single-stage implants were simultaneously grafted (Smith et al. 2009). The simultaneous placement of an implant with an onlay graft can be technically challenging. This is due to the degree of potential pre-existing bony deficiency, the risk of graft fracture, the requirement for adequate immobilization and considerations of flap size, exposure and vascularity of the graft site. Pooled data has demonstrated that there is an increased failure rate of implants that are onlay grafted simultaneously by a mean difference of 8.1% when compared to staged implants (Chiapasco et al. 2009). Additionally implant survival rates in block-grafted sites may to be lower than when particulate-grafted (Wallace and Froum 2003).

Some authors prefer simultaneous placement when the residual alveolar bone presents adequate quality and quantity to support primary stability (Chiapasco et al. 2006), an essential requirement for osseo-integration (Albrektsson et al. 1981, Clementini et al. 2013). Studies have shown open sinus lifting with
simultaneous implant placement to have good success rates if the native maxillary height below the antrum was ≥ 4mm (Peleg et al. 1998, Cosci and Luccioli 2000) and even when there was as little as 1-3mm of vertical bone height (Felice et al. 2013). With respect to onlay grafts, surprisingly, and despite the potential for complication, one review of pooled data, found that a large proportion (63.4%) of implants were placed simultaneously with onlay grafts of different sizes (Chiapasco et al. 2009). One retrospective cohort study of 674 implants showed that when augmentation was performed, implants placed 149 to 186 days (4.9 to 6.1 months) after augmentation were nearly ten times more likely (p<0.001) to fail than implants that were placed simultaneously with the graft (Carr et al. 2003). This was a surprising finding that was not readily explained as no risk factors in the delayed group were identified. Adjustments were made for potential confounding clinical and demographic (exposure) variables as well as outcome variables. It should be noted by these results that simultaneous augmentation and implant placement may have practical advantages and may be a successful cost- and time-saving approach in appropriate situations.

2.3.2 Single-stage versus two-stage implants

Single-stage implants involve simultaneous placement of the fixture and trans-mucosal healing abutment. The fixture is therefore exposed to the oral cavity and potentially unwanted loading, causing micro-movements, which may give rise to failure to osseointegrate (Albrektsson et al. 1981). Two-stage implants, proposed
initially by Professor Branemark (Branemark et al. 1977), involve two surgical procedures: the first to place the fixture and the second to expose and place a healing abutment after successful integration. Similarly to bone graft healing periods, there is no consensus regarding the need for or length of implant healing prior to exposure, and practices vary amongst clinicians and authors. It is notable that a review of the literature demonstrated no significant difference in implant failure between the one- and two-stage groups, although trends did favour two-stage particularly in edentulous cases (Esposito et al. 2009a).

Single-stage implants were proposed by Buser and colleagues (Buser et al. 1990) and have been shown by multiple other centres to be successful and give comparable results to two-stage implants in optimal circumstances (Carr et al. 2003, Esposito et al. 2009a). Indications to bury an implant might be if primary stability were lacking on implant insertion. This might be a reflection of poor quality (density) or inadequate volume of bone. Furthermore, if extensively simultaneously grafted, complete coverage during the healing phase would more successfully isolate the graft and implant from oral organisms that might cause infection. Indeed, one retrospective study of implants placed in augmented bone found that the all the implants that failed were single-stage (Smith et al. 2009).

Edentulous patients that wear their prosthesis during the healing phase might also be better with buried implants to avoid excessive loading on healing abutments that might give rise to micro-movements, although this theory has been contested by some authors (Buser et al. 1990).
The length of healing period conventionally used in un-augmented/native bone is three to four months for mandibular implants and six to eight months in the maxilla (Esposito et al. 2009a) due to increased speed of healing and osteogenesis in the mandible (Kotze et al. 2014). Early exposure and/or loading is possible, provided conditions are optimised to facilitate early secondary stability that can withstand the demands of loading forces (Esposito et al. 2007). Examples of techniques to increase secondary stability are to ensure the highest quality of bone (D1) and to under-cut the implant osteotomy in order to maximise primary stability in the first instance. Meticulous surgical technique, such as copious irrigation, ensures no over-heating and necrosis of bone. Materials that might be used to assist include use of bio-active agents or specific bio-active implant surface coatings. No literature has been found to directly compare different healing periods in order to recommend timing of loading following placement in specific circumstances. One analysis attempted to divide timings in to immediate (within one week), early (between one week and two months) and conventional (after two months) in order to compare them. No significant difference in success rates was shown (Esposito et al. 2007) and there was no evidence to support any specific length of healing time in two-stage implants.

2.3.3 Timing of soft tissue surgery with respect to extraction, augmentation and implant placement

Post extraction reconstruction of alveolar ridge defects requires augmentation
followed by flap advancement in order to achieve primary closure. The advantage of performing this at least six to eight weeks after extraction is that the socket has had time to epithelialise, allowing the surgeon to maintain the soft tissue architecture upon closure, as there is no soft tissue deficit. This is of particular importance in the aesthetic zone (Misch 2011). It has also been suggested that soft tissue corrective surgery should be performed at least eight weeks prior to bone grafting (Misch 2011). The benefit of such correction early might be to facilitate tension-free wound closure, thus reducing risk of dehiscence and infection of the subsequent graft. Simultaneous soft tissue surgery by way of connective tissue grafting and implant placement is not readily described or advocated in the literature, although it is possible. Disadvantages of this technique might be increased risk of wound dehiscence or infection.

2.4 Dimension of augmentation

Techniques of augmentation may also be defined by their intention to treat inadequate ridge height and/or width or both. Different defects carry different challenges, depending on the number of walls of the deficiency, location and length. Gain in height of the alveolus is more difficult to achieve than width as it requires inherent stability or retention of the graft material and it stretches the limits of native soft tissue coverage. Horizontal defects may have some retaining walls, and so may be relatively protected. The additional clinical problem vertical
insufficiency presents is the fact that ridges are usually also deficient in width.

Whilst there is relatively little documentation in the literature of the dimensional limits of successful vertical and horizontal grafting, it is clear that complex situations with severe atrophy or post-ablative bony deficits require procedures that are not in the everyday armamentarium of every private practitioner. Alternatives such as free tissue transfer with micro-vascular techniques should be considered in addition to the other more technically challenging augmentation methods of ridge splitting/sandwich techniques, corrective jaw surgery, and distraction osteogenesis.

2.4.1 Vertical augmentation and its limitations

Vertical augmentation may be defined as any technique required to enable a site to receive an implant of greater than or equal to 9mm length (Esposito et al. 2009b). The minimum vertical dimension of bone required for implant placement ideally corresponds to the vertical dimension of the implant being placed, whilst taking into account anatomical limitations such as the IAN or maxillary antrum, although it is possible to successfully place an implant that protrudes slightly in to the maxillary antrum without surrounding bone (Boyne 1993). Some implant companies start their regular platform implant range at 6mm length (Straumann Pty Ltd.: Basel, Switzerland and Astratech- Dentsply International: Mannheim, Germany). However, given that surface area increases with length for any given implant system, clinicians will place longer implants, usually up to 13-15mm, and if bone allows, due to their biomechanical advantage
and increased area for osseointegration. Increasing and maintaining the vertical
dimension of bone in theory should also confer these advantages. Furthermore
vertical resorption of the alveolar ridge results in an increased inter-arch
distance with a resultant unfavourable intermaxillary relationship. The
prosthetic result can be both functionally and aesthetically unsatisfactory, with
long suprastructures and short implants. However, it is important to carefully
consider the necessity to vertically augment, particularly where there may be
increased risk of failure or complications such as in the atrophic mandible. The
limitations of vertical augmentation have not been clearly defined. There do not
appear to be any definitive guidelines regarding the limits of vertical height that
can be obtained from free-standing particulate or onlay bone grafts. This may be
because the limitations are already dictated by the soft tissue envelope of the
recipient site.

In a comprehensive review of bone augmentation techniques and meta-analysis
of two trials comparing vertical augmentation procedures to short implants,
there were more implant failures (odds ratio (OR) 5.74 (95% confidence interval
(CI) 0.92 to 35.82; borderline significance, P=0.06) and statistically more
complications (OR=4.97; 95% CI 1.10 to 22.40) in the vertically augmented
group than in the short implant group (Esposito et al. 2009b). The problems with
interpretation of the findings of this review were multiple. In the augmentation
trial, one specific technique was adopted of inlay augmentation with BioOss®
(Geistlich Biomaterials: Pharma North America Inc.) blocks in the posterior
mandible. Such a trial could not answer for the multiple other techniques and
materials that could be employed to vertically augment the posterior mandible or other locations in the mandible or maxilla. Furthermore, the follow-up period for this trial was limited to just 4 months. The trial that used shorter implants considered 11mm implants to be in the 'short' group, which many practitioners might consider a normal/standard length i.e. not short. The cut-off for the length of an implant that would fall in the short category is not defined in the literature. One cut-off could be 6mm, after which standard dental implants are not available in some ranges, although many practitioners would consider any length less than 8-9mm to be short (Esposito et al. 2009b).

Some studies have demonstrated that vertical regeneration of bone (GBR) beyond the skeletal envelope, of up to 7mm, may be possible with rigid impenetrable unresorbable membranes that allow for improved space maintenance. One such human study treated 5 partially edentulous patients with vertical deficiency, allowing the implants to protrude from the native bone from 4-7mm, and placing a titanium-reinforced e-PTFE membrane to cover the sites. No filler or graft material was used. Vertical bone gain of up to 4mm was achieved. Histologic sections showed mean direct contact between the implant surface and regenerated bone of 42% (Simion et al. 1994). These results have been supported by animal studies (Jovanovic et al. 1995). The use of particulate autogenous bone as a filler material may boost the vertical height gained by a further 3mm, demonstrating a mean 4.95mm of bone gain (Tinti et al. 1996). Such achievements are not insignificant as they can make implant placement an option in patients for whom anatomical constraints would have otherwise
precluded their placement, such as in the posterior mandible, where the IAN limits the vertical dimension. However, little data exists about the long-term outcome and stability of implants placed in such bone as well as the resorption pattern of bone produced by the GBR technique.

When comparing various vertical bone augmentation techniques in a meta-analysis of three trials, the only statistically significant findings were that more vertical bone gain could be obtained with DO than with inlay autogenous grafts (mean difference 3.25 mm; 95% CI 1.66 to 4.84) and that more height could be gained with a bone substitute than with autogenous bone in guided bone regeneration (mean difference 0.60 mm; 95% CI 0.21 to 0.99) in posterior atrophic mandibles (Esposito et al. 2009b). The benefit of DO would seem rational in light of the fact that tissue histiogenesis would enable improved immediate soft tissue coverage and blood supply of distracted rather than implanted bone. In this regard, it would also seem logical that the greater the attempted increase in height, the greater the risk of graft complication or failure, although the measurement at which this becomes a significantly increased risk has not been clearly documented in the literature. Otherwise, overall, there has been insufficient evidence to suggest that any one particular technique, from a range of DO, various GBR techniques, autogenous onlay block grafting, or inlay grafting with both autogenous bone and bone substitutes, is more efficacious over another.
2.4.2  *Horizontal augmentation and its limitations*

Horizontal augmentation may be defined as any technique employed to enable placement of an implant equal or greater to 3.5mm diameter (Esposito et al. 2009b). There are studies in the literature that present good long-term outcomes of implants in horizontally augmented ridges by GBR, with equivalent success to native bone (Jensen and Terheyden 2009). Implant survival in sites augmented laterally by GBR, onlay grafting or ridge splitting has been shown in one meta-analysis to range from 91.7 to 100%. This is comparable to non-augmented sites, where survival is 93.2 to 100% (Donos et al. 2008). Dehiscences and fenestrations may be considered horizontal defects. In one such study, 526 implants were placed and loaded in horizontally regenerated bone in 352 patients. e-PTFE barrier membranes were used with both autogenous bone and allogenic bone grafts to regenerate the bone using either a simultaneous or a staged approach. With the loss of eight implants during a follow-up period of 6 to 74 months post-loading, the overall success rate was 97.5%. The mean cumulative radiographic bone loss as determined over 74 months of loading was only 0.64 mm, and occurred during the first year and a half after loading (Nevins et al. 1998). However, other studies that have monitored the stability of horizontally augmented bone by GBR over time have demonstrated that up to 40% of the initial bone obtained may be lost (Chiapasco et al. 1999). These results have been replicated in experimental studies in the rabbit model (Rasmusson et al. 1999). This finding suggests that it may be prudent to over-build the ridge horizontally in anticipation of the resorptive process. Specific
volumes or optimal dimensions for this have not been published in the literature.

A review that examined different methods of horizontal ridge augmentation did not identify a trial that might have helped to answer the question of whether or not horizontal augmentation was necessary or could be substituted by alternative treatment methods such as narrow implant placement. There was also no one particular augmentation technique that was found to be more statistically more advantageous over another (Esposito et al. 2009b) and the limitations of width gain in horizontal augmentation has not been clearly documented. Dehiscence and fenestration defects are usually confined within the walls of a defect. Building a ridge horizontally beyond the skeletal envelope requires stability and retention, which may be best achieved by way of DO or onlay grafting. In the context of jaw reconstruction following surgical ablation, studies have demonstrated successful reconstruction with full thickness block grafts of autogenous iliac crest, provided there has been a healthy tension free soft tissue envelope at the recipient site in a non-compromised patient. Successful mandibular reconstruction for lengths of up to 9cm may be achievable (Pogrel et al. 1997), although up to 6cm is a more comfortable length, with more predictable success rates (Foster et al. 1999).

### 2.5 Alternatives to augmentation

Alternatives to bony augmentation have been developed on the premise that cost and length of treatment may be reduced, in addition to the avoidance of
morbidity of the grafting process. However, despite the extensive literature demonstrating graft success, the main proposition is that implants placed in native bone may be more successful than those placed in grafted bone in the short and longer term (Widmark et al. 2001).

*Tilted/angulated/non-axially loaded implants* have been advocated by some authors as an alternative to bony augmentation. Axial implants have been defined as having direction of load ranging from 0 to 4 degrees, and non-axial from 12 to 30 degrees (Koutouzis and Wennstrom 2007). The premise of this technique is that implants are placed where bony buttresses exist for immediate stabilisation and osseointegration or where anatomical limitations on length and/or width do not exist, and the angulation is accepted. Examples include placement in the lateral nasal wall where the maxillary antra can be avoided or anterior to the mental foramina away from the IAN. The implants are angulated in such a way to achieve the best mechanical stability and antero-posterior spread across the arch whilst minimising distal cantilevering of the final prosthesis (Krekmanov 2000, Aparicio et al. 2001). This concept, in the mandible, is illustrated in figure 10. Studies have demonstrated similar bone levels in axially and non-axially loaded implants over a five-year period (Koutouzis and Wennstrom 2007) and no affect on the ten-year survival of implants (Sethi et al. 2002).

The concept of the ‘All On Four’ technique uses the principal of non-axially
loaded splinted implants which could be successfully immediately loaded to facilitate immediate full-arch rehabilitation in selected patients. The technique, investigated by Malo and Rangert employed four NobelBiocare (Kloten-Switzerland) Speedy TiUnite® implants; two anteriorly axially loaded and two posteriorly angulated at 30 degrees. At one year, 100% of the prostheses and up to 98.2% of the angulated implants were successful (Malo et al. 2003). Other authors have since replicated these results, and have demonstrated successes even in severely atrophic mandibles (Jensen and Adams 2009) as well as immediately after dental extractions (Villa and Rangert 2005, Butura et al. 2011). However, there is still controversy regarding the long-term stability of angulated and All-On-Four implants (Patzelt et al. 2014) and the threshold of risk versus benefit of grafting versus use of this particular technique is yet to be defined. Additionally prosthetic rehabilitation may be more complex due to the need for angulated abutments, and there may be associated prosthetic complications such as fractures of the superstructure or screw loosening (Malo et al. 2012). As such, many authors and practitioners do not yet advocate this technique in routine practice.
Figure 10: Radiograph of All-On-Four mandibular implants, where four implants have been placed anterior to the mental foramina: two central implants are axially loaded and two laterally are non-axially loaded, in order to provide some cross-arch spread with minimal cantilever of the prosthesis. Four zygomatic implants (quad-zygomas) have been placed in the upper arch.

Zygomatic implants are placed in the body of the zygoma in situations where the maxilla is atrophic, and they integrate with this bone in order to achieve long-term stability and provide cross-arch stabilisation. These implants are also angulated, but start at about 40mm and increase in length by small increments. They may pass through or in front of the maxillary antrum or though the lateral wall. Configurations include two zygomatic implants one side (as shown in figure 10) or one zygomatic implant and one anterior axially loaded implant on each side, distributing the masticatory load evenly between the bilateral zygomatic arches and the anterior maxillary bone. The positioning and inclination of the implants is clearly shown in figure 11. A review by Block et al. in 2009 suggested
a 98% success rate in such implants over a 10-month to 10-year period (Block et al. 2009). This method of dental rehabilitation has gained popularity in recent years as evidence of efficacy grows, but it has a major drawback that specific technical expertise is required for its practice.

Figure 11: Zygomatic implants a. 3-Dimensional positioning; b. intra-operative photograph demonstrating the path of a zygomatic implant through the antrum.

_Narrow implants_ may have a diameter of 3mm or less (Esposito et al. 2009b) or 3.3mm according to other authors (Benic et al. 2013). Narrow implants are a proposed alternative to horizontal ridge augmentation. One RCT comparing narrow Ti-Zr to regular diameter implants for single tooth replacement demonstrated no difference in marginal bone loss at one-year between the two
groups (Benic et al. 2013). This RCT compared 3.3mm (narrow) to 4.1mm (regular) diameter implants rather than narrow implants versus wider diameter implants requiring grafting. The Zr alloy was theorised to have increased strength and reduced propensity for fatigue fracture, a demonstrated drawback of narrow un-alloyed Ti implants (Zinsli et al. 2004), without compromising the ability to osseo-integrate (Al-Nawas et al. 2012). Other authors have demonstrated similar success in the use of narrow implants in multi-unit prostheses (Chiapasco et al. 2012), although they have also not been compared directly with augmented sites. Thus, whilst results for narrow implants are promising, evidence for optimal long term results when compared to horizontal ridge augmentation and normal diameter implants does not appear to exist.

Short implants range from 8.5 to 5mm in length (Esposito et al. 2009b). They may be used to overcome vertical anatomical limitations including IAN and the maxillary antra, as shown in figure 12. However, as previously noted, unacceptable prosthetic outcomes may result from unfavourable inter-arch relationships in severely resorbed cases or in cases where there is localised bone loss adjacent to natural teeth. However, as proposed in two systematic reviews of the literature (Esposito et al. 2009b, Annibali et al. 2012) they may be a viable alternative to vertical ridge augmentation. Indeed, in a comparative study in the private practice setting, short implants (6mm and 8mm) were demonstrated to have similar survival rates to longer (10 to 16mm) dental implants (Arlin 2006).
Figure 12: Radiograph of short implants in the posterior maxilla avoiding the antrum.

*Optimised/different implant surfaces* may help to increase primary and secondary stability of implants in sub-optimal circumstances but their detailed discussion is beyond this scope of this thesis. Some implant surfaces are purported to stimulate formation of new bone. However, these surfaces are still under investigation and there is no currently evidence that they can be used to boost the volume or quality of native bone, as an alternative to grafting. Examples of bio-active surfaces include fibronectin and collagen coatings that may promote osteoblast adhesion and differentiation, and thus bone formation and osseointegration (Garcia and Reyes 2005). However, in vivo studies have failed to demonstrate significantly improved results (Yeo 2014). It is becoming increasingly suggested from the literature, however, that the one important factor with respect to implant surface is that roughened surfaces may produce higher success rates than machined surfaces (Chiapasco et al. 2009, Annibali et al. 2012).
2.6 Complications of augmentation

Many studies observe implant outcome as a measure of augmentation or graft success. Thus implant success rates and outcomes in grafted and un-grafted sites may be used to compare augmentation protocols or examine their potential for complications. There are multiple criteria that can be used to define implant success such as: 1. Lack of mobility; 2. Lack of pain of other unwanted symptoms such as altered sensation; 3. No peri-implant infection; 4. No aberrant radiographic changes such as a peri-implant radiolucency; 5. No peri-implant pocketing >5mm and/or bleeding on probing; 6. Maintenance of bone with <1.5mm crestal bone loss in first year with <0.2mm bone loss every year thereafter (Albrektsson et al. 1986, Buser et al. 1990, Mombelli and Lang 1994). More recently it has been suggested that no more than 2mm of bone loss after five years from prosthesis placement could be a marker of success (Wennstrom and Palmer 1999). Implant loss is variable and in some cases unpredictable, particularly when examining longer term figures. Success rates of different augmentation protocols have often been extrapolated from implant success rates rather than directly measured. Further to this, there is limited documentation in the literature of the rates of specific complications of augmentation with respect to the different techniques, materials and timing of augmentation. For example, there are few studies that report the percentage volume change in grafted bony dehiscences (improved bone coverage of implants for example): gains in height, width or volume as measured clinically or radiographically, the percentage of cases in need of re-grafting or additional grafting at implant placement, or soft
tissue stability.

Complications can be classified into donor site, recipient implant (or graft) site and systemic. Systemic complications will not be discussed here. They can be also be divided according to augmentation procedure, as the risks and outcomes of different methods of augmentation may vary. These differences should be taken into consideration by practitioners and patients when contemplating choice of augmentation procedure. Bone augmentation procedures may fail, and this may or may not preclude the placement of a dental implant, necessitate further procedure(s) or cause reduced long-term survival of an implant that is initially successfully placed.

2.6.1 Donor-site complications

Autogenous bone harvesting carries donor-site morbidity, which intra-orally, includes specifically the risk of temporary or permanent neural disturbances due to IAN or mental nerve injury. The incidence of long-term neural disturbances can be as high as 51% when bone is harvested from the mandibular symphysis (Clavero and Lundgren 2003); and 0-4% when harvested from the mandibular ramus (Misch 1997, Clavero and Lundgren 2003). These results were obtained before the routine use of CBCT technology, which in theory should assist in further reducing the rate of IAN damage in ramus block grafting, as it enables accurate 3-dimensional nerve localisation.

Harvesting bone from the iliac crest specifically carries risks of temporary or permanent neurosensory damage to the lateral thigh dermatome, gait
disturbance and pain. Some centres still use split-thickness calvarium as a donor site, as demonstrated by Chiapasco et al. in 2009, where it was used in nearly 5% of augmentation cases. The risks here of scar and hair-loss are not insignificant. The main disadvantage however would be the need for specific technical expertise that would preclude its everyday use in addition to the potential for major intra-cranial complications such as haemorrhage and meningitis.

2.6.2 Recipient-site complications

Recipient site complications may be surgical or biological. Surgical complications are technical and immediate operative or post-operative events such as injury to nerves and other structures causing pain, bleeding and swelling, and neurosensory disturbance. Insufficient bone quantity or quality resulting in bone perforation and/or inadequate primary stability, and sinus membrane perforation are also immediate technical/surgical complications. Biological complications include those that require interaction between the host or biological processes and the graft or implant such as infection and failure of graft integration, bone loss, failure to osseointegrate, loss of implant integration and peri-implantitis. There is some over-lap between the two groups of complication.

2.6.2.1 Neurosensory disturbance

In a well-planned and placed dental implant, the risk to the IAN or mental nerve should be low. Apart from the obvious errors of over-drilling the osteotomy length or placement of the implant apex in to the IAN canal, other causes of altered neurosensory function include compression of the nerve by a haematoma
at the implant apex (above the nerve or adjacent to the canal) or injury during administration of local anaesthetic or raising of the soft tissue flap. With respect to augmentation practice, care must be taken when handling soft tissues not to put traction on or avulse the mental nerve. The use of long screws to secure a block graft may also injure the IAN in its canal. However, where augmentation procedures are performed successfully, they may indirectly reduce the risk of this complication, as they increase the bone height and/or width away from the nerve. Despite augmentation procedures, improved planning measures and technology, reported injury rates range from 0 to 40% (Renton 2010). This has lead some authors to recommend a 4mm zone of safety from the radiographic IAN and planned implant osteotomy (Renton 2010). This zone should be taken in to consideration when planning the desired dimensional change of the ridge.

2.6.2.2 Insufficient bone

Insufficient bone for implant placement may be brought about by failure of graft integration, and most frequently, mucosal dehiscence and infection that may result in graft loss (Jensen and Terheyden 2009). Post-augmentation bone resorption may continue in cases where implant placement is very delayed. Additionally relapse of bone gain may occur prior to implant placement. Relapse around the coronal aspect of distracted bone segments prior to implant placement has lead some authors to recommend over-distraction by 20% (Saulacic et al. 2005). It has been recommended that augmentation sites generally should be over-built for the same reason (Chiapasco et al. 2009).
Insufficient bone may result in bony perforation of the implant or inadequate primary stability, which may be represented by low insertion torque. The rate of insufficient bone for implant placement following specific augmentation procedures is not obviously quoted in the literature.

Failure of graft integration may occur due to failure of the graft to re-vascularise as a result of poor recipient site vascularity, increased density of the graft and failure to adequately immobilise the graft or to achieve adequate contact with the recipient bed. Mandibular cortico-cancellous bone grafts may thus be more prone to fail than maxillary due to poorer vascularity of the recipient site with age (Bradley 1981). Techniques used to overcome this include perforation of the cortical bone of the graft and recipient site, as illustrated in figure 13, to encourage bleeding and the simultaneous use of particulate bone or bio-active agents such as PRPs to stimulate angiogenesis.

Figure 13: Recipient site perforation. Points of bleeding can be seen. Some authors do this to encourage re-vascularisation of the graft.
Infection is the most commonly reported immediate post-operative complication, although it may be under-reported, particularly in cases of minor infection. Partial graft loss due to wound dehiscence and or infection, in onlay grafts in particular, has been shown to occur in 3.3% of cases, when data from multiple studies has been pooled, with total loss in 1.4% (Chiapasco et al. 2009). This may be due to the additional stretching of soft tissues required to achieve primary closure, particularly where height has been gained. GBR failures are mainly related to membrane exposure, which may lead to infection and complete or partial bone loss. Dehiscence-type defects may be more prone to this complication than fenestration-type (13.7% versus 2.5% in a review of the pooled data) because, when augmented, fenestration type defects can have the flap designed so that the mucosal incision is safely away from the graft. However, in dehiscence-type defects, any minor opening of the mucosa at the suture line may be more likely to expose the graft material (Jensen and Terheyden 2009). Some studies suggested that e-PTFE membranes might be more prone to this complication than resorbable membranes (Donos et al. 2008), but others have suggested no difference between membrane types (Jensen and Terheyden 2009). In open sinus lifting, the reported rate of infection is between 0 and 2.5%, mean 0.8% (Tan et al. 2008).

Resorption of intra-orally harvested onlay grafts has been suggested to be between 0-25% irrespective of site or harvest (Misch 1997). Early experimental evidence suggests that cortico-cancellous grafts from membranous bone show less resorption (Smith and Abramson 1974, Zins and Whitaker 1983) and faster
revascularisation (Kusiak et al. 1985) than endochondral bone, and as such intra-oral harvest sites are ideal. Furthermore, the ectomesenchymal origin of mandibular bone has similar properties to intra-oral alveolar recipient bone (Misch 1997), and it is theorised that it has better capacity than extra-oral bone for integration and survival.

2.6.2.3 Post-placement bone loss

Progressive marginal bone loss has been suggested to be an important predictor of implant longevity, and can used as a criterion to compare different augmentation techniques (Donos et al. 2008). Bone loss may be secondary to a normal physiologic resorptive process such as in the functional adaptation of the peri-implant bone to the slightly excessive prosthetic load. Such aetiology can be suggested in cases where peri-implant crestal bone loss is seen in the absence of infection or inflammation where GBR has been used to form bone (Simion et al. 2001). Marginal bone loss of up to 2mm in the five year period from placement of prosthesis has been deemed to be acceptable (Wennstrom and Palmer 1999).

Vertically augmented ridges appear to be at risk of clinically significant crestal bone loss (Chiapasco et al. 2004). Thus whilst implants placed in vertically augmented bone may show good (100%) long-term survival, they might be at risk of being ‘unsuccessful’ according to the criteria defined by Albrektsson in 1986 (Jensen and Terheyden 2009). One study using iliac crest bone graft for vertical augmentation has demonstrated 50% vertical bone loss after 10 to 11 years despite 100% implant survival (Verhoeven et al. 2006). With respect to
GBR, one study, with up to 59 months of follow-up after simultaneous implant placement and grafting to treat fenestration and dehiscence defects demonstrated significantly increased marginal bone loss in the grafted group, but no significant difference in long-term implant outcome. Marginal bone loss was associated with barrier membrane exposure due to flap dehiscence, which had a higher incidence when e-PTFE membranes were used (Zitzmann et al. 2001). Bone resorption (mean 2mm) and remodelling without infection or overt inflammation has also been shown in one study to occur around the apex of closed sinus-lifted implants, where osseointegration and loading has been previously successful. Radiographic analysis showed a sequential significant reduction in bone height and remodelling of the sinus floor at a higher (more apical) level with a new cortical plate (Bragger et al. 2004). This did not appear to compromise implant or prosthetic outcome however, and the implant apices remained in the majority of cases (92%) surrounded by new bone.

2.6.2.4 Peri-implantitis and other soft tissue complications

Peri-implantitis is a destructive inflammatory process affecting peri-implant hard and soft tissues, which if untreated, may lead to loss of implant osseointegration and ultimately implant failure. Peri-implantitis is thought to be caused by colonisation of the implant-tissue interface with oral organisms, similar to those responsible for periodontal disease (Leonhardt et al. 1999). The aetiology of peri-implantitis is multi-factorial, and the integrity of peri-implant soft tissues and good underlying bony support may be essential for risk
reduction by acting as a barrier to infection by way of resistance to attachment loss (Orsini et al. 2004). There does not currently appear to be much literature examining the risk of peri-implantitis in bone grafted sites.

A 2009 literature review of the local risk factors for implant failure found that there were no studies that demonstrated a relationship between soft tissue thickness or width of keratinised tissue and implant survival or peri-implant mucosal recession (Martin et al. 2009). One study, however, did demonstrate a statistically significant mean increase in alveolar bone loss around implants where there was <2mm crestal width of keratinised tissue (Bouri et al. 2008). Other authors have defined the dimension of keratinised gingiva deemed to be essential for long-term survival as being ≥ 2mm masticatory gingiva with ≥ 1mm of attached gingiva in the bucco-lingual dimension (Lang and Loe 1972). It has been suggested that this tissue may have increased resistance to infection from oral organisms, perhaps due to the fact that it is less mobile at the implant-abutment interface resulting in reduced gingival inflammation and optimised oral hygiene (Orsini et al. 2004). Despite the controversy surrounding the benefits, some clinicians routinely undertake connective tissue grafting, where it is lacking, in order to optimise the peri-implant soft tissues. The importance of this keratinised gingival interface in the prevention of peri-implantitis has not be conclusively proven (Cochran et al. 2009).

2.6.2.5 Sinus membrane perforation

Sinus membrane perforation is, in the literature, the most common documented
complication of open sinus lifting, occurring in approximately mean 10-20% of pooled cases (range 4.8 to 58%) (Pjetursson et al. 2008, Chiapasco et al. 2009). It is a major reported adverse event that may result in graft infection and loss, precluding implant placement (Tonetti et al. 2008). Options for clinicians, when this occurs, are to 1. Do nothing/continue with the grafting procedure +/- implant placement; 2. Lift the sinus membrane further away from sinus floor and graft; 3. Place a barrier membrane or other substance such as fibrin glue between the graft and the sinus cavity; 4. Abandon the procedure and await healing. There are no trials to compare the results of each of these actions and there are no published thresholds for which any one action is felt to be preferred over another, except that if the tear is very ‘large’, it is anecdotally suggested to be prudent to abandon the procedure and wait for healing. Despite this sinus perforation rate, the same studies found the infection and sinusitis rate to be only on average 3%, suggesting that less than half of torn membranes carry more serious sequelae that might affect graft or implant outcome (Pjetursson et al. 2008, Chiapasco et al. 2009). Indeed, the only major proven risk factor for maxillary sinusitis following sinus lifting appeared to be, in one paper, pre-existing sinus disease (Timmenga et al. 1997). There is still controversy in the literature over whether sinus membrane perforation influences implant survival (Pjetursson et al. 2008).

The closed sinus lift technique relies on the integrity of the Schneiderian membrane particularly if graft material is to be injected in to the osteotomy site. One disadvantage if this technique is the uncertainty about inadvertent
perforation. Whilst one study has suggested that the sinus floor may be elevated successfully without membrane perforation (Engelke and Deckwer 1997), other endoscopic studies have demonstrated that there is a risk of perforation especially when graft material is injected into the osteotomy site to elevate the membrane (Berengo et al. 2004). It appears that small perforations and extravasation of graft material are of little clinical consequence in terms of graft loss, infection or implant loss (Berengo et al. 2004). Numbers generally in these observational studies are very low.

2.6.2.6 Problems with osseointegration: delayed integration, failure to integrate and loss of integration

With respect to augmentation, there does not appear to be data to look specifically at the causes of delayed implant osseointegration or failure of osseointegration. Loss of integration might be recorded as an implant loss or failure to survive, but the specific aetiology such as infection, peri-implantitis or graft failure is rarely delineated in the literature. It appears that the most important influence on successful and timely osseointegration is primary stability of the implant. Any factor that reduces this, whether technical or biologic, may therefore result in delayed osseointegration or implant failure altogether. Apart from bone density differences, the literature does not suggest any distinction between materials or techniques including membrane use that might influence primary stability.
2.7 Outcomes of common methods of augmentation

2.7.1 GBR and particulate bone grafting

In general, the literature reports that GBR is reliable and successful for treating horizontal and vertical bony defects, and bone levels appear to be stable (peri-implant vertical bone height resorption 1-2.9mm) after follow-up ranging from one to five years (Simion et al. 2001, Chiapasco et al. 2004). A meta-analysis looking specifically at GBR with membrane demonstrated evidence that the survival of implants placed in augmented sites was equivalent to those placed in non-regenerated bone (Hammerle et al. 2002). Cumulative success or survival rates, respectively, for implants in regenerated bone ranged from 79.4 to 100% after 5 years of function. No significant differences were found by the controlled trials that compared survival rates between augmented and native bone (Hammerle et al. 2002). This included cases where the barrier membranes were made of e-PTFE and collagen. Another review of the literature also demonstrated similar results between survival and success rates of implants placed in augmented sites with resorbable membranes (95-100% survival; 91% success) and non-resorbable barriers (92-100% survival; 62-100% success) (Chiapasco et al. 2006).

It is clear from the literature that this technique of augmentation is successful. Questions that may be more difficult to answer based on current published evidence are: What is the resultant percentage defect fill when dehiscence and fenestration type defects are augmented? One review of the literature suggested
a mean defect fill of 81.7% on site re-entry after grafting (Jensen and Terheyden 2009); What is the nature and size of implant-related defects that have to be grafted verses those do not, and how does this affect the long-term outcome? Examples of variables include the number of implant threads that might be exposed post placement or the size of the dehiscence as calculated by number of walls present. Additionally, when GBR is used in conjunction with simultaneous implant placement, the relative ‘safety’ of single-stage (where the graft is theoretically exposed to the oral cavity) needs to be compared to two-stage implant surgery (primary mucosal closure), ideally by RCT.

2.7.2 Onlay bone grafting

One analysis of pooled data gave an overall survival rate in the onlay graft-augmented maxilla and mandible of 87%, range 60-100%; median 91.5% (Chiapasco et al. 2009). The mean survival rate of maxillary implants placed in conjunction with augmentation was 81.8%, versus 89.9% when placed as a staged approach. Mandibular implants had a better overall survival rate of 94.8% when simultaneously placed versus 100% after a healing period (Chiapasco et al. 2009).

Implant success rate may be linked to bone donor site as well as timing of placement. Indeed, pooled data has suggested that iliac crest bone grafts have a higher failure rate of implants (17.5%) versus calvarial grafts (6%) and intra-oral sites (5%) (Chiapasco et al. 2009). These findings are consistent with the suggestion that intra-oral bone grafts are more successful than extra-oral donor
sites. However, studies may be confounded by the fact that patients that require extra-oral bone harvesting usually require more extensive augmentation and may therefore be more complex and more prone to complications.

2.7.3 *Inlay or interpositional grafting*

Pooled data has demonstrated implant success rates in ridge splitting and expansion of 86.2% to 97.5% (median 95.5%) and survival 91% to 97.3% (median 94%), which were consistent with implants placed in native (non-augmented) bone (Chiapasasco et al. 2009). This data combined a number of techniques, including ridge split with interpositionally placed collagen sponge, autogenous bone chips, hyaluronic acid, with or without the use of a barrier membrane and implants were placed simultaneously. In the edentulous mandible, this ‘sandwich technique’ has been demonstrated to be successful in increasing bony height by up to 8mm (Jensen 2006). In the maxilla, vertical gain has been shown to range from 3 to 6 mm, with good stability following implant placement over a 5-year follow-up period (Jensen et al. 2006a). Overall in the literature, this procedure has been demonstrated to be successful, enabling the provision of implants without major complication, which can be avoided if the height of the native bone is at least 4mm above the IAN (Jensen 2006).

2.7.4 *Open sinus lifts*

Open sinus lifting is a reliable technique with good long-term results, permitting dental implant placement in the atrophic posterior maxilla. Survival rates vary from 61.7% to 100%, with an average of 91.8% (Wallace and Froum 2003) or
96.5% at three years (95% CI=95-98%) using roughened surface implants (Pjetursson et al. 2008). Other studies have suggested that implant outcome in sinus lifted sites may be poorer compared to placement in native bone (Wannfors et al. 2000), and a consensus report showed that where maxillary implants were placed in <6mm of native bone, 17% of subjects experienced implant loss (Tonetti et al. 2008).

It is also difficult to decipher the most effective materials for opens sinus lifting based on the literature because studies do not have consistent materials or combinations of materials and as such are difficult to compare. However, one systematic review suggested that implants placed in sinuses elevated with particulate autografts had higher survival rates than those that were augmented with block grafts (Wallace and Froum 2003). In contrast, a consensus report by the Academy of Osseointegration on sinus grafting, published in 1998, using pooled data from 3554 placed implants in 1007 sinus graft procedures suggested that there was no significant difference in outcome between autogenous cortico-cancellous and particulate bone in terms of implant outcome at 6 year follow-up (Jensen et al. 1998). The major drawback in drawing from outcome data from the 1990s and in this report in particular was that the majority of implants placed had a machined surface, and as such long-term outcomes were less successful. Another more recent systematic review suggested that the combination of autogenous bone and bone substitutes showed significantly lower annual failure rates (1.47%) than bone substitutes used alone as grafting material (2.59%) (p<0.001) (Pjetursson et al. 2008). Most strikingly, the use of a barrier
membrane to cover the lateral window appeared to elevate implant survival rate overall from 88.6% to 97.9% (P=0.001) (Pjetursson et al. 2008).

There is scant documentation of the quality and quantity (height) of residual native bone, which would affect the primary stability of simultaneously placed implants in open-sinus lifted maxillae. It is safe to suggest that additional bone is probably not needed if the height of native bone is 7mm or above (Lundgren et al. 2004), even if the apical portion of the implant protrudes into the sinus cavity. Two questions remain: 1. What is the minimal height of native maxilla required to ensure implant success in simultaneous open sinus lift and implant placement for both one- and two-staged implants; 2. At what height of native bone in the posterior maxilla is an open sinus (with healing period) lift obligatory? I.e. when does the risk of failure become unacceptable?

With respect to timing of implant placement after open sinus lifting, one RCT compared survival rates of implants that were placed simultaneously in block bone versus delayed placement in particulate bone, all harvested from iliac crest (Wannfors et al. 2000). It could not be used to compare simultaneous or delayed placement with open sinus lifting because numbers in each group were too small (n=20) and the nature of the materials used in each group was clearly different. The authors did not explain their reasoning for this difference in technique between the two groups.

2.7.5 Closed sinus lifts

Overall, the three-year survival rate of implants placed in conjunction with a
closed sinus lift was around 93% (95% CI=87.4–96.0%), according to one meta-analysis (Tan et al. 2008). However, closed sinus lift cases may experience up to 11% implant loss over three years (Tonetti et al. 2008). The level of native maxillary bone in closed sinus-lifted sites also influences implant success rate. In a retrospective analysis of 174 implants placed in 101 patients, the survival rate was 96% or higher when the pre-treatment bone height was 5 mm or more and dropped to 85.7% when the pre-treatment bone height was 4 mm or less (Rosen et al. 1999). However, implants placed in as little as 2.3mm native bone have been shown to be successful (Bragger et al. 2004). Because of the heterogeneity of studies it is difficult to compare surgical techniques or grafting materials with respect to implant outcome in closed sinus lift cases.

2.7.6 Socket preservation

There appears to be insufficient evidence that socket (ridge) preservation improves ability to place an implant after tooth extraction (Darby et al. 2009, Willenbacher et al. 2015). There is also insufficient evidence to support any one particular technique or material with respect to the volume or quality of bone obtained (Darby et al. 2009, Hammerle et al. 2012). However, it has been suggested that dehiscences and fenestrations that occur at tooth extraction may be filled with fibrous tissue, which may occupy a significant portion of the socket, reducing the quality of bone for implant placement if not treated with ridge preservation (Darby et al. 2009). Furthermore, ridge preservation may reduce the degree of bone resorption post-extraction, resulting in approximately 3mm
gain in width and to 1mm gain in height when compared with un-preserved sites (Vittorini Orgeas et al. 2013). Thus, whilst this procedure may not replace the need for further augmentation, subsequent procedures may be simplified.

2.8 Drawbacks of the literature

Despite a vast number of publications of studies, trials, systematic reviews and meta-analyses looking at the efficacy of bone grafting procedures, there remains much controversy regarding the optimal techniques for particular clinical situations. There is a paucity of large or multi-centre well-designed RCTs to provide the best level of evidence for augmentation procedures. Methodology is poor in general and variable between studies, which results in difficulty making direct comparisons. This includes poorly defined inclusion or exclusion criteria, ill-defined outcome/success criteria and inadequate sample sizes. Short follow-up periods make it difficult to extrapolate results to longer-term implant outcome, for example, for results at 10-, 20- and 30-years. Timings may be calculated from insertion or after loading, and this detail is sometimes not specified. For the most part, implant survival may be defined as the implant remaining in situ during the entire observation period. This may not reflect implant success, or the successful maintenance of osseointegration over time, or for example, stable bone levels and lack of peri-implantitis or aberrant peri-implant soft tissue changes. Outcome of augmentation itself is not documented as often, rather outcome of implants in augmented sites. Thus, it is difficult to
decipher directly the success of specific augmentation techniques.

From the literature it is difficult to comment on the success of one material or combinations of materials over another. This is again because studies are often not directly comparable, due to differing augmentation techniques and a vast array of variations. Often, the nature of smaller defects being augmented is not specified, including their location in the arches, number of walls present, and extent of implant exposure and insertion torque, particularly in retrospective studies. In some studies, patients with known systemic risk factors for implant failure have been excluded, which results in selection bias, and results might not be an accurate representation of every-day practice.

This study aimed to reduce the void in this augmentation data by examining every-day techniques and practices, including the use of materials and relative timing of procedures, and extrapolating from this any potential for increased complication at the recipient/implant site.
3. CHAPTER 3: METHODS

A retrospective cohort design was used to study the population of patients receiving implant treatment at private dental practices within Victoria, Australia. The study was approved by The University of Melbourne Human Research Ethics Committee, approval number: 1033122 (April 2010). It was supported by the Evident Foundation, a not-for-profit dental-practice based research network hosted by the Australian Dental Association Victoria Branch (ADAVB), which facilitates and supports coordinated high-quality research between dental practitioners and academic dentists from the Melbourne Dental School, and the Oral Health Cooperative Research Centre based at Melbourne Dental School, University of Melbourne.

Dental clinicians qualified on or before December 2004, registered in Victoria, and placing and/or restoring implants in private practice were invited to participate in the study. Recruitment was via advertising in the Australian Dental Association Victoria Branch newsletter and direct approaches from members of the research team. Additionally, Victorian branches of special interest groups were requested to contact their membership, recommending participation.

Clinicians who provided informed consent were visited by members of the research team to establish a process by which patient records could be identified and reviewed. Treatment codes were used to identify those patients who met the inclusion criterion of at least one implant placed or restored within the study period of 1st of January 2005 to 31st December 2009 inclusive. Records that
were missing or unavailable, patients who did not follow up on proposed implant treatments or chose other restorative options were excluded from the study.

A data collection template was designed to collect information from the patient records (see appendix). This was modified independently by restorative and surgical members of the Steering group, with a statistician, and was reviewed again by all members of the Steering group to reach a consensus on the details and format of data collection. The Steering group consisted of experienced general, specialist, academic dentists and oral and maxillofacial surgeons. The protocol was tested by and modified using sample records. Practitioners were de-identified by a numerical ID.

Data extraction was conducted by two trained and calibrated research assistants with specific training in implant terminology and previous experience of extracting data from dental records.

Information was collected regarding:

- Clinician demographics
- Patient demographics (birth year and gender)
- Patient co-morbidities/systemic host factors (diabetes, osteoporosis, bisphosphonate use radiotherapy and smoking status)
- Oral status/local host factors (periodontal disease and tooth wear)
- Implant details (site, system, dimensions)
• Surgical information (surgery type, hard- and soft-tissue augmentation/preservation procedures, antibiotic use, osseointegration assessment and loading, and relevant dates)

• Restorations/prosthodontic information (connection type, loading protocol, use of interim and provisional restoration and method of retention)

• Complications (type, management and outcome)

Research Assistants were provided with guidelines to help ensure standardised data entry. Data retrieved from a patient’s record could relate directly to treatment provided by the participating clinician or, for treatment provided by another dentist on referral, information was gleaned from referral correspondence. Where data was recorded verbatim, clinically trained members of the Steering group reviewed the verbatim fields and categorised entries appropriately.

Further clarification regarding the materials and techniques employed within practices was obtained by way of an additional questionnaire that was sent electronically specifically to the practitioners discovered to undertake augmentation procedures. Information collected included:

1. Source of autogenous bone: intra- versus extra- oral

2. Nature of 'sinus-lifting' practices

3. Membrane use
4. Materials used routinely for the different augmentation procedures

5. Soft tissue grafting practices

Responses were used to further clarify and classify the original data set.

Each implant that underwent an adjunctive or augmentation procedure during the 5-year observation period was scrutinised, along with the additional descriptive information, to ensure that the information gained was maximized for each database entry. The data was appropriately classified and then analysed.

Descriptive data for paper 1 included information on techniques of augmentation, including materials, membrane use and timing of procedures. Data for paper 2 included biological complications: infection, bone loss, failure to osseointegrate, loss of implant integration, peri-implantitis; and surgical (technical) complications: neuro-sensory disturbance, pain, bleeding, swelling, bone perforation, insufficient bone quantity or quality or inadequate primary stability.

3.1.1 Statistical analysis

As there were two levels of variation (dentists and records per dentist), statistical advice was that the minimum number of records required for adequate power would be 1000, despite the clustering resulting from multiple records per practitioner.

All information on the data collection template was entered into a Microsoft® Access database, (Microsoft Corporation, WA, USA), created specifically for the
study. The database was imported into IBM SPSS™ Statistical Package for the Social Sciences (Version 21, SPSS Inc., Chicago, IL, USA) and GenStat® (Version 14, VSN International) for analysis.

Descriptive statistics including frequencies of various characteristics of augmentation procedures and cross-tabulation for paper 1 were performed using SPSS. Chi-Square or unpaired T-test were used where appropriate for statistical analysis. Paper 2 examined the complications of augmentation and the complication rates in the augmented and non-augmented groups. Uni- and multivariate analyses were used to compare the complication rates between the two groups and to test if any of the implant or graft/surgical variables had an influence on differences in complication rates between them: p<0.05 was a significant difference.
4. CHAPTER 4: JOURNAL ARTICLE 1

4.1 Abstract

Purpose

This paper documents the augmentation procedures performed in conjunction with dental implant placement, using data collected during a five-year retrospective assay of dental implants placed and restored in private dental practices in Victoria (Australia).

Materials and Methods

Data were collected from the patient files of recruited practitioners by trained and calibrated research assistants. Information was collected on augmentation techniques of onlay and particulate grafting, open and closed sinus lifting, socket preservation and connective-tissue grafting. Cross tabulation was carried out in IBM SPSS™ to provide descriptive statistics on frequency, timing of procedures, materials.

Results

8486 implants were placed: 2282(26.9%) required ≥1 hard-tissue procedure. There were 484(5.7%) soft-tissue procedures. The most common augmentation procedure was particulate grafting (1820(21.4% of implants)). 931(35.9%) hard-tissue procedures used barrier membrane. 75.9% of membranes were Bio-gide® (Geistlich Biomaterials: Pharma North America Inc.). Bio-Oss® (Geistlich
Biomaterials: Pharma North America Inc.) and autogenous bone were the most commonly used materials in all augmentation techniques. 1148(63.1%) particulate-grafted sites had simultaneous, single-stage implants placed; 92.9% onlay grafts and 83.7% open sinus lifts had a healing period before implant placement (mean overall healing period 6.7 months). The anterior maxilla was the most common site for all augmentation procedures.

Conclusions

There is little published data demonstrating features of augmentation protocols in private practice. This study presents the results of a large and diverse group of independent practitioners and patients. Despite this diversity, the practices observed were largely in keeping with the internationally-published evidence-base. Augmentation procedures were required for nearly 1/3 of implants placed, highlighting their importance in routine dental implant treatment.

Keywords

Guided bone regeneration, Graft*; Surgical technique*; Augmentation; Dental implant*

4.2 Introduction

Bone augmentation procedures are a routine aspect of dental implant rehabilitation. Little published data is currently available to describe the various
augmentation procedures that are being undertaken by private practitioners in conjunction with dental implant placement. Augmentation procedures may be performed in order to increase the ridge width and/or height depending on the pattern of resorption and atrophy that has taken place, and the restorative requirements, in particular, of axial loading.

There are no definitive guidelines regarding the optimal timing of implant placement following augmentation. Implants may be placed after a variable period of healing following augmentation (delayed); they may also be successfully placed at the same time as augmentation1,2,3 (simultaneous), although long-term successes may vary.1

Augmentation procedures include particulate grafting or Guided-Bone Regeneration (GBR), cortico-cancellous block grafting, and open and closed sinus lifting. One of the principles of GBR is the creation of space for ingrowth of bone and adequate tissue support, for which the use of a barrier membrane has been deemed to be necessary.4 There is no real consensus on the most appropriate materials for these augmentation procedures or the benefits of barrier membrane.5

Socket (or ridge) preservation is another adjunctive hard-tissue procedure that may help preserve ridge volume by reducing the rate of post-extraction changes, and thereby simplify subsequent augmentation or implant procedures.6 This is carried out at the time of dental extraction, followed by a variable period of healing. One systematic review reported a small statistically significant gain in
bone height and width following socket preservation\textsuperscript{7}. However, the clinical benefit of such a small difference on implant outcome was unknown\textsuperscript{6,7}. The use of a barrier membrane without graft material may be sufficient, or even preferred, for optimisation of wound healing in extraction sites\textsuperscript{7}.

Soft tissues may also be augmented during implant management, in particular, by using of connective tissue grafts from the palate. Connective tissue grafting has been suggested to improve aesthetics and thickness of peri-implant tissues in addition to helping to re-build lost inter-dental papillae\textsuperscript{8}. This is particularly useful in patients with a thin biotype, where thinning of peri-implant tissues may compromise aesthetics and cleansibility of the final restoration.

The aim of this study was to present and examine the augmentation procedures used by a group of Victorian general and specialist dentists and oral and maxillofacial surgeons who participated in a retrospective cohort study of implant treatment in private practice over a five-year period.

\textbf{4.3 Material and Methods}

The methods and design of this study have been previously described\textsuperscript{9}. The study was approved by The University of Melbourne Human Research Ethics Committee (approval number 1033122) and conducted through the eviDent Foundation. EviDent is a Dental Practice Based Research Network (an initiative of the Australian Dental Association Victoria Branch and the Oral Health Cooperative Research Centre) that facilities practice-based dental research by supporting relationships between dental practitioners and academic
Clinicians qualified on or before December 2004, registered in Victoria (Australia), and placing and/or restoring implants in private practice were invited to participate in the study. Implants *placed or restored* within the study period of 1st of January 2005 to 31st December 2009 inclusive were included. Records that were missing or unavailable, patients who did not follow up on proposed implant treatments or chose other restorative options were excluded from the study.

Information regarding augmentation practices was collated and assessed separately from other data and classified. Further clarification regarding the materials and techniques employed within practices was obtained using an additional questionnaire sent specifically to those practitioners undertaking augmentation procedures. Information collected included: source of autogenous bone: intra- versus extra- oral; nature of ‘sinus-lifting’ practices; membrane use; materials used routinely for the different augmentation procedures; and soft tissue grafting practices.

Statistical analysis

All information on the data collection template was entered into a Microsoft® Access database, (Microsoft Corporation, WA, USA), created specifically for the study. The database was imported into SPSS™ Statistical Package for the Social
Sciences (Version 21, SPSS Inc., Chicago, IL, USA) for analysis. Descriptive statistics and frequencies of various characteristics of augmentation procedures were calculated for this paper using cross-tabulation, and where appropriate Chi-squared or unpaired T-tests were used for statistical analysis. P value <0.05 was taken as significant.

4.4 Results

Thirty-four practitioners participated in the main study; a combination of general dentists and specialist dentists and oral and maxillofacial surgeons. The additional questionnaire was sent to seventeen practitioners, thirteen of whom responded. The overall number of patient files that met the inclusion criteria was 4116. The total number of implants placed was 8486 and 26.9% of these underwent a hard-tissue augmentation procedure.

Table 1 is a summary of the adjunctive procedures performed. There were some implants placed that underwent more than one hard-tissue procedure at a given site. Additionally, there were a small number of hard tissue procedures the nature of which were not elucidated, which were separated from the main (specified) hard-tissue procedure data and not included in the calculations.
Table 1 Summary of adjunctive procedures by frequency and proportion.

<table>
<thead>
<tr>
<th></th>
<th>Frequency (% of total implants placed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of implants</td>
<td>8486</td>
</tr>
<tr>
<td>Total number of hard tissue procedures (specified)</td>
<td>2590 (30.5)</td>
</tr>
<tr>
<td>Number of implants that underwent at least one hard tissue procedure</td>
<td>2282 (26.9)</td>
</tr>
<tr>
<td>Total number of soft tissue procedures</td>
<td>484 (5.7)</td>
</tr>
<tr>
<td>Hard tissue procedure not specified</td>
<td>61 (0.7)</td>
</tr>
</tbody>
</table>

Barrier membrane was used in 931 cases of hard tissue procedure (35.9%). 75.9% of these were resorbable xenograft (Bio-gide® (Geistlich Biomaterials: Pharma North America Inc.)); 1.8% ‘collagen membrane barrier;’ 0.5% polytetrafluoroethylene (PTFE). For 21.8% the type of membrane used could not be ascertained. 1436 (55.4%) hard-tissue augmentation cases did not use a membrane; in 223 (8.6%) cases it was unclear whether a membrane was used or not.
70.3% of performed hard tissue procedures involved particulate grafting, which preceded the placement of 1820 (21.4%) implants placed. Figure 1 illustrates the proportions of the different materials used for this procedure. The source of autogenous bone, the second most common graft material, was intra-oral in 65.5%, not-specified in 34.0% and extra-oral in 0.7% of cases.

![Diagram of material proportions](image)

**Figure 1** Particulate grafting (n=1820): proportions of the different materials used.

The most common combinations of materials used in particulate grafting were: autogenous bone alone (21%), Bio-Oss® (Geistlich Biomaterials: Pharma North America Inc.) with a barrier membrane (20%) and autogenous bone and Bio-Oss® (Geistlich Biomaterials: Pharma North America Inc.) with a barrier
membrane (19%). A barrier membrane was used in 46% of particulate grafted cases and not used in 3%. In 51% of cases the use of membrane was not recorded.

The timing of implant placement following particulate grafting was calculated. 1483 (81.5%) cases that underwent particulate grafting had an implant placed simultaneously: 1148 (63.1%) were single stage implants; 328 (18.0%) were two-stage; 7 (0.4%) did not have the stages of implant placement recorded. The remainder, 337 (18.5%) of cases that underwent particulate grafting, had a delay to implant placement. The majority of implants that were subsequently placed, 203 (60.2%), were single-stage. The mean overall delay to implant placement was 192.2 days (Standard Error (SE) of mean = 8.0). There was no significant difference in delay if the implant was placed as a single-stage or as a two-stage procedure (192.4 days (SE 9.3); range 75-375 days versus 191.0 days (SE 11.9); range 25-400 days respectively), p=0.95.

Figure 2 illustrates the position of particulate-grafted implants in the maxilla and mandible. The majority were in the anterior maxilla (incisor region).
Onlay bone grafts were performed in 183 cases (2.2% of implants), and they represented only 7.1% of hard tissue procedures performed. Figure 3 illustrates the source of autogenous bone used for this procedure. Membrane use was lower in this group than in the particulate graft group. In 175 (92.4%) cases membrane was not used; Membrane was documented in 4 (2.2%). In 10 (5.4%) cases it was not clear whether or not membrane was used.
The timing of implant placement following onlay grafting was calculated. An implant was placed simultaneously in 13 (7.1%) cases that underwent onlay grafting. The majority of implants placed into an onlay-grafted site, 176 (92.9%), were placed after a period of healing. Of these, 112 (63.9%) were placed as a single-stage implant. The mean overall delay to implant placement was 189.0 days (SE 13.9; range 9-2127 days) and there was no significant difference in healing period between single-stage and two-stage implants that were placed following onlay grafting (p=0.21).

Figure 4 illustrates the position of onlay-grafted implants in the maxilla and mandible. The majority were placed in the maxilla, with a fairly equal proportion anteriorly and posteriorly.
Figure 4  Frequency of implants placed with particulate grafts by location: anterior, posterior and canine position for each jaw.

3.8% of performed hard tissue procedures were open sinus lifts. There were 98 cases, associated with 3.7% of implants that were placed in the posterior maxilla. There were 180 sinus lift procedures that were ‘not specified,’ which could have represented a either open or closed sinus lift procedures.

Figure 5 illustrates the frequency of each category of material that was used in open sinus lifting. Autogenous bone (used alone and in combination) was obtained intra-orally for 32 implants, extra-orally for 33 implants and for 16 implants the source was not specified. Where a combination of materials was used, 100% was autogenous bone combined with Bio-Oss®(Geistlich Biomaterials: Pharma North America Inc.). It is not possible to decipher if the autogenous bone used was in the form of cortico-cancellous block or particulate.
Membrane was used in 18 (18.3%) open sinus lift cases; not used in 76 (77.6%) cases; not recorded in 4 (4.1%) cases.

![Bar chart showing frequency of open sinus lift materials used by type, and source of autogenous bone (n=98).](image)

**Figure 5** Frequency of open sinus lift materials used by type, and source of autogenous bone (n=98).

The timing of implant placement following open sinus lifting was assessed. The majority of implants, 83.7%, were placed after a period of healing (delayed); 70.7% of these were placed as single-stage implant. The remainder, 16.3%, were placed as a simultaneous procedure with 100% of these placed as single-stage. The mean overall delay to implant placement was 199.7 days (SE 6.6; range 19-1308 days). There was no significant difference in delay if the implant was
placed as a single-stage or as a two-stage procedure (195.0 (SE 8.1; range 75-320 days) versus 196.7 (SE 5.5; range 125-275 days) respectively, p=0.10. Open sinus lifts and unspecified sinus lifts were often accompanied by an additional procedure (in 79.5% and 63.7% of cases respectively). Additional procedures included onlay or particulate bone grafting or both.

6.0% of hard tissue procedures performed were closed sinus lifts. There were 155 cases documented, which were associated with 5.8% of implants placed in the posterior maxilla. Figure 6 illustrates the proportion of closed sinus lifts that were performed alone versus those that underwent some simultaneous particulate grafting. In this study, closed sinus lift and particulate grafting were performed together to a greater extent than closed sinus lifting alone; and mostly (89.5%) with a single-staged implant.
Socket (ridge) preservation was carried out in 154 (1.8%) cases. This represented 5.9% of hard tissue procedures performed in the cohort. Figure 7 demonstrates the materials used for this procedure. Bio-Oss® (Geistlich Biomaterials: Pharma North America Inc.) was the material most commonly used alone or in combination with autogenous bone. Membrane was used in 103 (66.8%) socket preservation cases; not used in 35 (22.8%) and not recorded in 16 (10.4%). The mean interval to implant placement following ridge-preservation was 162.8 days (SE 16.9; range 12-2127 days). 16.2% of ridge-preserved cases were followed by particulate graft where an implant was eventually placed.
The overall mean delay to implant placement following any hard tissue augmentation procedure was calculated at 205.3 days (SE 12.3; range 2-2127 days) or 6.7 months.

Soft tissue grafting was performed in 484 (5.7%) cases and is summarised in Table 2.
Table 2 Summary of soft tissue procedures performed and timing in relation to other procedures (n=484).

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Frequency (% of total soft tissue procedures performed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connective tissue grafts</td>
<td>439 (90.7)</td>
</tr>
<tr>
<td>Soft tissue procedures at same time as a hard tissue procedure and implant placement</td>
<td>244 (50.4)</td>
</tr>
<tr>
<td>At same time as hard tissue procedure alone</td>
<td>9 (1.9)</td>
</tr>
<tr>
<td>At same time as second stage surgery</td>
<td>4 (0.8)</td>
</tr>
<tr>
<td>Performed at a different time to the above or timing unrecorded</td>
<td>201 (41.5)</td>
</tr>
</tbody>
</table>
Figure 8 illustrates the location of soft tissue grafting in the maxilla and mandible. The majority of procedures performed were in the anterior maxilla.

Figure 8 Frequency of implants placed with soft-tissue grafts by location: anterior, posterior and canine position for each jaw.

4.5 Discussion

The practices of private practitioners in Victoria, Australia with respect to grafting and other augmentation procedures in conjunction with dental implant therapy have been described. Such specific descriptive data is rare in the implant literature. The high proportion of implants requiring a hard tissue augmentation procedure (nearly one third) demonstrates the importance of this aspect of surgery in relation to treatment planning and the potential for complications, or
influence of such procedures on implant success rates. Features of these practices will be discussed in turn with reference to the literature.

Particulate and onlay grafting

Particulate grafting was by far the most common hard-tissue adjunctive procedure employed. As there is no obvious equivalent study in the literature, rates of particulate and onlay grafting cannot be compared directly to other publications. However, one retrospective study of a smaller population, where all implant sites were grafted, demonstrated a particulate augmentation rate of 47.6% versus a greater percentage (52.3%) of block grafts.\textsuperscript{10}

A large proportion of particulate grafted sites (81.5%) and a smaller proportion of those that required an onlay graft (7.1%) had implants placed simultaneously. The current evidence-base does not present a clear indication or ‘cut-off’ for simultaneous versus delayed implant placement although some authors prefer immediate placement when the residual alveolar bone presents adequate quality and quantity to support primary stability,\textsuperscript{11} an essential requirement for osseointegration.\textsuperscript{12} This study did not record the size or nature of the defect that required grafting but could infer that the defects requiring grafting in this instance were small, such as crestal or labial thread exposure, and/or that the implant had good primary stability. The simultaneous placement of an implant with an onlay graft can be technically difficult, due to the degree of potential pre-existing bony deficiency, the risk of graft fracture and requirement for adequate immobilization and considerations of flap size, exposure and vascularity of the
graft site. Authors who have advocated a delayed approach have done so on the basis that a re-vascularised graft has a greater regenerative and healing capacity\textsuperscript{13} in addition to the fact that diminished bone contact has been found around dental implants placed simultaneously with grafting.\textsuperscript{14} However, in one literature review of pooled data, 63.4\% of implants were placed simultaneously with onlay grafting.\textsuperscript{15} This demonstrates a large discrepancy from practices observed in this study, which may be explained by the pressure of treating patients in private practice versus the protocols of academic centres. Additionally a degree of caution may have been exercised in our practitioner cohort due to the suggestion that implant survival rates in block-grafted sites may to be lower than when particulate-grafted.\textsuperscript{16}

Sinus lifting

16.3\% of implants were placed as a single-stage procedure simultaneous with an open sinus lift. The remainder were two-stage. Simultaneous placement may have practical advantages and is a cost and time-saving approach in appropriate situations.

A previous study with pooled data showed that as many as 40\% of implants were being placed simultaneously, with good outcomes (survival rate 61-100\%, mean 95\%).\textsuperscript{15} Studies have shown open sinus lifting with simultaneous implant placement to have good success rates if the native maxillary height below the antrum was \( \geq 4 \text{mm} \)\textsuperscript{17,18} and even when there was as little as 1-3\text{mm} of vertical bone height.\textsuperscript{19} In this study, the proportion of simultaneously placed implants
was lower than that which is published. It is difficult to comment on reasons for this difference, as our study did not record data regarding the residual height of native bone.

Ridge-preservation

There was a mean delay of 162.8 days (5.4 months) to implant placement from ridge-preservation. 16.2% of ridge-preserved sites in this study underwent further grafting prior to implant placement.

There is currently no consensus regarding the period of delay to implant placement following ridge-preservation. The literature focuses on the evidence of benefit of the procedure such as reduced rate of subsequent vertical and horizontal ridge resorption following extraction.\textsuperscript{20} However, published delays to implant placement range from three to over seven months.\textsuperscript{20}

Healing periods

The mean overall healing period following hard-tissue augmentation in this study for delayed implants was 205.3 days (6.7 months). Regardless of whether an implant was placed as a single or two-stage procedure, there was no difference in mean healing period. This practice is interesting in light of a previous retrospective study that demonstrated, on multi- and uni-variate analysis, that at bone grafted sites, single-stage implant placement was the only risk factor for failure.\textsuperscript{21}

Published healing periods (delay to implant placement) following augmentation
procedures range from three to nine months.\textsuperscript{5,22,23} The results of this study are in keeping with the literature.

Materials

Autogenous bone and Bio-Oss\textsuperscript{®} (Geistlich Biomaterials: Pharma North America Inc.) were the most commonly used materials in all augmentation techniques documented in this study, which is similar to another retrospective study of a smaller population.\textsuperscript{10} A proportion (37\%) of the onlay graft bone was harvested from an extra-oral source. The osteogenic properties of autogenous bone set it apart from other bio-materials in the augmentation process. Bio-Oss\textsuperscript{®} (Geistlich Biomaterials: Pharma North America Inc.) is recognised for its biocompatibility, versatility and osteoconductive properties, and its use has been extensively documented.\textsuperscript{24}

Extra-oral autogenous bone harvest, such as from the iliac crest, is a higher morbidity approach as compared to intra-oral harvest, and may be justified if large volumes of bone are required. It is interesting to note that in a recent review of the literature of bone augmentation procedures in implant dentistry, 80\% of onlay grafts overall were harvested from an extra-oral source.\textsuperscript{15} This difference from our local observations may represent the bias created by the increased complexity of cases performed in large specialist treatment centres and demonstrates that the published literature may not be representative of private practice activities.
Barrier membrane

Approximately half of the augmentation cases used a barrier membrane and half did not. Membrane was more likely to be used if Bio-Oss® (Geistlich Biomaterials: Pharma North America Inc.) was used as a particulate-graft or ridge-preservation material, alone, or in combination with particulate autogenous bone, compared to when particulate autogenous bone was used alone. This might be a reflection the particulate nature of Bio-Oss® (Geistlich Biomaterials: Pharma North America Inc.), seemingly requiring membrane for its retention. Membrane had its greatest use in socket/ridge-preservation (66.8%). The sparing use of membrane (2.2%), in conjunction with onlay grafting may be related to its retentive quality and relative resistance to resorption. The use of resorbable xenograft such as Bio-gide® (Geistlich Biomaterials: Pharma North America Inc.) as a barrier membrane had the greatest popularity (75.9%). Non-resorbable barrier membranes such as PTFE and titanium mesh were hardly used.

The benefit of membrane use in hard tissue augmentation procedures remains debated. The lack of consensus in the literature seems to be reflected in the overall rate of membrane use in this study. The use of a sub-periosteal barrier membrane has been suggested to assist in retention of a graft and thus yield more bone and/or reduce resorption. However, meta-analyses have demonstrated similar immediate and long-term success of augmentation with or without the use of resorbable and non-resorbable membranes. Another
A meta-analysis of four animal studies suggested that the amount of vertically augmented bone was 0.32 mm more in membrane-covered groups than in the non-membrane groups (p=0.006), but the clinical importance of this amount of augmentation was unclear. The published evidence for membrane in the enhancement of the physiologic healing process has been more convincing in the context of socket preservation, and this is reflected in the results of this study.

Non-resorbable barrier membranes such as PTFE and titanium mesh, though once highly advocated due to their imperviousness to soft tissue ingrowth and bacteria, are difficult to handle and carry increased morbidity. This sentiment may be reflected in the results of this survey. Bio-gide® (Geistlich Biomaterials: Pharma North America Inc.) however, whilst lacking rigidity for space maintenance, is relatively biocompatible and has favourable handling and resorption characteristics compared to other membranes.

One limitation of a retrospective survey is that data acquisition is limited by quality of record keeping, resulting in some procedures being difficult to classify and a number of ‘unspecified’ augmentation procedures. The use of the additional questionnaire helped to clarify some practices. This study and the proforma used may be used to contribute to the design of a prospective data collection tool for a future study and/or assist with record keeping of practitioners by highlighting where record keeping was deficient.

The study has been successful in broadly documenting the clinical practices of
practitioners in private practices in Victoria over a five-year period. There is currently little similar descriptive data published in the literature and no single study that has such a large sample size and such a diverse group of patients without the usual restrictions or exclusion criteria of studies carried out in academic centres. Information gleaned can be used to contribute to documentation of practices over time and correlate practices with surgical and implant complications and outcomes in future analyses.
4.6 References


7. Orgeas, G. V. et al. Surgical Techniques for Alveolar Socket Preservation: A


5. CHAPTER 5: JOURNAL ARTICLE 2

5.1 Abstract

Purpose

This aim of this paper was to document the complications associated with augmentation procedures performed in conjunction with dental implants, using data collected during a five-year retrospective assay of dental implants placed and restored in private dental practices in Victoria (Australia).

Materials and Methods

Data were collected from the patient files of recruited practitioners by trained and calibrated research assistants. Information was collected on augmentation techniques of onlay and particulate grafting, open and closed sinus lifting, socket preservation and connective-tissue grafting. Complications were categorised as surgical (technical): neuro-sensory disturbance, pain, bleeding, swelling, bone perforation, insufficient bone quantity or inadequate primary stability; and biological: Infection, bone loss, failure to osseointegrate, loss of integration and peri-implantitis. Cross-tabulation was carried out in IBM-SPSS™ Uni- and multivariate analysis using GenStat® was used to assess independent risk factors of augmentation complications. Complications in implants sites that were augmented were compared to the sites that were not augmented.
Results

During the period of January 2005 to December 2009, of 8486 implants that were placed, nearly one third (26.9%) underwent at least one augmentation procedure either before or at the same time as placement.

There was a significant difference in the overall complication rate between the augmented and un-augmented groups (17.3% versus 12.6%; p=<0.001) using uni-variate analysis. The hard tissue augmented group had significantly more cases of insufficient bone and/or more dehiscences (2.10% v 0.58%; p<0.001) and bone loss (0.61% v 0.19%; p=0.0014) at implant placement than the non-augmented group. In these cases, implants were placed and grafted simultaneously (p<0.05) with particulate autogenous bone and/or Bio-Oss (p<0.05) in combination with resorbable xenograft membrane (p<0.001). There was significantly more bone loss in open sinus lifted cases than in cases where implants were placed in native bone (1.90% v 0.30%; p=-0.009). Other factors such as augmentation technique or material used, healing period length or timing of implant placement, were not found significantly contribute to the complications, on multi-variate analysis.

Conclusions

The study demonstrated no increase graft complication that could be related to any specific augmentation technique, suggesting that routine grafting procedures used in private practice were safe and appropriate. A 5% increase in complication rate at augmented sites did not preclude implant placement or
aberrantly affect implant outcome.

Keywords

Guided bone regeneration, Graft* complication*; Surgical technique*; Augmentation; Dental implant*

5.2 Introduction

Augmentation procedures may be performed in the context of dental implant treatment where native bone is lacking or soft tissue is deficient. Bone augmentation procedures are commonly performed as an adjunct to dental implant rehabilitation\(^1\). They may be required in order to increase the ridge width and/or height depending on the pattern of resorption and atrophy that has taken place, and the restorative requirements such as axial loading of implants. Bone is required for primary stability, which is an important predictor of implant success\(^2\) and osseointegration.\(^3\) Augmentation procedures include particulate grafting or Guided-Bone Regeneration (GBR), cortico-cancellous block grafting, and open and closed sinus lifting. Socket (or ridge) preservation is another adjunctive hard-tissue procedure that may help preserve ridge volume by reducing the rate of post-extraction changes, and thereby simplify subsequent augmentation or implant procedures.\(^4\) There is no consensus on the most appropriate materials for these augmentation procedures, or the benefits and drawbacks of barrier membrane, with respect to the potential complications of
augmentation such as dehiscence, infection and graft loss or graft resorption.\textsuperscript{1} There is also no indication in the literature regarding which augmentation techniques lead to greatest implant success or lowest complication rate.

Soft tissues may also be augmented by using connective tissue grafts from the palate. Connective tissue grafting has been suggested to improve aesthetics and thickness of peri-implant tissues in addition to helping to re-build lost inter-dental papillae.\textsuperscript{5} This may be particularly useful in patients with a thin biotype, where thinning of peri-implant tissues may compromise aesthetics and cleansibility of the final restoration or contribute to implant failure in the long-term.\textsuperscript{6} The literature is not agreed on the these potential benefits, in particular with respect to the reduction in risk of implant complications such as loss of attachment or peri-implantitis.

Graft or augmentation complications may affect implant success and as such it is useful to examine the factors that may contribute to them during the treatment planning process. Recipient site complications may be biological: Infection, bone loss, failure to osseointegrate, loss of implant integration, peri-implantitis; or surgical (technical): neuro-sensory disturbance, pain, bleeding, swelling, bone perforation, insufficient bone quantity or quality or inadequate primary stability. Success rates of different augmentation protocols are often extrapolated from implant success rates rather than directly measured. Further to this, there is little documentation in the literature of the rates of specific complications of augmentation with respect to the different techniques, materials and timing of
augmentation.

The aim of this study was to present and examine the complications recorded at the recipient site in relation to the augmentation procedures performed in conjunction with dental implants by a group of Victorian general and specialist dentists, and oral and maxillofacial surgeons, who participated in a retrospective cohort study of implant treatment in private practice over a five-year period. Specifically the study wanted to quantify augmentation complications and their risk factors directly rather than using the implant outcomes/successes to deduce the efficacy of individual factors of augmentation such as techniques, materials and timings.

5.3  Material and Methods

A retrospective cohort design, with methods previously described,\textsuperscript{7} was used to review the population of patients receiving implant treatment at private dental practices within Victoria, Australia. Thirty-four practitioners participated in the main study; a combination of general dentists and specialist dentists, and oral and maxillofacial surgeons. The overall number of patient files that met the inclusion criteria was 4116. The total number of implants placed was 8486. Inclusion criteria were implants that were \textit{placed} or \textit{restored} within the study period of 1st of January 2005 to 31st December 2009 inclusive, by enrolled clinicians, qualified on or before December 2004 and registered in Victoria, Australia. Cases excluded were those with records missing or unavailable,
patients who did not follow up on proposed implant treatments or who chose other restorative options. Information was collected regarding: Clinician demographics; Patient demographics; Patient co-morbidities/systemic host factors; Oral status/local host factors; Implant specifications; Surgical information; Restorations/prosthodontic information; and Complications.

Details on augmentation practice were collated and assessed separately from other data and classified into surgery type, techniques, materials, timing, assessment and complications. Further clarification regarding the materials and techniques employed within practices was obtained using an additional questionnaire sent specifically to those practitioners undertaking augmentation procedures. The additional questionnaire was sent to seventeen practitioners, thirteen of whom responded. Information collected included: source of autogenous bone: intra- versus extra- oral; nature of ‘sinus-lifting’ practices; membrane use; materials used routinely for the different augmentation procedures; and soft tissue grafting practices. Complications were divided into biological and surgical, as previously described.

The study was approved by The University of Melbourne Human Research Ethics Committee (approval number 1033122) and conducted through the Evident Foundation. Evident is a Dental Practice Based Research Network (an initiative of the Australian Dental Association Victorian Branch and the Oral Health Cooperative Research Centre at the University of Melbourne) that facilitates practice-based dental research by supporting relationships between dental
practitioners and academic researchers.

Data were entered into a Microsoft® Access database, (Microsoft Corporation, WA, USA), created specifically for the study. The database was imported into SPSS™ Statistical Package for the Social Sciences (Version 21, SPSS Inc., Chicago, IL, USA) for analysis. Descriptive statistics and cross-tabulation was carried out using SPSS. GenStat® (Version 14, VSN International) was used compare the complication rates in the augmented and non-augmented groups using univariate analysis. Multivariate analysis was used to test if any of the implant or graft/surgical variables had an influence on differences in complication rates in both the augmented and non-augmented groups. p<0.05 was a significant difference.

5.4 Results

Out of 8486 implants placed, 26.9% underwent a hard-tissue augmentation procedure. There were n=2282 implants placed in the augmented group and n=6204 in the implant sites that were not augmented group. Table 1 is a summary of the adjunctive procedures performed. There were some implants placed that underwent more than one hard-tissue procedure at a given site. Additionally, there were a small number of hard tissue procedures the nature of which were not described in detail by the practitioner, and were separated from the main (specified) hard-tissue procedure data and not included in the subsequent calculations.
Table 1 Summary of adjunctive procedures by frequency and proportion.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Frequency (% of total implants placed); (% of hard tissue procedures)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of implants</td>
<td>8486</td>
</tr>
<tr>
<td>Total number of hard tissue procedures</td>
<td>2590 (30.5) (specified)</td>
</tr>
<tr>
<td>Number of implants that underwent at least one hard tissue procedure</td>
<td>2282 (26.9)</td>
</tr>
<tr>
<td>Particulate graft</td>
<td>1820 (20.4); (70.3)</td>
</tr>
<tr>
<td>Cortico-cancellous onlay graft</td>
<td>183 (2.2); (7.1)</td>
</tr>
<tr>
<td>Open sinus lift</td>
<td>98 (1.2); (3.8); (3.7% in posterior maxilla)</td>
</tr>
<tr>
<td>Closed sinus lift</td>
<td>155 (1.8); (6.0) (5.8% in posterior maxilla)</td>
</tr>
<tr>
<td>Socket (ridge) preservation</td>
<td>154 (1.8); (5.9)</td>
</tr>
<tr>
<td>Hard tissue procedure not specified</td>
<td>61 (0.7)</td>
</tr>
<tr>
<td>Total number of soft tissue procedures</td>
<td>484 (5.7)</td>
</tr>
</tbody>
</table>
The complication rate for any implant site that underwent hard tissue augmentation was 17.3% (13.3% surgical; 3.9% biological). Using uni-variate analysis, there was a significant difference in the overall graft complication rate between the augmented and non-augmented groups (17.3% versus 12.6%; p=<0.001). Table 2 is a summary of the percentage rates of some of the specific complications, where the difference between the augmented and non-augmented groups was not statistically significant on multi-variate analysis, such as the rate of infection at the recipient site. There was no significant difference in the augmented and non-augmented groups with respect to neurosensory disturbance, post-operative pain or infection, bleeding or swelling, failure to osseointegrate, delayed implant integration, loss of integration, insufficient primary stability or sinus membrane perforation.
### Table 2: Summary of complications using multi-variate analysis; p value for comparison between the two groups.

<table>
<thead>
<tr>
<th>Complication</th>
<th>Grafted</th>
<th>Not Grafted</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-operative infection</td>
<td>1.3</td>
<td>0.99</td>
<td>0.202</td>
</tr>
<tr>
<td>Lack of primary stability</td>
<td>0.92</td>
<td>0.67</td>
<td>0.233</td>
</tr>
<tr>
<td>Failure to integrate</td>
<td>2.19</td>
<td>2.23</td>
<td>0.905</td>
</tr>
<tr>
<td>Loss of integration</td>
<td>0.68</td>
<td>0.55</td>
<td>0.473</td>
</tr>
<tr>
<td>Peri-implantitis</td>
<td>0.89</td>
<td>1.08</td>
<td>0.456</td>
</tr>
</tbody>
</table>

Additionally there was no significant difference in biological complications of peri-implantitis or mucositis if the implant site was soft-tissue augmented (2.78% versus 2.62% respectively, p=0.837).

Implant sites that required bone grafting in order to facilitate implant placement had significantly more cases of insufficient bone and/or more dehiscences at implant placement than the non-augmented group (2.10% v 0.58%; p<0.001). Of these cases, there were significantly more implants that were placed and grafted
simultaneously (p=0.02) with particulate material (p=0.03), using a combination of autogenous (intra-orally harvested) particulate bone and Bio-Oss® (Geistlich Biomaterials: Pharma North America Inc.) in combination with resorbable xenograft membrane (p<0.001).

With respect to bone loss detected at implant placement (or pre-insertion bone resorption), there were significantly more cases documented in the augmented group versus the non-augmented group (0.61% v 0.19%; p=0.0014), and this included socket-preservation as an augmentation procedure. Indeed, 16.2% of ridge-preserved sites in this study subsequently underwent further grafting prior to implant placement. In these cases of bone loss prior to implant placement, a significantly greater number in the augmented group required further simultaneous grafting, (p=0.004). A significantly higher number of these were augmented with particulate material (p=0.003), a combination of autogenous (intra-orally harvested) particulate bone and Bio-Oss® (Geistlich Biomaterials: Pharma North America Inc.), used in combination with resorbable xenograft membrane (p<0.01). In these simultaneously particulate-augmented cases there was no statistically significant increase in rate of inadequate primary stability, or early or delayed problems with osseointegration, and thus it appeared that the implant outcome, at least in the short term, was unaffected.

In regard to those sites requiring open sinus lifting prior to implant placement, there was significantly more bone loss in open sinus lifted cases than in cases where implants were placed in native bone (1.90% v 0.30%; p=-0.009). The
degree of bone loss could not be quantified. There was no influence of different materials used on increased bone loss on multivariate analysis.

Looking at the healing times of augmentation, the mean overall healing period following hard-tissue augmentation in this study (delayed implants) was 205.3 days or 6.7 months (SE 12.3; range 2-2127 days). There was a mean interval of 162.8 days (5.4 months): SE 16.9; range 12-2127 days) overall to implant placement from ridge-preservation. Regardless of whether an implant was placed as a single or two-stage procedure, there was no difference in mean delay to implant placement from augmentation. Additionally, at each implant site, multiple hard and soft tissue procedures were often performed simultaneously. No relationship was demonstrated between time to implant placement following augmentation and complication rates in cases where implant placement was delayed due to a period of healing. For example, there was no increased risk of bone resorption if implant placement was delayed or poor quality bone if healing period was short.

On multi-variate analysis no difference was found between materials, techniques of onlay grafting, ridge preservation and closed sinus lifting and any specific graft complication.

5.5 Discussion

A five-year retrospective cohort study of implants that were placed in private
practice in Victoria, Australia, has demonstrated the potential for complications of grafting and augmentation practices. The high proportion of implants requiring a hard tissue augmentation procedure demonstrated the importance of this aspect of surgery in relation to treatment planning and the potential for complications, or influence of such procedures on implant success. There were no total graft failures recorded in this cohort. This was because, in contrast to other implant grafting studies, the end-point of all augmented sites in this study was implant placement. It should be noted, however, that the current study included multiple augmentation methods and was comprehensive in inclusion of minor sequelae such as pain, bleeding and swelling.

Augmentation gave rise to a statistically significant (5%) increase in complications as compared to the non-augmented group (17.3% in the augmented group verses 12.6%). However, the increased complication rate at any given site did not preclude implant placement or affect osseointegration in the short-term. There was no increase in potential recipient site biological and surgical complications of post-operative pain and infection, problems with integration or peri-implantitis between the augmented and non-augmented group. Indeed, the rate of infection in grafted cases in this study was actually quite low (1.3%). There was also no significant relationship found between the type of augmentation technique and these particular complications.

The increased complication rate in the augmented group was unsurprising, and has been documented in the published literature. However, this study refutes
the suggestion that implants placed in augmented bone may be less successful than those placed in native bone,\textsuperscript{9,10} in particular with respect to infection. Other studies have suggested that grafting may carry a higher 5-8\% rate of infection at the recipient site,\textsuperscript{11,12} and that onlay block grafting has been associated with increased (3.3\%) infection rate,\textsuperscript{13} but in this study, this was not the case. Kaing’s retrospective study of augmentation procedures in a smaller population suggested an even higher graft complication rate than that which was found in this study of 27.9\%, and a 12.7\% graft failure rate.\textsuperscript{14}

Looking at the significant differences that were found in this current study between the augmented and non-augmented groups, the increase in insufficient bone and/or more bony dehiscence and pre-placement bone loss in the augmented group compared to the non-augmented group was small (1.52\% and 0.42\% respectively). Thus whilst statistically significant, the clinical importance of this difference was difficult to interpret, particularly as this data had not obviously been previously reported in the literature. It would be unsurprising that cases requiring grafting might have a higher risk of having insufficient bone at time of implant placement, due to increased risk of graft failure to integrate,\textsuperscript{15,16} soft tissue dehiscence and exposure\textsuperscript{17} and bone resorption.\textsuperscript{16} However, the low rate of problems with integration after bone grafting in this study (<3\%) suggested that the case selection for augmentation was appropriate; whilst there might have been a dehiscence, or bone loss, this might not have been clinically significant. Unfortunately the quantity or degree and location of deficiency was not obtained pre- or post-operatively.
No one particular augmentation technique or material caused an increase in graft complication; there was no particular material that was found to be superior or inferior to another. It is useful to note, though, that where insufficient bone or dehiscence or bone loss were recorded, many sites were successfully simultaneously grafted with particulate autogenous bone or Bio-Oss® (Geistlich Biomaterials: Pharma North America Inc.), and in a significant number of these a resorbable xenograft membrane was used with the graft.

The rate of bone loss in open sinus lifted sites was low at 1.90%. There was significantly more bone loss at insertion in open sinus lifted sites than in cases where implants were placed in native bone, by 1.6%, although this percentage difference was very small. This finding was in keeping with another study, where the rate of excessive bone loss in sinus lifted maxillae was quoted to be around 1.3%. The influence of this loss on implant outcome was unknown. In open sinus lifting, major reported adverse events include sinus membrane perforation, graft infection and graft loss, precluding implant placement. In this study, there was still sufficient bone to place an implant and there was no significant increase in infection rate. There was also no influence of any particular material or of timing of implant placement on the complication rate, which is both reassuring and in keeping with the literature.

There was no evidence, in this study, that membrane or use of any one particular membrane type altered the complication rate. The use of membrane has support because of its theorised ability to provide space for ingrowth of bone and to
support local soft tissues, and to reduce bone resorption. However, there is a lack of consensus in the literature with respect to its benefit and any gain in bone has been suggested to be clinically questionable. Some studies have suggested that e-PTFE membranes might be more prone to exposure and infection than resorbable membranes, but others have suggested no difference between membrane types. The findings of this study have been found to be similar to the contemporary opinion on barrier membranes.

Simultaneous augmentation did not alter the complication rate in this study. This is interesting in light of a finding in another study that suggested simultaneous, single stage grafting and implant placement was the single-most important risk-factors for implant failure. Authors who have advocated a delayed approach have done so on the basis that a re-vascularised graft has a greater regenerative and healing capacity in addition to the fact that diminished bone contact has been found around dental implants placed simultaneously with grafting. One study, with up to 59 months of follow-up after simultaneous implant placement and GBR to treat fenestration and dehiscence defects demonstrated significantly increased marginal bone loss in the grafted group, but no significant difference in long-term implant outcome.

Length of healing period did not affect the rate of graft complication in this study. There are no definitive guidelines regarding the optimal timing of implant placement following augmentation or the length of healing period. Implants may be placed after a variable period of healing following augmentation (delayed);
they may also be successfully placed at the same time as augmentation (simultaneous),28,29,30 although long-term successes may vary.28 The timing of implant placement after augmentation has, in contrast, been shown to influence the volume or quality of bone (a feature that may be reflected in part by implant primary stability), particularly if there has been bone resorption. Whilst there is no consensus in the literature with respect to optimal timing of implant placement, the mean healing periods after augmentation and ridge preservation documented here were in keeping with those used in published trials and studies, of four months for mandibular implants and six to eight months in the maxilla.1,31,32,33

Ridge preservation was followed by further augmentation prior to implant placement in 16.2% of sites, suggesting on-going bone loss despite this ‘preventative’ augmentation procedure. There was no particular material or combination of materials, including use of barrier membrane, that influenced this outcome. Ridge preservation has been hypothesized to improve the post-extractional bone loss by 1 to 3mm,34 which may be a statistically significant difference, but may not be clinically significant if it does not obviate the need for further augmentation. Indeed, there has not been any conclusive evidence that socket (ridge) preservation improves ability to place an implant after tooth extraction,35 and this is confirmed by the results of this study.

Neither soft tissue augmentation by connective tissue grafting nor hard tissue augmentation altered the soft tissue complication rate, in particular, of peri-
implantitis. Peri-implantitis is a destructive inflammatory process affecting peri-implant hard and soft tissues, which if untreated, may lead to loss of implant osseointegration and ultimately implant loss. The integrity and width of peri-implant keratinised tissue as well as good underlying bony support may be essential for risk reduction by acting as a barrier to infection by way of resistance to attachment loss.6 There does not currently appear to be much literature examining the risk of peri-implantitis in bone grafted sites. There is also much debate over whether or not connective tissue grafting may reduce the risk of this implant-threatening complication. A 2009 literature review of the local risk factors for implant failure found that there were no studies that demonstrated a relationship between soft tissue thickness or width of keratinised tissue and implant survival or peri-implant mucosal recession.36 Despite the controversy, this study demonstrated that some clinicians routinely undertook connective tissue grafting.

The drawbacks of this study were related in the most part to its retrospective nature; data could only be obtained by accurate practitioner record keeping or were limited by proforma design. Thus, details that were not recorded included the size or nature of the defect that required grafting, the radiographic findings pre-or post-operatively and the follow-up period. The small increase in complication rate in the augmented group may have been explained by a true low number of complications reported in the study but also by the fact that the complication rate may have been under-reported overall. There were no exclusion criteria such as patient medical history or smoking that might have
artificially reduced the complication risk by introducing selection bias.

This study has, however, provided some documentation regarding the clinical practices and augmentation complications of practitioners in private practices in Victoria over a five-year period. It was unique in its coverage of the practices of independent private practitioners in large numbers and in a diverse group of patients, without the usual restrictions or exclusion criteria of controlled studies from academic institutions. There is currently little similar data published in the literature and no single study that has such a large sample size. Whilst there appeared to be increased risk of bone loss or insufficient bone at bone-augmented sites, complication rates associated with augmentation were equal to or lower than those documented in the literature. It was demonstrated that such traditional practices such as GBR, onlay bone grafting, ridge preservation and sinus lifting procedures were safe and appropriate in the private practice setting despite a recent drive to avoid augmentation by use of angulated, narrow or wide implants, in addition to zygomatic implants, as alternatives, where native bone might be lacking. There were no materials routinely used that increased the risk of graft complication. There also appeared to be no significant or clinically important increase in risk of infection, loss of bone or ultimately problems with osseointegration of implants placed in augmented bone.
5.6 References


14. Kaing L. et al. Assessment of bone grafts placed within an oral and


28. Vermeeren, J. I. et al. One-step reconstruction of the severely resorbed


6. CHAPTER 6: SUMMARY AND RECOMMENDATIONS FOR TREATMENT PLANNING

This thesis by publication has reported and analysed the surgical profiles and/or the augmentation complications of 8486 individual implants that were prescribed during the period of January 2005 – December 2009 in private practice settings in the state of Victoria, Australia.

The research questions set out in the aims and objectives have been answered. The first question: “What are the techniques employed, materials and timings of augmentation and adjunctive procedures in the setting of implant treatment? How do these compare to the published literature?” has been addressed in the first paper. A range of surgical augmentation procedures have been described and were performed in order to facilitate dental implant therapy in private practice. These included hard tissue augmentation by way of GBR, onlay grafting, open and closed sinus lifting and ridge preservation. Soft tissue augmentation employed was mostly connective tissue grafting. The materials used were specified, where possible, including the use of barrier membrane. The relative timing of procedures was also demonstrated. The observed practices were largely in keeping with the published literature, except for the relative timing of onlay grafting and sinus lifting with respect to implant placement. In this regard, the studied population employed a healing period in the majority of cases, whereas the literature suggested that implants were largely placed simultaneously. Additionally the most favoured site of bone harvest was intra-
oral, as compared to the published literature, where extra-oral sites were favoured.

The second research question: “What are the complications of these procedures and how do they compare to the published literature?” has been addressed in the second paper. Specific surgical and biological complications of augmentation have been examined by uni- and multi-variate analysis and complication rates in augmented sites have been compared to those of sites not augmented. Augmentation resulted in a small (5%) but statistically significant increase in overall complication rate, although in general, the complication rates in this study were lower than in other studies. Additionally, the complications that might have influenced implant outcome, such as those reflecting problems with implant osseointegration, were not increased by augmentation. It was demonstrated that such traditional practices such as GBR, onlay bone grafting, ridge preservation and sinus lifting procedures were safe and appropriate in the private practice setting.

It is very difficult to compare published studies and as such it remains difficult to recommend any one procedure or material over another with respect to augmentation success or long-term implant success or outcome. Indeed, every procedure has its advantages and disadvantages, and choice must be made on a case-by-case basis, bearing in mind cost, timing, invasiveness, patient factors, including aesthetic and functional demands, and surgeon factors such as training. Most authors agree that priority should be given to the simplest and least
invasive procedure that will enable goals to be met with the least risk of complication and in the shortest timeframe (Chiapasco et al. 2009). Given the high published rate of success of most augmentation procedures, it would seem that to quote a success rate of less than 90% for any proposed treatment plan would be, by today’s standards, unacceptable. Complication rates in every-day augmentation practice appear to be quite low overall (<5%). Further to this, this study did not highlight any one particular augmentation protocol or material that increased the risk of complication.

The following conclusions could be drawn from this research and available literature combined:

1. Autogenous cortico-cancellous block grafts from the ramus carry the lowest long-term morbidity of the intra-oral donor sites and should be considered before the symphysis where possible. Further to this, intra-oral harvest sites should be considered ahead of extra-oral sites if volume allows and onlay grafts should be cortico-cancellous as opposed to cancellous alone, as this has better capacity to resist resorption.

2. Due to possibility of resorption of grafted bone, the harvesting of oversized grafts should be encouraged. This practice may ensure sufficient bone for implant placement after revascularisation and remodelling. However, careful flap design and soft tissue handing is needed to ensure tension free closure, due to the increased risk of mucosal dehiscence and infection in vertically augmented and block-grafted sites.
3. In general delayed implant placement after augmentation with a period of healing produces more predictable outcomes than immediate implant placement. Thus in cases where implant survival is critical and grafting extensive or complex, a healing period is recommended.

4. However, the simultaneous grafting of implants to treat localised bone dehiscences or fenestrations, may not result in increased risk of graft complications such as infection or loss of osseointegration, and long-term implant survival is good. As such this can be recommended as a predictable treatment method.

5. Bone loss or insufficient bone after augmentation is more likely in bone-augmented sites. Vertical bone loss is particularly a long-term concern in vertically augmented ridges, even when implants have been placed and the graft is loaded. This should be taken in to consideration in treatment planning, although the implant survival does not appear to be affected.

6. It may be that augmentation sites in turn require further augmentation at time of implant placement due to insufficient bone or bone loss. However, if performed appropriately, the risk of further complication or implant failure should not be greater than in non-augmented sites in the short term. Further to this, socket preservation may not be essential following extraction and it may not avoid the need for grafting.

7. The combination of autogenous bone with bone substitute maximises the osteogenicity, osteoinductivity and osteoconductivity of the graft. Graft
combinations can be tailored to the specific requirements of the defect such as longevity, rigidity and bulk.

8. There is insufficient evidence from this research or literature review to support or refute the use of barrier membranes, either resorbable or non-resorbable, in any type of augmentation protocol. There is some data to suggest that barrier membranes may reduce graft resorption but there is no RCT evidence to support this. Overall, resorbable membranes show greater popularity than non-resorbable ones.

9. A residual bone height of 4mm or more is useful to avoid undue risk of adverse outcome in open and closed sinus lifted sites.

10. Connective tissue grafting does not appear to affect complication rates of augmentation or implant placement.
7. CONCLUSIONS

The benefit of this retrospective assessment of augmentation techniques undertaken is that the procedures that are realistically and routinely performed in modern every-day private practice have been compared to the published literature and to large specialist/academic centres that publish their work. Indeed the two papers written demonstrate that the procedures that are performed in Victoria carry the same diversity in implant augmentation treatment modalities than the in the published community except for the use of DO, interpositional bone grafting and Le Fort I osteotomy. Further to this, this particular research has contributed to the already published literature due to the following:

1. The data collected was broad enough in its inclusion criteria to be reflective of implant treatment patterns and outcomes in private practice. Exclusion criteria were clearly defined. This is lacking in the published literature. In this study, patients were not excluded on the basis of potential risk factors for reduced implant or augmentation success rate such as the use of anti-resorptive agents, diabetes or smoking;

2. The data sample was almost double in number of that of other studies, including a literature review of pooled data on augmentation procedures published by Chiapasco et al. in 2009, and as such was unprecedentedly large;

3. This research documented specifically the complications associated with grafting protocols and compared techniques by multi-variate analysis rather
than documenting simply the outcome of the implants. Thus the objective of assessing the techniques of augmentation with respect to complications was fulfilled;

4. The research addressed complications also by timing of procedures with respect to augmentation and healing periods, for which there is little published data.

The drawbacks in this research and in the published literature have highlighted some concepts that could be taken in to consideration when designing a future prospective study to examine augmentation protocols. Any future data collection proforma should give consideration to the following:

A. With respect to *assessment* of the recipient site:

1. The specific indication for augmentation and the nature and size of the defect (bony and/or soft tissue) as assessed clinically and radiographically;
2. Pre-operative radiographic findings;
3. The specific indication for any soft-tissue surgery including connective tissue graft, and site or harvest.

B. With respect to the *methods* of augmentation:

1. The approximate volume of bone harvested/used, and donor site, or bone substitute used with exact details of the product;
2. The use of membrane and type;
3. Specify if sinus lift is open or closed and if closed, if other augmentation simultaneously employed;
4. The specific technique of socket preservation employed such as primary closure and use of barrier membrane;
5. The design of the soft tissue flap and closure technique.

C. With respect to the outcomes, short- and long-term outcomes need to be better defined:
1. The clinical appearance of the grafted site at re-entry for implant placement including volume change;
2. The requirement for re-grafting or additional augmentation at implant placement;
3. The insertion torque of the implant;
4. Secondary stability at second stage and results of any torque-testing;
5. Post-operative radiographic findings, including bone density and volume;
6. The length of follow-up period and any observed clinical or radiographic changes, specifically peri-implant probing depths (soft tissue stability) and crestal bone loss in mm.

In considering the above points, any future study would be improved, and its contribution to the literature would be vastly enhanced.
8. REFERENCES

AGHALOO TL AND MOY PK. 2007. Which hard tissue augmentation techniques are the most successful in furnishing bony support for implant placement? The International journal of oral & maxillofacial implants 22 Suppl: 49-70.

AL-NAWAS B ET AL. 2012. A double-blind randomized controlled trial (RCT) of Titanium-13Zirconium versus Titanium Grade IV small-diameter bone level implants in edentulous mandibles--results from a 1-year observation period. Clinical implant dentistry and related research 14: 896-904.


ANTOUN H, SITBON JM, MARTINEZ H AND MISSIKA P. 2001. A prospective randomized study comparing two techniques of bone augmentation:


BLOCK MS, HAGGERTY CJ AND FISHER GR. 2009. Nongrafting implant options


BUTURA CC, GALINDO DF AND JENSEN OT. 2011. Mandibular all-on-four


CHIAPASCO M, ROMEO E, CASENTINI P AND RIMONDINI L. 2004. Alveolar
distraction osteogenesis vs. vertical guided bone regeneration for the correction of vertically deficient edentulous ridges: a 1-3-year prospective study on humans. Clinical oral implants research 15: 82-95.


COSCI F AND LUCCIOLI M. 2000. A new sinus lift technique in conjunction with


JUNG RE, WINDISCH SI, EGGENSCHWILER AM, THOMA DS, WEBER FE AND HAMMERLE CH. 2009. A randomized-controlled clinical trial evaluating clinical and radiological outcomes after 3 and 5 years of dental implants
placed in bone regenerated by means of GBR techniques with or without the addition of BMP-2. Clinical oral implants research 20: 660-666.


KREKMANOV L. 2000. Placement of posterior mandibular and maxillary implants in patients with severe bone deficiency: a clinical report of


MALO P, DE ARAUJO NOBRE M, LOPES A, FRANCISCHONE C AND RIGOLIZZO M. 2012. "All-on-4" immediate-function concept for completely edentulous maxillae: a clinical report on the medium (3 years) and long-term (5 years) outcomes. Clinical implant dentistry and related research 14 Suppl 1: e139-150.


MARX RE, CARLSON ER, EICHSTAEDT RM, SCHIMMELE SR, STRAUSS JE AND


RAGHOEBAR GM, SCHORTINGHUIS J, LIEM RS, RUBEN JL, VAN DER WAL JE AND


TINTI C, PARMA-BENFENATI S AND POLIZZI G. 1996. Vertical ridge


Surgical techniques for alveolar socket preservation: a systematic review.


Comparison of platelet, leukocyte, and growth factor levels in point-of-care platelet-enriched plasma, prepared using a modified Curasan kit, with preparations received from a local blood bank. Clinical oral implants
research 14: 357-362.


9. **APPENDIX** Data collection proforma

Recorder initials:

Case ID:

Patient year of birth:

Gender: male/female

**A. Systemic host factors**

i. Diabetes: yes ☑️ type 1 ☐ or type 2 ☑️ Controlled ☐ or uncontrolled ☐ or unknown ☐

or

no ☐

ii. Osteoporosis or osteopaenia: yes ☐ or no ☐

iii. Previous head and neck radiotherapy:

yes ☑️ date completed dd / mm / yyyy

no ☐

or

☐

iv. Bisphosphonate use: yes ☑️ IV ☐ or oral ☑️ duration (mths): ☐ ☐

⇒ date last dose dd / mm / yyyy
v. Allergy to penicillin:

yes □ or no □

vi. Periodontitis:

yes □ or no □

vii. Other systemic condition of note:

.........................................................................................................................................................

B. Local host factors

i. Was tooth wear noted? yes □ erosion □ abrasion □ attrition □ type not recorded □ or

no □

ii. Smoker yes □ How many? Not known □ or enter no. smoked/day □ or

no □ or

previous □ or

not recorded □

C. Implant information
i. Implant site

ii. Reason for treatment:

........................................................................................................................................

........................................................................................................................................

iii. Implant system/brand (check one line only):

........................................................................................................................................

**Ankylos** □ or Ankylos C/X Type □

**Astra Tech** □ Type ▶

straight walled □ or tapered (TX) □

Surface ▶ Tioblast □ or Osseospeed □

**Biomet 3i** □ Type ▶ Nanotite PREVAIL (internal/Certain) □ ▶ parallel or tapered

Nanotite parallel □ or tapered ▶ (intern/Certain) □ or external Osseotite PREVAIL

□ (internal/Certain) parallel □ or tapered Osseotite parallel □ or tapered □

▶ (intern/Certain) □ or external Full Osseotite parallel □ or tapered □

▶ (intern/Certain) or external Full Osseotite XP parallel □ ▶ (internal/Certain) □ or external

· **MIS** □ Type ▶

Seven □ Mistral □ Bio □ Com □ Lance □ Uno □ Ex-hex □

· **Neoss** ▶ Bimodal □ or ProActive □
- **Nobel Biocare** Type ➔

  NobelSpeedy ➔ Replace □ or Groovy □

  Branemark Shorty □

  Branemark Mk III ➔ Groovy □ or Shorty □

  NobelReplace Straight Groovy □ or Tapered Groovy □

  NobelReplace Select Straight □ or Tapered □

  NobelDirect ➔ 3.0 □ or Groovy □ or Oval □ or Posterior □

  NobelActive □

  Surface ➔ machined □ or TiUnite □

- **Southern Dental** □ Type ➔

  Tapered implant □ Parallel implant □ Tri-Nex ➔ Parallel □ or Tapered □

  OCT-X ➔ OCT-XP Parallel □ or OCT-XT Tapered □

- **Straumann** □ Type ➔

  Standard Plus ➔ NN or RN □ or WN □

  Standard ➔ RN □ or WN □

  Tapered effect ➔ RN □ or WN □
Crossfit □→ Narrow (NC) □ or Regular (RC) □

Surface □→ TPS □ or SLA □ or SLActive □

· Other □ → describe ........................................................

1v. Implant diameter (mm).

v. Implant length (mm).

vi. Connection type (describe if known)? ..............................................................

vii. Any other implant identifier/name:
............................................................................................................................

viii. Were any other implants placed at the same time?
............................................................................................................................

2. Surgical information

i. Implant site

ii. Date fixture placed dd / mm / yyyy

iii. Timing of extraction: date of extraction dd / mm / yyyy

or

approximate timing ..............................................................................................
iv. Was socket or ridge preservation described? yes □ describe ................................................................. or no □

v. Surgery type: 1 stage □ or 2 stage □ ➔ date of 2nd stage surgery dd / mm / yyyy

vi. Immediate tooth loading: yes □ or no □

vii. Bone graft (select as many as necessary): yes □ ➔ date of graft if known dd / mm / yyyy

➔ type:

sinus floor elevation □

Block graft □ describe ............... Or no □

bone generation procedure □ ➔ membrane □ or no membrane □

➔ material

Bioss □ Bone ceramic □ Autogenous bone □ Other □ ➔ describe

Other □ describe ........................................................................................................................................

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viii. Soft tissue graft: Soft tissue graft \( \Rightarrow \) yes \( \Rightarrow \) date of graft \( \text{dd / mm / yyyy} \)

or no

ix. Antibiotic use:

yes \( \Rightarrow \) describe..............................................................................................................................

or no

x. Was a complication reported at time of surgery? yes \( \Rightarrow \) how many complications? \( \Rightarrow \) or no

Complication 1

date of complication: \( \text{dd / mm / yyyy} \)

type of complication: .............................................................

how was the complication managed?

.................................................................................................................................

what was the outcome?

.................................................................................................................................

Complication 2

date of complication: \( \text{dd / mm / yyyy} \)

type of complication: .............................................................

how was the complication managed?

.................................................................................................................................
what was the outcome?
........................................................................................................................................

xi. Were later complications reported? yes □ ➔ how many complications? □ □

or no □

Complication 1

date of complication: dd / mm / yyyy

type of complication: ................................................................................................................

how was the complication managed?
........................................................................................................................................

what was the outcome?
........................................................................................................................................

Complication 2

date of complication: dd / mm / yyyy

type of complication: ................................................................................................................

how was the complication managed?
........................................................................................................................................

what was the outcome?
........................................................................................................................................

xii. Was the implant removed/lost: yes □ ➔ removed □ or lost □

➔ date of removal/loss: dd/mm yyyy
or

no

xiii. Was success/osseointegration assessed? Yes □

or not reported □

If yes ➔ date tested dd/mm/yyyy

How was it assessed? (Select as many as necessary):

radiograph □torque test ➔ fixture □or healing abutment □or n.r. □

➔ value in Ncm □ □or not reported □

percussion □resonance frequency analysis (RFA) □

other ➔ describe: ..............................................................

3. Restorative information

i. Implant site/s:

ii. Pontic site/s:

iii. Reason for treatment:

iv. Type of restoration (select one only)

1. Simple:

Single tooth □ or Single tooth cantilever □ or 3-unit (2 implant) bridge □

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Crown type ➔ metal ceramic □ or ceramic □ or gold □

Abutment type ➔ stock □ ➔ describe: .............................................................. or

Cad-Cam □ ➔ metal □ or titanium □ or aluminium oxide □

or 2. Multi-unit □ How many units?

Full arch? yes □ or no □

➔ Was a framework used? yes □ type of framework ➔

a. titanium □ b. high-gold □ c. semi-precious metal □ d. base metal □ e. cobalt
chromium □ f. zirconia □ g. other □

describe: ......................................................

or

no

or not reported □

➔ what was the veneering material? acrylic resin □ ceramic □ metal □

composite type □

or 3. Overdenture □

maxillary □ ➔

How many units?
or

mandibular □

How many units?

□ method of retention □ ball □ or bar □ or locator □

v. Timing of implant loading:

date of implant placement dd/mm/yyyy Loading dd/mm/yyyy

Or approximate timing of implant placement dd/mm/yyyy

or

unknown timing □

vi. Interim restoration?

yes □ partial denture □ or suck-down □ or bonded bridge □ or

no □

vii. Provisional restoration?

yes □ description: .................................................................................. □ how long in function? □ months

or

no □

viii. Definitive restoration insertion date dd/mm/yyyy
ix. Method of restoration retention (select one)

- screw retained [ ]
- cross-pin [ ]
- cement [ ] cement type.................................................................
- not applicable [ ]

x. Was a complication reported? yes [ ] how many complications? [ ] or no [ ]

**Complication 1**

date of complication: dd / mm / yyyy

type of complication: .................................................................

how was the complication managed?

.............................................................................................................

what was the outcome?

.............................................................................................................

.............................................................................................................

**Complication 2**

date of complication: dd / mm / yyyy

type of complication: .................................................................

how was the complication managed?

.............................................................................................................
what was the outcome?

.............................................................................................................

Complication 3

date of complication: \text{dd / mm / yyyy}

type of complication: ..........................................................................................

how was the complication managed?

.............................................................................................................

what was the outcome?

.............................................................................................................
Author/s: Dastaran, Mehrnoosh

Title: A retrospective analysis of grafting and adjunctive procedures performed to facilitate dental implant therapy in private practice

Date: 2016

Persistent Link: http://hdl.handle.net/11343/119569

File Description: A retrospective analysis of grafting and adjunctive procedures performed to facilitate dental implant therapy in private practice

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