Clinical, radiographic and histologic evaluation of a novel alveolar ridge reconstruction approach in post-extraction dehiscence defects: a case series study

Marian Antonious

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CLINICAL, RADIOGRAPHIC AND HISTOLOGIC EVALUATION OF A NOVEL ALVEOLAR RIDGE RECONSTRUCTION APPROACH IN POST-EXTRACTION DEHISCENCE DEFECTS: A CASE SERIES STUDY

by

Marian Antonious

A thesis submitted in partial fulfillment of the requirements for the Master of Science degree in Oral Science in the Graduate College of The University of Iowa

May 2018

Thesis Supervisor: Associate Professor Gustavo Avila-Ortiz
CERTIFICATE OF APPROVAL

MASTER’S THESIS

This is to certify that the Master’s thesis of

Marian Antonious

has been approved by the Examining Committee for the thesis requirement for the Master of Science degree in Oral Science at the May 2018 graduation.

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To my father, Nabil, and my mother, Neven: my best friends. You’ve taught me what it means to have a strong work ethic. Thank you for all that you do for us.

To my brother, Andrew, you have never stopped believing in me. Thank you for continuously inspire me to be the best me.

To my husband, Mina. Your constant support and patience is enabling and you have made our life together the most special thing I have known. Thank you for supporting me during my post-graduate training and in life.
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Many people have helped with or contributed to this project, either directly or indirectly, and they deserve recognition.

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ABSTRACT

Purpose:

The purpose of this case series study was to clinically, radiographically and histologically evaluate the treatment of dehiscence defects in extraction sockets using a minimally-invasive GBR technique that involved the application of a particulate bone allograft and a non-resorbable d-PTFE (Dense polytetrafluoroethylene) membrane.

Methods:

Subjects with single-rooted teeth exhibiting a bone dehiscence defect indicated for extraction and interested in future implant therapy for tooth replacement were recruited based on eligibility criteria. An intraoral scan and a cone-beam computed tomography (CBCT) scan of the arch containing the tooth to be extracted were obtained prior to tooth extraction. Following minimally invasive tooth extraction and debridement, the presence of a dehiscence defect was confirmed. After creating a soft tissue ‘pouch’ using tunneling instruments, a d-PTFE barrier membrane, trimmed to a size and shape that would allow for complete extension over the intact bone surrounding the dehiscence defect, was tucked between the mucosa and the alveolar bone. Then, the extraction sockets were grafted with particulate allograft and sealed with an extension of the membrane, which was stabilized using a cross mattress suture. Subjects were recalled at one, two, five, and twenty week(s) to monitor healing and assess the level of discomfort using a visual analog scale at the end of each visit. At the 5-week visit, the membrane was gently removed and the site was left to heal by secondary intention. At 20 weeks after tooth extraction a second intraoral scan and CBCT scan were obtained to radiographically
evaluate the site for implant placement. Bone volumetric reconstructions of the alveolar ridge at baseline and at 20 weeks were made using the CBCT data to assess changes affecting the bone housing. If the site healed adequately, implant placement was performed at 24 weeks after tooth extraction. At the time of implant placement, a bone core biopsy was obtained in order to histologically analyze the characteristics of the grafted substrate. The ability to achieve implant placement and the need for additional grafting at the time of implant placement were recorded. Subjects returned for the final study visit at 2 weeks following implant placement to evaluate the healing prior to being referred to the restorative dentist.

The main outcomes of interest included the magnitude of volumetric changes of the alveolar ridge, both at a hard and soft tissue level, as measured using the radiographic CBCT and intraoral scan data. Secondary outcomes included the change in buccal and lingual bone height, histologic outcomes, and patient-centered outcomes. One-sample t-tests were performed to assess whether the observed changes in volume and bone heights were significantly different than zero.

**Results:**

At baseline, the average defect height in an apico-coronal dimension as measured clinically was 7.7mm. Linear radiographic measurements revealed an increase in buccal bone height of 4.87mm at 20 weeks following the surgery, indicating that the ridge defects were effectively repaired. Interestingly, the average reduction in ridge volume at 20 weeks was only 1.69% as measured on CBCT scans and 12.15% as measured on the intraoral scans; only the latter, which included the soft tissue component of the alveolar ridge, was found to be statistically significant. All treated sites demonstrated adequate
ridge volume and height at the 20-week follow-up to allow for implant placement at 24 weeks, without need for further site development or delayed implant placement. All implants demonstrated adequate primary stability at the time of implant placement. Although adequate bony housing was present at all of the prepared osteotomies to provide stability, seven of the fourteen sites underwent additional bone grafting at the time of implant placement to increase the thickness of the buccal bone and provide support for a stable soft tissue profile. The histological analysis of bone core biopsies [n=9] revealed the presence of remaining allograft particles that were well integrated with vital bone. Among these samples, an average area of 31.4% mineralized tissue, 17.7% remaining allograft, and 50.9% non-mineralized tissue was measured. Additionally, the procedure employed was very well accepted by patients, with low reported pain that was decreasing over the follow-up period. The highest mean pain reported score using the VAS scale was 19/100 at the 2-week follow-up following the baseline surgery and this decreased and remained low [mean VAS ranging 3.1-7.8] through the remainder of the study. Patients reported a very high satisfaction level at the study’s completion – a mean of 95.1% satisfaction.

**Conclusions:**

The reconstructive technique employed in this study for the treatment of extraction sites exhibiting significant bone dehiscences was highly successful, allowing for the predictable treatment of deficient ridges via implant therapy, and it was well accepted by the participants.
Tooth loss, particularly in the esthetic zone, can severely impact a patient’s quality of life. Even more, following tooth loss, there is a decrease of bone structure that occurs during the remodeling process. When severe, the resulting defects may limit the patient’s replacement options, specifically implant-supported crowns, and may result in an esthetically compromised situation. In those cases, multiple surgical procedures may be indicated to restore function and esthetics.

While these resorptive events occur even in intact sockets, the effects are especially pronounced when there is a large deficiency in the bony walls of the socket. Although there is a large body of evidence in the literature on the treatment and healing of intact sockets, there is a scarcity of evidence on the management and treatment outcomes of compromised sockets, which are even more critical to manage appropriately to achieve desired outcomes.

This study evaluated the clinical, radiographic, histologic, and patient-centered outcomes of a novel treatment approach to manage extraction sockets exhibiting bone deficiencies. A specific goal of this treatment approach was to allow for successful implant placement without the need for a separate bone grafting procedure.

Upon completion of the study it was observed that this procedure indeed allowed for the successful rebuilding of the deficient ridges, optimizing implant placement without the need for a separate bone grafting procedure, saving the study participants time, cost, and reducing potential morbidity. Importantly, the technique was patient-friendly with high reported satisfaction and low reported pain scores.
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BACKGROUND

Tooth loss is commonly associated with an unfavorable impact on quality of life. Speech impairment, reduced mastication efficiency, or esthetic concerns severe enough to compromise social interactions are some of the most relevant consequences of tooth loss. There are various tooth replacement options available, both fixed and removable, to eliminate or reduce the aforementioned problems. However, tooth loss itself may affect the patient’s replacement options as it may induce significant volumetric loss on the surrounding alveolar bone that is required for implant-supported fixed restorations. The loss of a tooth from within its socket causes a loss of the PDL-mediated mechano-stimulation that is responsible for the maintenance of periodontal bone structure (Araujo, Silva et al. 2015). Following tooth extraction, ridge remodeling takes place and, eventually, a reduction in bone volume results. In severe cases, the deficiencies that result from this remodeling process preclude the ability to treat the patient with implant-supported prostheses without multiple surgical interventions that are carefully staged, at the expense of the patient’s psychosocial well-being, time, money, and potential morbidity (Seibert and Salama 1996).

To better understand the effects of tooth loss on the alveolar bone, it is first important to understand the structure and biology of the periodontium that supports the tooth.

Gingiva

Anatomy and definitions

The oral mucosa is a mucous membrane that lines the oral cavity. It can be categorized as either masticatory mucosa – present at the coronal portion of the alveolar process nearest to the crown [the gingiva] and on the hard palate, or as lining mucosa – present apical to the masticatory mucosa, lining the alveolar ridge, floor of the mouth, cheeks, soft palate, and ventral tongue (Lindhe, Karring et al. 2003).

The masticatory mucosa is also termed the keratinized gingiva and its anatomic borders are the mucogingival junction apically and the free gingival margin coronally. The masticatory mucosa, or gingiva, can be further subdivided into the free gingiva and the
attached gingiva. The anatomic borders of the free gingiva include the gingival margin coronally and the free gingival groove apically. The latter has been shown to be present at about one third of sites and to be more clinically discernable at healthy sites: 27% of maxillary teeth and 38% of mandibular permanent teeth showed the presence of this groove, than at inflamed sites: 22% of maxillary and 28% of mandibular teeth with mild inflammation (Ainamo and Loe 1966). The attached gingiva is bordered by the mucogingival junction apically and the free gingival groove coronally (Lindhe, Karring et al. 2003).

The free gingiva is composed of the epithelial and connective tissue structures coronal to the junctional epithelial attachment. It includes the oral epithelium, oral sulcular epithelium, and the junctional epithelium (Lindhe, Karring et al. 2003).

Oral epithelium: The oral epithelium is a keratinized, stratified, squamous epithelium. Ninety percent of the total cell population in the epithelium is comprised of keratin-producing cells (keratinocytes), which can be categorized based on their degree of differentiation. From least differentiated to most, the cell layers include: basal layer or stratum basale, prickle cell layer or stratum spinosum, granular cell layer or stratum granulosum, and keratinized cell layer or stratum corneum. The oral epithelium also contains melanocytes, Langherhans cells, Merkel cells, and inflammatory cells. Melanocytes are pigment producing cells. The melanin production by oral melanocytes is genetically determined and the resulting color of the mucosa is determined by several factors: the number and melanogenic activity of the melanocytes; the population, size and distribution of the melanosomes; type of melanins and masking of the keratinized epithelium; and the vascularization of tissues and level of hemoglobin present in the blood. Physiologic pigmentation is a benign condition of darkened mucosa, which may be patchy or uniform, and is more common in black people and darker skinned whites than in lighter skinned whites. Langerhans cells are immune cells that are antigen presenting cells. Merkel’s cells are involved in sensory function.

The oral sulcular epithelium and the junctional epithelium comprise the dentogingival epithelium. Beneath the epithelium is the connective tissue, lamina propria, which is the predominant tissue component of the gingiva.
The gingival lamina propria forms a papillary body beneath the oral gingival and oral sulcular epithelium. The junction between the oral epithelium and the underlying connective tissue is wavy and consists of connective tissue projects called papillae and epithelial ridges in between, called rete pegs. The lamina propria consists of 5-8% cells, 57-60% connective tissue fibers/fibrous proteins, and 35% residual tissue [ground substance of the intercellular matrix, vascular elements, and nerves]. The main cell type is the fibroblast, which maintains the integrity of the lamina propria by producing connective tissue substances like collagen, proteoglycans and elastin. The fibroblast is also involved in remodeling of the gingiva, through the production of collagenase and collagenase inhibitors. Other cells include mast cells, macrophages and inflammatory cells. The connective tissue fibers will be discussed in a later section, under the dentogingival junction (Schroeder 1986, Lindhe, Karring et al. 2003).

Stippling of the attached gingiva, often referred to as the orange peel appearance, is identified in health and is well developed in areas of high keratinization [Owings, 1969]. Theories of the morphological principles involved in its development include the collagen fibers responsible for the attachment of the gingiva to the alveolar bone exerting a tension to cause visible depressions in the gingiva (Orban 1948, Rosenberg and Massler 1967). Another theory is that the characteristic appearance is due to epithelial rather than connective tissue organization. This second theory states that the stippling is a result of the interdigitation of the epithelial rete pegs (Orban 1948, Karring 1970). Loss of stippling is thought to be a sign of early gingivitis, as it disappears with the advancement of the inflammatory process (Orban 1948). Mild inflammation, however, does not always result in loss of stippling (Ainamo and Loe 1966). While not always detectable in healthy gingiva, its presence does indicate health (Kyllar, Witter et al. 2010)

Dentogingival junction – anatomy and function

The dentogingival junction is an interface between the tooth and gingival tissues around the tooth and is comprised of both epithelial and connective tissue structures. The epithelial structures include the gingival, sulcular and junctional epithelium. The
connective tissue compartment can be divided into the superficial and deep compartments (Nanci and Bosshardt 2006).

The sulcular epithelium is nonkeratinized epithelium that lines the gingival sulcus. Its coronal border is the free gingival margin and its apical border is the junctional epithelium.

The junctional epithelium is the epithelial layer that mediates the adhesion of the gingival tissues to the tooth surface (Hormia, Owaribe et al. 2001). It is nondifferentiated, stratified squamous epithelium and arises from the reduced enamel epithelium as the tooth erupts, forming a collar around the cervical portion of the tooth (Nanci and Bosshardt 2006).

In 1966, Listgarten evaluated the tissues at the dentogingival interface microscopically using en bloc samples of human erupted teeth with intact gingiva attached to the tooth. Samples obtained from 15 patients showed that cementum was sometimes found over the enamel, apical to the epithelial attachment. They also demonstrated that an epithelial attachment was sometimes present to the enamel or to the cementum, and that this attachment was via hemidesmosomes (Listgarten 1966).

In 1976, Kobayashi corroborated these findings with his study on the dento-epithelial junction in Rhesus monkeys. An epithelial attachment could again be observed either to the enamel, to the afibrillar cementum covering the enamel, or to the cementum. In addition, he found that the basal lamina between the junctional epithelium and the tooth included three layers: the upper lamina lucida, the mid lamina densa and the newly defined sub-lamina lucida between the lamina densa and the tooth (Kobayashi, Rose et al. 1976).

The epithelial cells are interposed between the internal extracellular matrix facing the tooth, termed the internal basal lamina [IBL], and the external extracellular matrix facing the connective tissue, termed the external basal lamina [EBL] (Bartold, Walsh et al. 2000). The attachment of the junctional epithelial cells to both the IBL and EBL is via hemidesmosomes – multiprotein adhesion complexes. The IBL is unique from epithelial basement membrane elsewhere in that it lacks type IV collagen and prototypic laminin,
while an epithelium-specific laminin variant called laminin-5 has been found to be a major component of this structure (Bartold, Walsh et al. 2000, Hormia, Owaribe et al. 2001). It has been proposed that the IBL is responsible for providing mechanical strength and for creating a tight seal that protects the periodontal tissues from the oral environment (Bartold, Walsh et al. 2000, Nanci and Bosshardt 2006).

As far as thickness of the junctional epithelium, it is thickest near the sulcus and tapers to just a few cells in thickness apically along the tooth. The cells are flattened and oriented parallel to the tooth (Nanci and Bosshardt 2006).

In comparing the junctional epithelium to the epithelium of the gingiva: more cytoplasm, rough endoplasmic reticulum, and Golgi bodies are present in junctional epithelium, as well as fewer tonofilaments and desmosomes, and wider intercellular spaces. The intercellular spaces are important in that they contain polymorphonuclear leukocytes and monocytes that pass from the connective tissue through the junctional epithelium and into the sulcus [Nanci and Bosshardt 2006]. Mononuclear cells and the molecules they secrete are involved in the first line defense against perpetual microbial challenge (Nanci and Bosshardt 2006).

<table>
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<tr>
<th>Epithelium</th>
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<tr>
<td>Oral epithelium</td>
<td>• Keratinized or parakeratinized [mostly parakeratinized] stratified squamous epithelium</td>
</tr>
<tr>
<td>Sulcular epithelium</td>
<td>• Thin, nonkeratinized stratified squamous epithelium</td>
</tr>
<tr>
<td></td>
<td>• No rete pegs</td>
</tr>
<tr>
<td></td>
<td>• Its depth in normal gingiva is 1.8mm on average and its depth increases in conditions of periodontal disease (Kumar 2011)</td>
</tr>
<tr>
<td>Junctional epithelium</td>
<td>• Collar-like band of stratified squamous nonkeratinizing epithelium</td>
</tr>
<tr>
<td></td>
<td>• Usually 3-4 layers early in life and thickens with age, to 10 or even 20 cell layers</td>
</tr>
<tr>
<td></td>
<td>• The length varies from 0.25-1.35mm</td>
</tr>
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(Carranza 1995)

The interdental papilla

The papilla occupies the interdental space between the teeth and consists of a dense connective tissue covered by oral epithelium. The shape is determined by factors such as
the course of the CEJ, the contact position and width of the proximal tooth surfaces.

Cohen first described the morphology of the interdental papilla [Cohen, 1959]. He noted that it is narrower and takes on a pyramidal shape at anterior sites, with the tip located immediately beneath the contact point. Contrastingly, in posterior sites, it is broader and had been described as having a concave, indented shape.

To determine if the papilla reforms following surgical excision, Kohl and Zander stripped the interproximal tissue on monkeys (Kohl and Zander 1961). They found that the papilla reforms and takes on the same shape by 2 months post-operatively. On the contrary, however, Holmes showed in a clinical study on dental students that an excised interdental papilla does not regenerate completely to its original outline and height. In those papillae not fully regenerated, there was a space ranging 0.5-2mm between the papilla and the interproximal contact point, and in all cases the regenerated papillae did not fill the embrasure space as completely as it had pre-operatively (Holmes 1965).

The connective tissue attachment

The subepithelial connective tissue that supports the junctional epithelium differs from that supporting the gingival epithelium (Nanci and Bosshardt 2006). There is an extensive vascular plexus in the connective tissue supporting the junctional epithelium, with inflammatory cells like PMNs and T-lymphocytes continually present and exiting from this venule network to migrate across the junctional epithelium and into the sulcus and eventually the oral fluid. In addition, the subepithelial connective tissue supporting the gingival epithelium provides signals that allow for progression of the differentiation of the epithelium into stratified squamous epithelium. This signaling seemingly is not present in deeper connective tissues, so the tissue in contact with it does not attain the same differentiation. This point of view helps to support and explain why the junctional epithelium is nonkeratinized, even though both the junctional epithelium and the gingival epithelium are supported by a similar lamina propria. Another theory is that it relates to the constant inflammation present in the connective tissue at the dentogingival junction. Findings from studies on Rhesus monkeys support this idea, in that with the implementation of strict and consistent oral hygiene and antibiotic treatment, the sulcular
epithelium has been shown to keratinize, and this was consistent with clinical evidence of reduced inflammation (Bye, Caffesse et al. 1980, Caffesse, Kornman et al. 1980).

**Principal connective tissue fibers**

The connective tissue fibers are produced by fibroblasts and are referred to as the supra-alveolar fibers. There are 5 principal fiber bundle groups: (Schroeder 1986, Schroeder and Listgarten 1997).

1. Dentogingival fibers originate from the cementum just apical to the cementoenamel junction and then splay out into the free marginal and attached gingiva as 3 relatively well demarcated subgroups.
   a) Subgroup A turns coronally and obliquely into the free gingival margin, where it provides support to the junctional epithelium and the interdental papilla.
   b) Subgroup B courses laterally into the attached gingiva and the apical most segment of the free gingival margin.
   c) Subgroup C turns apically from the cementum near the cementoenamel junction, appearing to sweep down and across the crest of the alveolar bone and into the attached gingiva.

2. Alveologingival fibers go from the periosteum covering the height of the alveolar crest and splay coronally into the substance of the attached gingiva terminating in the free gingiva facially and lingually and in the interdental papilla mesially and distally.

3. Circular fibers are not attached to any calcified structure; they encircle each tooth within the substance of the gingiva near the cervix.

4. Dentoperiosteal fibers are anchored in the cementum near the neck of each tooth, but apical to the dentogingival fibers. They insert into the crest of the alveolar bone and on the lateral aspect of the cortical plate. Some of the dentoperiosteal fibers may also insert into the muscles of the vestibule or the sublingual sulcus.

5. Transeptal fibers are located in the interdental tissue coronal to the crest of the interseptal bone, with their ends inserted into the cervical cementum of the mesial or distal neighbor tooth. These fibers provide support for the interdental gingiva and maintain the integrity of the dentition within the dental arch.
There are also secondary connective tissue fibers which include: periostogingival, interpapillary, transgingival, intercircular, semicircular, and intergingival (Page, Ammons et al. 1974).

**Gingiva - dimensions**

The width of the attached gingiva is variable between and within individuals. Bowers studied the width of the buccal attached gingiva on 160 subjects with normal appearing gingiva and 80 additional subjects with malposed teeth, high frenal attachments, or recession (Bowers 1963). He found that the attached gingiva was greater in the maxilla than in the mandible. In the maxilla, the sites with the greatest width of attached gingiva were the central and lateral incisors, with a decrease in width seen over the canine and first premolar, then a slight increase over the second premolar and molars. In the mandible, the sites with the greatest width of AG were the central and lateral incisors, with a sharp decrease in width at the canine and first premolar, then a slight increase in width over the second premolar, another increase over the first molar, then decreased in the second molar region. This pattern was consistent in his study population regardless of age and sex, though some subjects generally had a wider zone of attached gingiva than others and with increasing age there was an increase in mean widths as well. He also found that in sites with a high frenal attachment or exhibiting recession, the width of attached gingiva was narrower or even absent.

Over a decade later, Voigt and colleagues reported the mean width of lingual attached gingiva in the mandible and found that the width was greatest at the molar sites [4.7mm at the first and second molars], followed by the premolars [2.2-2.5mm], and least at the incisor and canine sites [1.3-1.4mm]. Similar to the findings in the Bowers study, the patterns were consistent between individuals and no sex differences were seen, though the widths did vary between individuals (Voigt, Goran et al. 1978).

**Gingiva – functions**

Keratinized gingiva has been extensively studied regarding the impact of its presence and thickness on the ability to achieve and maintain periodontal and peri-implant health. In a
classic study by Lang and Loe, a strong association was shown between the presence of an adequate band of keratinized gingiva [at least 2mm in apico-coronal width] and attached gingiva [at least 1mm] with periodontal health (Lang and Loe 1972). In a later study by Kennedy et al, however, it was shown that periodontal health can be achieved in sites with less keratinized gingival thickness, so long as there was adequate control of dental plaque (Kennedy, Bird et al. 1985). Wennstrom studied whether these sites were more prone to the development of recession and, again, found that with adequate oral hygiene, these sites did not necessarily develop recession over the 5-year observation period (Wennstrom 1987). Around implants, sites with narrow keratinized gingival thickness were shown to have higher prevalence of inflammation in a cross-sectional study (Bouri, Bissada et al. 2008).

Masticatory mucosa is composed of keratinized epithelium with an underlying layer of compact fibrous tissue, namely lamina propria. The keratinized epithelium has been shown to have distinct resistance to deformation, with multiple rows of cells connected by intercellular adhesions. The lamina propria has a superficial papillary layer and a deeper reticular layer. The papillary layer consists of collagen fibers that are randomly oriented, while the reticular layer consists of an abundance of fibers oriented perpendicularly to the periosteum. These structures comprise the mucoperiosteum, and are responsible for the firm attachment of the oral mucosa to the bone, and the resulting resistance of the masticatory mucosa to compression and shear forces (Chen, Ahmad et al. 2015).

**Dentogingival junction - dimensions**

The soft tissue attachment to the tooth consists of the junctional epithelium and the connective tissue attachment. These structures have been classified, in combination with the sulcular epithelium, as the “biologic width” (Cohen 1962). In a classic study by Gargiulo, 30 human cadavers were used to measure average dimensions of these structures. A total of 325 surfaces on 287 teeth were used to measure: depth of the gingival sulcus, length of the attached epithelium, most apical point of the epithelial attachment from the cemento-enamel junction, distance of the cemento-enamel junction from the alveolar bone, and distance from the most apical point of the epithelial
attachment to the alveolar bone. Specimens were subdivided by phases of passive eruption and it was found that an apical shift of the entire dentogingival junction occurred from stage to stage during passive eruption. When all the specimens were grouped together, 0.69mm was the average measurement for the sulcular epithelium, 0.97mm for the junctional epithelium [found to be the most variable], and 1.07 for the connective tissue attachment [found to be the most constant] (Gargiulo, Wentz et al. 1961). These dimensions were found to vary both between and within individuals, at different sites in the mouth and different tooth surfaces. A similar study was conducted many years later by Vacek et al using 10 cadaver jaws, and similar findings were reported. Specifically, an average measurement of 1.34mm was found for the sulcus depth, 1.14mm was found for the epithelial attachment, and 0.77mm was found for the connective tissue attachment (Vacek, Gher et al. 1994).

A systematic review and meta-analysis by Schmidt et al in 2013 evaluated the reported mean biologic width measurements across studies (Schmidt, Sahrmann et al. 2013). The average biologic width from two meta-analyses [with 6 studies included] ranged from 2.15mm to 2.30mm. Factors that contributed to the large variability included tooth type and site, presence of a subgingival restoration, periodontal diseases or history of surgery. In regards to tooth location, biologic width was found to be smaller at anterior sites as compared to posterior. The mean junctional epithelium ranged from 0.57mm-1.14mm. The meta-analysis revealed that posterior teeth, especially molars, have a greater junctional epithelium dimension than anterior teeth. On average, molar sites had a junctional epithelium of 1.12mm to 1.2mm. In comparison, anterior teeth had an average junctional epithelium dimension of 0.97mm to 0.99mm. Different sites around the tooth also demonstrated varying dimensions. The mesial and distal sites showed a greater thickness of more than 1mm, on average, in the junctional epithelium attachment than buccal and oral sites.

The mean connective tissue attachment ranged 0.77mm to 1.10mm. In contrast to the trend for junctional epithelium, connective tissue attachment means were greater for buccal and oral sites compared to mesial and distal. Buccal and oral sites averaged 1.13mm to 1.31mm in connective tissue attachment, while mesial and distal sites
averaged 0.95mm to 1.05mm. For restored teeth, the average dimension was 0.84mm and for non-restored teeth, 0.76mm.

In regards to variability of these two structures, 2 studies showed greater variability in the connective tissue attachment (Orban 1924, Gargiulo, Wentz et al. 1961), while 1 study showed greater variability in the junctional epithelium measurement (Vacek, Gher et al. 1994).

**Periodontal ligament**

The periodontal ligament is highly vascular and cellular connective tissue that surrounds the roots. In a horizontal dimension, its anatomic borders include the alveolar bone of the socket wall, or the alveolar bone proper, and the root cementum. Coronally, the periodontal ligament is continuous with the lamina propria of the gingiva (Lindhe, Karring et al. 2003).

**Cementum**

Cementum is an avascular mineralized connective tissue that covers the entire root surface, forming the interface between root dentin and the periodontal ligament (Schroeder 1986, Cho and Garant 2000). Cementum can be classified as acellular or cellular, depending on whether cementoblasts are present; intrinsic or extrinsic, depending on whether collagen fibers were formed either by cementoblasts [intrinsic] or fibroblasts and PDL [extrinsic]. Extrinsic cementum becomes incorporated as Sharpey’s fibers within the cementum while intrinsic fibers are unrelated to collagen fibers of the PDL.

Acellular cementum is found at the coronal and middle sections of the root, intermediate cementum exists at the CEJ, and cellular cementum is found at the apical and interradicular sites (Arzate, Zeichner-David et al. 2015).

Coronal cementum had first been found to lack collagen fibrils, and therefore it was termed afribillar cementum as opposed to fibrillar cementum (Listgarten 1968). Shortly later, in a study by Listgarten and Kamin, cellular and fibrillar portions were discovered
in coronal cementum (Listgarten and Kamin 1969), posing difficulty in arriving at a classification system. In 1981, Jones proposed a detailed classification system to include: afibrillar [acellular], extrinsic fiber [acellular], mixed (extrinsic and intrinsic) fiber [acellular, cellular], and intrinsic fiber [cellular] (SJ 1981). Schroeder uses the following classification system (Schroeder 1986):

1) Acellular afibrillar cementum [AAC], found at the coronal level, covering the enamel surface. It is about 1-15 μm in thickness.

2) Acellular extrinsic fiber cementum [AEFC], found on the cervical third of roots and contains densely packed Sharpey’s fibers. It is about 30-230 μm in thickness.

3) Cellular, mixed stratified cementum [CMSC], found primarily in the apical third of the root and furcation areas. It is a coproduct of fibroblasts and cementoblasts and its thickness ranges 100-1000 μm. It is very irregular in its layers and cell distribution.

4) Cellular intrinsic fiber cementum [CIFC], found mostly as a substance filled into the resorption lacunae of the root, and its thickness varies with the depth of this resorption. It contains no collagen fibers. Like CMSC, CIFC is also a coproduct of cementoblasts and fibroblasts.

Cementum is composed of Sharpey’s fibers, collagen, glycosaminoglycans, proteoglycans and inorganic hydroxyapatite (Arzate, Zeichner-David et al. 2015). The functions of cementum include providing functional tooth support and protecting the root dentin, compensating for occlusal wear by lengthening the root, repair functions in cases of root fracture, and may contribute to tooth eruption, by permitting tooth movements (Schroeder 1986).

**Bone**

The alveolar process consists of alveolar bone proper, cortical plates, and spongy bone. Histologically, the alveolar bone consists of osteons of the Haversian system, interstitial lamellae, and bundle bone.

The alveolar bone houses and protects the roots of erupted and functioning teeth, absorbs the occlusal forces during mastication, and undergoes remodeling with tooth formation and eruption – so tooth position and shape affect bone morphology (Schroeder 1986, Cho
and Garant 2000). It also supplies vessels to the periodontal ligament and anchors the roots of teeth to the alveoli via the insertion of Sharpey’s fibers into the alveolar bone (Kumar 2011).

In thickness, the alveolar bone proper is roughly 0.1 to 0.4mm and contains both lamellated and bundle bone (Kumar 2011). It is what forms the alveolar wall of the tooth socket and, because it is perforated by many openings carrying interalveolar nerves and blood vessels to the PDL, its radiographic name is the “cribriform plate,” or the “lamina dura”. The lamina dura was once thought to be denser than the surrounding alveolar bone and therefore more opaque because of that (Shanks SC 1951). Using transverse ground sections across the mandible and microradiography, however, Manson demonstrated that this was not the case (Manson 1963). He found no evidence of a high-density band that would correspond to the lamina dura and that only if the radiograph ray is perpendicular, passing through a greater thickness of bone than the width of the plate, will a radio-opaque line that corresponds to the alveolar bone proper be found radiographically. There are openings in the apical and coronal regions of the alveolar bone proper, called the Volkmann’s canals. These canals, connecting the PDL to the bone marrow spaces, contain blood vessels, lymphatics, and nerve fibers. There are more of these canals present in the crestal third than in the middle and apical thirds of the socket, and more are present towards the posterior of the dental arch (Schroeder 1986, Cho and Garant 2000).

Lamellar bone contains osteons – a blood vessel surrounded by concentric lamellae. Some lamellae are arranged parallel to adjacent marrow spaces while others have Haversian systems.

The bundle bone is the bone that is anchored to the PDL. It is characterized by thin lamellae running parallel to each other and to the root surface as well as Sharpey’s fibers that are continuous with the PDL. Sharpey’s fibers insert into the alveolar bone proper, anchoring the root to the bone (Schroeder 1986, Kumar 2011).

The outer and inner cortical plates outline the alveolar process. The thickness of these plates is greater in the mandible than in the maxilla, and the buccal plate of the mandible is slightly thicker than the lingual plate. Specifically, in the mandible, the buccal plate ranges 1.9mm at the area of the mandibular foramen to 2.9mm at the area of the first and
second molars, on average. The lingual plate in the mandible ranges 1.6mm at the mandibular foramen to 2.4mm at the mental foramen, on average. In anterior regions, the variable thickness in the buccal and lingual plates is dependent on the location of the teeth in the alveolar housing. With increasing age, the porosity of the cortical plates increases due to age-dependent decreases in apposition and increases in resorption. The density of the alveolar bone, on the other hand, slightly increases with age. Externally, the cortical plates are lined by the periosteum, and they consist of osteons and interstitial lamellae (Schroeder 1986).

The spongy bone is positioned in between the alveolar bone proper and the cortical plates. The trabeculae of spongy bone are surrounded by marrow that is rich in adipocytes and pluripotent stem cells. Spongy bone is more highly present in the maxilla than in the mandible and it is mostly present at the interdental and interradicular septae; minimal spongy bone is present at the vestibular and lingual sites, except in the palate. The trabeculae can be arranged either in a regular, ladder-like, horizontal orientation – seen mostly in the mandible, or a various, irregular orientation – seen mostly in the maxilla. The former is referred to as type I and the latter as type II spongy bone (Schroeder 1986, Kumar 2011).

Bone resorption following extraction is highly influenced by bone topography. There is considerable variation among the position of roots within the alveolar housing at anterior sites versus posterior sites in the mouth. Anterior teeth in both the maxilla and the mandible are, to an extent, inclined labially. This commonly results in the following three structural characteristics. The first is juga alveolaria which is a palpable root eminence, commonly found facial to the maxillary canines. The second is that the bony plate tends to be extremely thin covering protruding roots; therefore, there is no cancellous bone between the alveolar bone proper and the cortical plates, but rather a fusion of these structures. Third, there may be a defect in the bony plate, resulting in dehiscences or fenestrations. A dehiscence is defined as an incomplete coverage of a localized area of bone over a root, extending from the alveolar crest in an apical direction. A fenestration is defined as an incomplete coverage of bone over a root, apical to an intact alveolar crest (Schroeder 1986).
Periodontal tissue thickness

The bucco-lingual thickness of periodontal tissues as well as the morphology of the marginal gingiva can be referred to as the periodontal phenotype. Historically, two basic categories have been described: thin and scalloped, or thick and flat. The thin and scalloped biotype has been associated with the following characteristics (Cohen 2009).

Delicate thin periodontium is characterized as follows:

1. Highly scalloped gingival tissue
2. Usually slight gingival recession
3. Highly scalloped osseous contours
4. Underlying dehiscences and/or fenestrations
5. Minimum zones of KG
6. Small incisal contact areas
7. Insult results in recession
8. Triangular anatomic crowns
9. Subtle diminutive convexities in cervical third of the facial surface

On the contrary, the thick and flat biotype has been associated with the following characteristics:

1. Thick periodontium
2. Flat gingival contour
3. Gingival margins usually coronal to the CEJ
4. Thick, flat osseous contour
5. Wide zone of keratinized gingiva
6. Broad apical contact areas
7. Square anatomic crowns
8. Insult results in PD or redundant tissue
9. Bulbous convexities in cervical third of the facial surface

In clinical practice, however, periodontal phenotype is often not clearly dichotomous but rather a subjective classification, as many cases are not clearly one or the other. The biotype has received extensive recognition in the periodontal literature as it has been shown to be a highly influential variable for both the susceptibility of sites to disease

The relationship between tooth form and bone morphology was evaluated in a study by Becker and colleagues in 1997 (Becker, Ochsenbein et al. 1997). Measurements were performed on 111 dry human skulls that were separated into three different groups based on the scallop of the bone’s morphology comparing the interproximal bone height to the buccal bone height: flat, scalloped, and pronounced scallop. The mean distance from the mid-buccal crest to the interdental crest was 2.1mm in the flat group, 2.8mm in the scalloped group and 4.1mm in the pronounced scallop group. However, the investigators were not able to demonstrate a relationship between bone anatomy and tooth shape. The number of buccal dehiscences and fenestrations were also recorded in this study and it was found that the pronounced scallop group had the highest mean number of dehiscences: 1.2, as compared to 0.5 for the flat and scalloped groups, though this difference did not reach statistical significance.

Several studies have reported patterns of the buccal-lingual thickness of the gingiva (Goaslind, Robertson et al. 1977, Olsson, Lindhe et al. 1993, Muller, Schaller et al. 2000). Gingival thickness has been shown to increase from anterior to posterior in mandibular sites, while being more constant in maxillary sites (Goaslind, Robertson et al. 1977). The authors used a novel transformer probe to measure gingival thickness coronal to the sulcus, the free gingival thickness, and at the level of the center of the attached gingiva, the attached gingival thickness. They found that the average thickness of the free gingiva was 1.56mm [ranging 0.53-2.62mm], slightly wider to that of the attached gingiva, at 1.25mm [ranging 0.43-2.29mm]. While gingival thickness was found to vary between subjects, there were some general trends noted. Specifically, the thickness of the gingiva at the base of the sulcus was proportional to the free gingival width, while attached gingival thickness was inversely proportional to the width of attached gingiva. Olsson et al 1993 studied whether crown width to length ratios could help distinguish
gingival morphology and identify biotype. They found that maxillary incisor shape was indeed related with trends in gingival morphology (Olsson, Lindhe et al. 1993). Long, narrow crown form was associated with thin free-gingiva, a narrow zone of keratinized gingiva, shallow probing depths and a pronounced scallop in gingival margin contour [increased gingival angle, and increased papilla height]. While the authors were able to demonstrate that crown form helps to determine marginal soft tissue positions, they were not able to show that biotype was related to the thickness of the gingiva, as the differences between groups were statistically insignificant. A study done by Muller in 2000 aimed to quantify masticatory mucosal thickness at different sites in the mouth. Among the 40 healthy subjects, facial gingiva [measured 1-2mm apical to the gingival margin] among maxillary sites was thinnest over the canine: 0.70mm on average. This was followed by 0.81mm at maxillary second premolars, 0.84mm at maxillary first premolars, 0.86mm at maxillary lateral incisors, 1.00mm at maxillary central incisors, and 1.29mm at maxillary third molars. The thickness at mandibular teeth was smallest in the region of incisors, canines, and 1st premolars, 0.65-0.71mm. Distal mandibular sites had increased average thicknesses: 2.34mm was the average at mandibular third molar sites. Of note, these average values were lower in females [1.69mm overall average compared to 1.91mm] (Muller, Schaller et al. 2000).

The bone topography is the main determining factor of the overlying soft tissue positions. Bone resorption following an extraction directly influences soft tissue contours and esthetics, in addition to providing functional implant support. It is therefore prudent to maintain, or establish, the proper bone foundation to allow for optimum esthetic soft tissue contours to be achieved. This concept is of particular relevance in implant therapy, as the level of the interproximal papilla has been shown to be dependent on the interproximal bone level next to the adjacent tooth (Kan, Rungcharassaeng et al. 2003, Degidi, Nardi et al. 2008).

**Tooth extraction**

To better understand the resorptive process that follows tooth extraction and the extent of its impact, several studies have measured and reported clinical, radiographic, and histologic outcomes following extraction. Socket healing has been extensively studied
since the 1930s. A histologic study using a canine model by Clafin in 1936 provided early information regarding the timeline of healing, and although the rate of healing is faster in dogs than in humans, the sequence of biological events is the same. He found that day 1 following extraction, blood clot formation was evident. This was followed by osteoclast activity noted at day 3 and later bone formation by days 5-7. Complete epithelialization over the socket was noted between days 7-9 and the socket was completely full by the end of the study period, at day 31, though osteoclasts were still evident (Claflin 1936). A longer study period was completed in a similar study which also used a canine model by Cardaropoli and colleagues in 2003. The findings were similar to those reported many decades prior by Clafin. Blood clot formation was again noted at day 1, and this was followed by the formation of a provisional matrix by 7 days. Clear evidence of woven bone formation as noted at 14 days [delayed in comparison to the findings in Clafin’s study] at which time new blood vessel formation was also noted (Cardaropoli, Araujo et al. 2003). At day 30, the socket was completely filled – just as in Clafin’s report, most of which by mineralized bone [88%]. This bone continued to mature and by day 90 it was noted that the previously immature woven bone had become mature lamellar bone. Further maturation continued, and by day 180 there was increased mineralization noted as well as an increased proportion of bone marrow.

In another socket healing study, also in an animal model (mongrel dogs), Araujo and colleagues found new bone formation as early as 7 days, along the apical portion of the socket adjacent to the bundle bone. By day 14, the apical and lateral areas of the socket demonstrated woven bone formation and along the newly formed woven bone, osteoblasts were present. At 28 days, the crestal bundle bone had been completely lost and the crestal lamellar bone was replaced with woven bone. Additionally, there was evidence of osteoclast activity along the outer buccal and lingual walls. By day 56 mineralized tissue consisting of both woven and lamellar bone was evident between the buccal and lingual walls (Araujo and Lindhe 2005).

The question of the severity of dimensional changes that occur during socket healing has been explored by several studies. As previously documented in classic studies, it is well known that there is a significant bone resorptive process that naturally takes place
following tooth extraction (Atwood 1971, Atwood 1979), but recent investigations have
demonstrated that this resorption especially affects the most coronal aspect of the facial
bony plate (Chappuis, Engel et al. 2013, Avila-Ortiz, Rodriguez et al. 2014). This is
partially explained by the naturally thinner facial alveolar bone. A cadaver study by Han
and Jung pointed out a noteworthy difference in facial bone thickness of approximately 2
times thinner respective to the palatal bone at 3 mm apical to the crest in maxillary
anterior teeth (Han and Jung 2011). Aside from dimensional factors, the more
pronounced resorption on the buccal side is also a consequence of the characteristic
biologic and structural properties of the bone at that location. In a preclinical study by
Araujo and coworkers published in 2005, it was shown that the remodeling process
occurs in two phases. The first phase involves rapid remodeling of the alveolar bone
proper, which includes areas of the so-called ‘bundle bone’, which is tooth-dependent
bone that was previously in connection with the root cementum via Sharpey’s fibers. The
second phase is characterized by bone remodeling from the outer surface of both the
buccal and lingual cortical plates, primarily mediated by late osteoclastic action. The very
crestal region of the buccal bone was found to mainly or solely consist of bundle bone.
Thus, as the bundle bone underwent turnover, there was a more pronounced reduction in
crest height on the buccal side (Araujo and Lindhe 2005).

Effectively, the ridge position is transferred to a more lingual or palatal position due to
this preferential bone remodeling pattern at the expense of ingrowth of the soft tissue,
which is more pronounced in the presence of thin phenotypes (Chappuis, Engel et al.
2015).

This presents an important consideration when reviewing the findings in the literature. As
previously mentioned in the anatomy section, the anterior maxilla presents with buccal
bone that is much thinner than that found in the posterior. For this reason, this study will
be limited to anterior sites for increased relevance of its findings.

Several studies have attempted to quantify the extent of bone reduction after tooth
extraction. In a highly referenced study, Schropp and coworkers reported a horizontal
reduction of the alveolar ridge of ∼ 50% following posterior tooth extraction without
further intervention, which corresponds to an estimate loss of about 5 to 7 mm of bone
width (Schropp, Wenzel et al. 2003). Several systematic reviews have corroborated that bone loss following tooth extraction follows a combined horizontal and vertical pattern, affecting the interproximal (mesial and distal), lingual and, particularly, buccal bone height (Van der Weijden, Dell'Acqua et al. 2009, Tan, Wong et al. 2012).

To facilitate implant placement and reduce the need for ancillary site development procedures, the treatment planning process for maintaining or establishing the proper bony support must begin before implant placement, at the time of tooth extraction. In this regard, alveolar ridge preservation via socket grafting/filling (ARP) is a therapeutic alternative that has become a key component of contemporary clinical dentistry. This technique, which emerged in the mid-80s, was rationalized upon the notion that filling the space left by the extracted tooth would emulate a ‘root retention effect’ for alveolar bone volume preservation. However, in light of current evidence it is more likely that the presence of a biomaterial with a resorption rate slower than the blood clot that naturally forms in extraction sockets contributes to slowing down the resorptive physiologic processes. At any rate, several systematic reviews and meta-analyses have consistently shown that ARP is effective in preventing physiologic bone loss after extraction in intact sockets (Vignoletti, Matesanz et al. 2012, Vittorini Orgeas, Clementini et al. 2013, Avila-Ortiz, Elangovan et al. 2014, De Risi, Clementini et al. 2015, Willenbacher, Al-Nawas et al. 2015). Nonetheless, there is little evidence regarding the effectiveness of interceptive ridge reconstruction techniques for the management of sites that present alveolar bone damage at the time of tooth extraction. This is of great clinical relevance, because proper management of sockets presenting dehiscence defects is even more crucial to protect the remaining bone or to build sufficient bone for future implant placement than those extraction sites presenting intact or well-preserved bony walls.

A classic randomized controlled trial examined the clinical and histologic differences between untreated extraction sites versus extraction sites treated with ridge preservation with use of FDBA and collagen membrane (Iasella, Greenwell et al. 2003). The changes in horizontal ridge width, measured at the midpoint of the alveolar crest using calipers, were less than half in the ridge preservation group versus the extraction alone group, about 1.2mm decreased width versus about 2.6mm. The vertical ridge height changes,
measured with the aid of occlusal stents, were about 1.3mm of gain in the ridge preservation group while a loss in height of about 0.9mm was noted in the extraction alone group, amounting to a difference of 2.2mm in height between groups. The amount of vertical gain noted in the ridge preservation group in this study is higher than previously reported – previous studies demonstrated a range of averages amounting to a loss of 0.38mm to a gain in 1.10mm (Lekovic, Kenney et al. 1997, Lekovic, Camargo et al. 1998, Simon, Von Hagen et al. 2000). Histological analysis of bone core biopsies obtained between 4 to 6 months following extraction revealed a similar amount of total bone and trabecular space between the two groups. As can be expected, the ridge preservation group consisted of both vital and non-vital bone, likely residual graft particles. It is also of significance that the ridge preservation group lost some soft tissue thickness – about 0.1mm on the buccal aspect and 0.6mm on the lingual aspect, while the extraction alone group gained about 0.5mm (Iasella, Greenwell et al. 2003). A similar pattern of soft tissue changes has also been demonstrated with the application of GBR using a resorbable membrane in the treatment of alveolar ridge defects (Kirkland, Greenwell et al. 2000). It is important to note that the study discussed above, by Iasella and colleagues, did not specifically examine sockets with defects in the facial bone (Iasella, Greenwell et al. 2003).

**Dehiscence defects**

Oftentimes, teeth that are indicated for extraction present with pre-existing bone loss due to periodontal disease, endodontic disease, pathology, orthodontic treatment, or trauma upon presurgical examination. Additionally, during tooth extraction there is an inevitable potential for mechanical injury, such as buccal plate fracture or damage to the crestal bone during the extraction procedure. To minimize the possibly detrimental effects of the extraction process, several minimally traumatic extraction techniques aiming at preserving the bony housing of the alveolar process have been proposed, such as the use of powered periotomes and piezoelectric instruments (Weiss, Stern et al. 2011). Even still, it has recently been reported that 9.4% of extraction sites showed buccal plate loss, and that an overwhelming 28% of extraction sites showed dehiscence defects immediately post-extraction [compared to only 4% with existing pre-extraction
dehiscences], in spite of having undergone extraction with atraumatic measures (Leblebicioglu, Hegde et al. 2015). Similar findings are reported in a more recent study by Chen and colleagues in 2017 that explored post-extraction dimensional changes among 34 subjects. Post-extraction defects of the buccal bone in the anterior maxilla were found to be very common at 53%, with half of the defects being dehiscence defects and half being fenestrations. Indeed, a relationship was found between non-intact buccal bony plates at the time of extraction and the amount of reduction in ridge width noted 8 weeks following (Chen and Darby 2017).

Due to the structural nature of dehisced sockets, their surgical management generally involves the application of guided bone regeneration (GBR) techniques. GBR is founded on the biologic principle of ‘compartmentalization,’ originally hypothesized by Melcher in the 1970s (Melcher 1976), and subsequent validated in the early guided tissue regeneration (GTR) studies conducted in the early 1980s (Karring, Nyman et al. 1980, Nyman, Lindhe et al. 1982, Gottlow, Nyman et al. 1984, Lindhe, Nyman et al. 1984). The cells to first populate and mature in a periodontal wound were found to determine the type of tissues that occupy the site. Significant differences in the cellular kinetics have been observed between soft tissue cells, like fibroblasts and keratinocytes, and hard tissue cells, like osteocytes. This finding is what led to the birth of the concept of epithelial exclusion by means of a biocompatible barrier membrane. Since then, membranes have been primarily utilized to prevent the ingrowth and division of undesired cells in order to allow time for the desired cells to access the space. This development led to novel possibilities to regenerate not only periodontal defects, including cementum, periodontal ligament, and alveolar bone, but also to treat alveolar ridges presenting insufficient bone volume for the placement of dental implants via GBR (Buser, Bragger et al. 1990, Nyman 1991, Lang, Hammerle et al. 1994, Hammerle and Karring 1998, Hammerle and Jung 2003). Besides wound compartmentalization or cell occlusion, the use of a membrane also facilitates blood clot stabilization and space maintenance, both of which have been noted to be prerequisites for successful guided bone regeneration (Wang and Boyapati 2006).
The application of this concept specifically to dehisced sockets is reported in a recent retrospective pilot study by Tan-Chu and colleagues that included 11 patients. The authors describe the use of the “Ice Cream Cone Flapless Grafting Technique,” involving the insertion of a resorbable collagen membrane shaped like an ice-cream cone into the extraction socket which is then grafted using human freeze-dried bone allograft. Using CBCT data, the bucco-lingual dimensional change of the ridge was found to be a loss of 0.46-2.25mm with a mean loss of 1.28mm. Overall, this study demonstrated the successful treatment of dehisced sockets using this approach. However, the outcomes were limited to linear changes in a bucco-lingual dimension; volumetric changes were not reported. Given the retrospective nature of the study, the bucco-lingual periodontal thickness and the dimensions of the dehiscence defects that were originally encountered were also not reported. These are important considerations that would help to appreciate the technique’s application in various clinical scenarios (Tan-Chu, Tuminelli et al. 2014).

**Material Selection**

Historically, bone grafting procedures have been performed predominantly with the use of autogenous bone grafts. While autogenous bone grafts have beneficial properties such as osteogenesis, they have the main drawback of necessitating an additional surgical site for harvesting. Other grafting materials have in turn been introduced that allow for successful grafting without the risk for the increased morbidity associated with a separate surgical site. Over the years, numerous studies that include the use of a seemingly endless variety of biomaterials (e.g. autologous bone, allografts, xenografts and alloplastic materials) and surgical techniques have been conducted in the field of alveolar ridge preservation (ARP) (Darby, Chen et al. 2009). Many of these studies have tested the efficacy of surgical approaches based on the principles of GBR. Solid evidence has shown that the concomitant use of a barrier membrane in combination with a bone grafting material leads to effective attenuation of bone resorption, a reduced need for bone augmentation at the time of implant placement and an increased likelihood of reaching an esthetic outcome that demonstrates peri-implant health (Iasella, Greenwell et al. 2003, Barone, Orlando et al. 2012, Avila-Ortiz, Elangovan et al. 2014, Koutouzis and Lipton 2016).
In the present study, allograft particles comprised of a combination of demineralized and mineralized freeze-dried allograft with a particle size range of 0.25-1mm [70% FDBA/30% DFDBA] were used. The combination would allow for taking advantage of the beneficial properties of both materials, as DFDBA has been shown to result in greater percentage of vital bone than FDBA (Wood and Mealey 2012), while FDBA has been shown to be more osteoconductive, in areas further from the native bone (Piattelli, Scarano et al. 1996). As well, the large range of particle size will also optimize healing, as the smaller pore sizes will allow for adequate interparticle space for angiogenesis while the larger particle sizes will have slower resorption and thus allow for longer term space maintenance for bone regeneration (Zaner and Yukna 1984).

Also, instead of the absorbable membrane, a fully occlusive, dense polytetrafluoroethylene (dPTFE) membrane was used in the present study. Given that this study involves the treatment of non-intact sockets, using this nonresorbable barrier would more predictably provide adequate epithelial exclusion over the lengthened duration of healing. The dPTFE membrane’s smaller pore size may allow it to more easily withstand its exposure to oral bacteria when left exposed. As primary closure is therefore not necessary, a minimal-invasive tunneling procedure was employed rather than full flap reflection. As well, due to the membrane’s density, fibrous ingrowth is blocked, allowing for easy retrieval without the need for local anesthetic, reducing the trauma associated with the second stage retrieval surgery – which is a significant disadvantage associated with non-absorbable membranes.

The present study evaluated clinical, radiographic, histologic, and patient-centered outcomes following the use of this minimally-invasive GBR technique in the treatment of dehisced sockets. The evidence obtained from this study will provide valuable information that will directly apply to the management of non-intact extraction sockets, a commonly encountered clinical situation that is less explored in the literature than the preservation of intact sockets via socket grafting.
PURPOSE AND OBJECTIVES

Purpose

The purpose of this case series study was to clinically, radiographically and histologically evaluate the treatment of dehiscence defects in extraction sockets using a minimally-invasive GBR technique that involves the application of particulate bone allograft and a non-resorbable dPTFE membrane.

Objectives

Primary

- To evaluate the magnitude of volumetric changes of the alveolar ridge after 5 months of healing following the application of a novel post-extraction ridge reconstruction technique, both at the hard and soft tissue level.

Secondary

- To radiographically measure the magnitude of apico-coronal (mid-facial and mid-lingual height) linear variations of the ridge after 20 weeks of healing.
- To determine the proportion of sites that require additional bone grafting procedures (delayed or simultaneous) to obtain circumferential bone support for implants placed in an ideal prosthetic location after 6 months of healing.
- To analyze the histologic and histomorphometric characteristics of the bone substrate formed after grafting dehisced alveolar sockets with a combination allograft.
- To evaluate patient-related outcomes including the self-reported level of discomfort at different time points following the proposed ridge reconstruction technique as well as overall satisfaction with participation.
MATERIALS AND METHODS

Study Design

This was a prospective case series study conducted at the University of Iowa College of Dentistry Periodontics Clinic in Iowa City, Iowa. The experimental protocol was approved by the University of Iowa Institutional Review Board in January 2017 (IRB approval #201612718). The study was also registered in the National Institutes of Health database for clinical trials, under the clinicaltrials.gov identifier NCT02980211. The study was initiated in March 2017 and is currently ongoing.

Target Population

A total of 18 adult subjects with tooth-bound, single-rooted teeth that were indicated for extraction, and also presented with a dehiscence defect in the bone surrounding the tooth planned for extraction, were recruited.

Inclusion and Exclusion Criteria

Inclusion Criteria

- Provision of informed consent

- Age: 18 years or older

- Subjects with a single-rooted tooth indicated for extraction bounded by stable, natural teeth

- Tooth planned for extraction must have a dehiscence defect in the surrounding bone, observed clinically and/or radiographically, that affects at least one third of the bone height

- Subjects must be interested in replacing the tooth with a single implant-supported fixed restoration

- Subjects must be able and willing to follow instructions related to the study procedures

- Subjects must have read, understood and signed an informed consent form
Exclusion Criteria

- Mandibular incisors

- Subjects with organ failure (e.g. liver, kidney)

- Subjects with severe hematologic disorders, such as hemophilia or leukemia

- Subjects with uncontrolled and/or severe metabolic bone diseases or disorders, such as osteoporosis, thyroid disorders or Paget’s disease

- Subjects taking any medication or supplement known to largely influence bone metabolism, such as IV bisphosphonates, long-term history of oral bisphosphonates or chronic intake of glucocorticoids

- Pregnant women (as indicated by positive serum HCG test) or nursing mothers

- Subjects with conditions that would result in compromised healing (e.g. poorly controlled diabetes, active heavy tobacco use [>10 cigs/day])

- Subjects who, at the discretion of the investigators, would be unsuitable candidates for the study due to safety, psychological or practical reasons (e.g. known allergies to any product used for the study, limited mouth opening, etc.)

Study Visits and Clinical Procedures

The study length per subject was approximately 26 weeks with a total of 8 visits.

VISIT 1: Screening

Subjects in need of extraction of a tooth-bound, single-rooted tooth (with the exception of lower incisors) that presents a dehiscence defect in the surrounding bone and meet the inclusion and none of the exclusion criteria were eligible to participate. Initially, the informed consent was presented to the subject to explain the nature of the study, as well as the potential risks and expected benefits. All screened patients, whether they decided to participate in the study or not, were given a copy of the document for review. For those
subjects interested in participating, medical and dental histories were entered, or updated, in the electronic health record. Then, the investigator conducted a clinical and radiographic evaluation of the site of interest to confirm eligibility. If available, existing periapical radiographs of the site (no older than 6 months) were evaluated, otherwise a new radiograph was obtained for diagnostic purposes. An intraoral scan of the area of interest was obtained using a 3M Tru-definition scanner. An ObtraGate (Ivoclar Vivadent) was inserted into the subject’s mouth to separate the buccal mucosa from the ridge. The site of interest was isolated and dried using an air-water syringe, 3M High resolution scanning spray was applied liberally, and the scan was obtained to include the full dimension of the edentulous alveolar ridge, to the extent of the buccal and lingual vestibules, and the neighboring teeth to allow for subsequent super-imposition of this pre-operative scan and the future scan of the healed ridge. A cone-beam computed tomography (CBCT) scan was obtained and reviewed to prepare for the surgical approach and to assess the existence of dehiscence defects, if not previously confirmed clinically. CBCT scans were obtained using an i-CAT FLX system (Imaging Sciences International Inc., Hatfield, PA, USA). Only the arch that contained the site of interest was scanned to minimize the radiation exposure. Similar to previous investigations, the field of view was approximately 6 cm at 0.3mm voxel size and the exposure factor settings were fixed at 120 kVp and 5 mAs for all scans. Eligible subjects were scheduled for Visit 2 within 10 weeks of the screening visit.

VISIT 2: Tooth Extraction and Ridge Reconstruction (TE)

Medical and dental histories were reviewed and updated, if necessary. Profound local anesthesia at the surgical site was achieved using a local infiltrative technique. Intraoral photographs of the surgical site were obtained. Width of keratinized mucosa on the buccal and thickness of the buccal and lingual mucosa were measured using a UNC-15 probe and an endo condenser or file, respectively. Tooth extraction was completed in a minimally traumatic, flapless, fashion. Following tooth extraction, the existence of the suspected dehiscence defect was confirmed; absence of a defect resulted in subject exclusion from the study and the case was considered an intent-to-treat. Horizontal and vertical dimensions of the alveolar ridge defect were measured using a UNC-15 probe.
After creating a soft tissue ‘pouch’ using tunneling instruments, a non-absorbable dense-PTFE (dPTFE) [Cytoplast TXT-200, Osteogenics Biomedical] barrier membrane, trimmed to the size and shape that would allow for complete extension over the existing defect, was tucked between the mucosa and the alveolar bone. The socket was then grafted using a combination particulate bone allograft [EnCore, Osteogenics Biomedical] and the socket access was sealed with an extension of the dPTFE membrane to ensure complete coverage of the bone graft and the crestal bone. An external cross mattress suture was applied to stabilize the marginal mucosa. Below is an example of one of the cases treated in this study.

Figure 1: Preoperative photos demonstrating a healed submarginal sinus tract on the buccal aspect of #5 (left) and the occlusal view of the ridge with the tooth in place (right).
Figure 2: Periapical radiograph [left] demonstrating a peri-apical radiolucency (rarefying osteitis) consistent with clinical diagnosis of symptomatic apical periodontitis and failed root canal treatment. Right: CBCT coronal slice [right] demonstrating complete absence of the buccal plate.

Figure 3: Baseline clinical measurements of soft tissue thickness at the mid-buccal (left) and mid-palatal (right) using an endodontic explorer with a rubber stopper.

Figure 4: Action-photo of minimally-traumatic extraction using forceps (left) and lateral view of extracted tooth (right).
Figure 5: Baseline clinical measurement of dehiscence defect size in an apico-coronal dimension following tooth extraction.

Figure 6: The dPTFE membrane trimmed to size.
Figure 7: Intraoperative photos of the reconstructive procedure. Top row: occlusal view following minimally-traumatic extraction (left) and placement of the dPTFE membrane into a tunneled pouch created between the buccal flap and the buccal bone (right). Bottom row: graft placement into the socket (left) and membrane secured into the palatal flap and sutured with a cross mattress and a single interrupted suture (right).
Figure 8: Immediate postoperative photo [left] and periapical radiograph [right] demonstrating complete and homogenous distribution of the grafting material.

An intraoral periapical radiograph was taken upon completion of the ridge preservation surgery to verify adequate distribution of the grafting material. Detailed written and verbal post-operative instructions were given to the subject. This included care to avoid mechanical disturbance or excessive pressure of the surgical site and to avoid brushing the area for one week. Chlorhexidine gluconate 0.12% mouthrinse was prescribed and subjects were instructed to gently rinse twice daily over the exposed membrane, thirty seconds at a time, and to avoid any eating or drinking for 30 minutes following rinsing. Systemic antibiotic prescriptions were prescribed for each patient Over-the-counter analgesics (e.g. NSAIDs and Acetaminophen) were recommended for pain-control with instructions to take the analgesics around-the-clock for 48 hours then as needed for pain control. Any adverse events (AEs) were recorded.

VISIT 3: Postop (TE + 1 week ± 2 days)

Medical and dental histories were reviewed and updated, if necessary. Buccal and occlusal photographs of the surgical site were obtained. Sutures were removed, if suitable. Gentle plaque debridement was provided and oral hygiene instructions were reviewed. Visual assessment of the healing status was made using a modified wound healing scale (WHI). See table below.
### Modified Wound Healing Scale (Mod-CHWS)

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Uneventful wound healing with no gingival edema, erythema, suppuration or discomfort</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Uneventful wound healing with slight/moderate gingival edema, erythema, or discomfort, but no suppuration</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Poor wound healing with significant gingival edema, erythema, discomfort, loss of barrier or any suppuration</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Modified Wound Healing Scale.

At each visit, the patient’s current level of discomfort was assessed and recorded by the patient using a visual analog scale (VAS) of 100 points. See below. Any AEs were also recorded.

### DISCOMFORT

<table>
<thead>
<tr>
<th>Less</th>
<th>More</th>
</tr>
</thead>
</table>

Table 2: Visual analog scale for patient-reported discomfort.

VISIT 4: Postop (TE + 2 weeks ± 4 days)

Medical and dental histories were reviewed and updated, if necessary. Buccal and occlusal photographs of the surgical site were obtained. Sutures were removed, if they were still present. Gentle plaque debridement was provided and oral hygiene instructions were reviewed. Visual assessment of the healing status was made using a WHI. Level of discomfort was assessed by the patient using a VAS of 100 points. Any AEs were recorded. Figure 6 shows the aspect of a normally healing site at 1, 2, 5, and 20 weeks postoperatively.

VISIT 5: Postop (TE + 5 weeks ± 7 days)

Medical and dental histories were reviewed and updated, if necessary. Buccal and occlusal photographs of the surgical site were obtained. Visual assessment of the healing
status was made using a WHI. During this visit, the dPTFE membrane was gently retrieved and discarded using tissue forceps. No local anesthesia was required for this step. After membrane removal, the site was swabbed with 0.12% CHX solution and gentle pressure was applied for 1 minute with a sterile cotton gauze. Then, oral hygiene instructions were reviewed and the site was left to heal by secondary intention. Level of discomfort was assessed by the patient using a VAS of 100 points. Any AEs were recorded.

VISIT 6: Follow-up and second CBCT scan (TE + 20 weeks ± 7 days)

Medical and dental histories were reviewed and updated, if necessary. Buccal and occlusal photographs of the surgical site were obtained and any AEs were recorded. Additionally, during this visit, a second intraoral scan and a second intraoral scan and segmental CBCT scan was obtained for all patients, using a similar field of view with the same settings employed at baseline, as detailed above.
Figure 9: Clinical appearance over the follow-up visits. Top row, from left to right: 1 week post-op, 2 week post-op, 5 week post-op. Bottom row: clinical appearance immediately after removal of membrane at 5 weeks (left) and 20 week post-op (right).

VISIT 7: Bone core biopsy and Implant Placement (TE + 24 weeks ± 7 days)

Medical and dental histories were reviewed and updated, if necessary. Buccal and occlusal photographs of the surgical site were obtained. After administration of local anesthesia and exposure of the healed ridge, a trephine drill (2.75 mm diameter) was used to harvest a bone core for histologic analyses. The bone core was immediately submerged in a solution of 10% neutral buffered formalin (NBF). Tactile bone quality type, according to the Misch scale, was evaluated and recorded (see below). Selection of implant system was left to the judgment of the restorative dentist. However, preference was given to Astra EV. Implant site preparation and placement was completed according to the implant system manufacturer’s recommendations. An intraoral periapical radiograph was obtained to assess final implant placement. When a one-stage approach was feasible, a healing abutment was placed. Depending on the buccal soft tissue thickness, ancillary soft tissue augmentation procedures were performed when indicated. When a two-stage procedure was chosen, a cover screw was placed and the implant was submerged. The same postoperative instructions were given as were given following the baseline surgery [Visit 2]. Any AEs were recorded.

<table>
<thead>
<tr>
<th>Tactile Bone Quality Type (Misch Scale)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
</tr>
<tr>
<td>D2</td>
</tr>
<tr>
<td>D3</td>
</tr>
<tr>
<td>D4</td>
</tr>
</tbody>
</table>

Table 3: Tactile Bone Quality Type.
Figure 10: Bone core biopsy and implant placement visit. Top row: pre-operative buccal (left) and occlusal (right) views of healed ridge. Second row, from left to right: alveolar ridge following full thickness flap reflection, occlusal view following removal of bone core biopsy, view of bone core within the trephine. Bottom row, from left to right: implant in place, immediate post-operative view, 2-weeks post-operative view.

VISIT 8 (Final): Postop (Implant Placement + 2 weeks ± 4 days)

Medical and dental histories were reviewed and updated, if necessary. Buccal and occlusal photographs of the surgical site were obtained. Sutures were removed. Dental plaque was gently debrided and oral hygiene instructions were reviewed. Visual assessment of the healing status was made using a WHI. Level of discomfort was assessed by the patient using a VAS of 100 points. As well, level of patient satisfaction was recorded by the patient. See figure below.

<table>
<thead>
<tr>
<th>How satisfied are you after participating in the study?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less......................................................................................More</td>
</tr>
</tbody>
</table>

Figure 11: VAS for patient satisfaction assessed at study completion

Any AEs were recorded and, upon completion of this visit, the patients were referred back to the restorative dentist to complete tooth replacement therapy.

Radiographic Evaluation
A single examiner (EC) performed the digital scan and radiographic evaluations (both 3-dimensional and linear).

Volumetric radiographic measurements:
The CBCT volumetric datasets were exported as Digital Imaging and Communications in Medicine (DICOM) files which were then imported into Simplant 16 Pro by Materialise (Dentsply Implants). With this software, a region of interest (ROI) was selected.
A consistent threshold was used to separate the soft and hard tissue elements in the scans to allow for volumetric analyses to be performed on the alveolar bone and manual segmentation was performed as deemed necessary to obtain an accurate volumetric assessment.

The scan obtained at the baseline visit was viewed side-by-side with the scan taken at 20-weeks. Using adjacent teeth and other landmarks, a ROI was selected for each of the scans. The ROI was confined to the following borders: a horizontal plane at the apical extent of the root tip or guiding landmark at the equivalent location when the tooth was not present (apical boundary), the alveolar crest (coronal boundary), the buccal and palatal plates of the alveolar bone (bucco-lingual boundaries), and vertical planes placed at the location of the interproximal height of contours of the adjacent crowns (mesio-distal boundaries).

A total volume in cubic mm was quantified using the software and used to calculate absolute and percentage loss in volume.
Figure 12: Top: Volume of interest selected on CBCT scan for use in volumetric assessment. Bottom row: buccal view of VOI (left) and occlusal view (right)

Linear radiographic measurements:
The same examiner (EC) also made linear measurements on the CBCT scans using InVivo 5.4 software (Anatomage, Los Angeles, CA). Linear measurements were obtained in a manner similar to that employed for the volumetric measurements, using specific landmarks to ensure that the parameters are measured at a similar location on both scans. On the pre-operative scan, the buccal bone height and lingual bone height were measured as a distance from a determined landmark – the CEJ of the adjacent tooth, for example. The same measurements were made on the post-operative scans.
Figure 13: Linear radiographic measurements performed on orthoradial slices. From left to right: centering the reference line at the level of the adjacent tooth’s CEJ, measurements from this reference line to the buccal and lingual bone crest on the baseline CBCT scan, measurements performed on the 20-week CBCT scan of the healed ridge.

Digital scans
At baseline and at the 20-week follow-up exam, digital dental impressions were made using the True Definition scanner (3M) and exported as stereolithography (STL) files. The scans included neighboring teeth in the sextant and extended to the base of the vestibule.

Volumetric scan measurements on STL files:
The STL files were opened using Meshmixer (Autodesk) where the scanned impression was made into a digital solid for volumetric analysis (performed by the same examiner, EC). Volumetric changes were determined by first superimposing the two digital solids using neighboring teeth as landmarks and then trimming the superimposed digital casts to include only the ROI, and finally opening the trimmed solids in Netfabb (Autodesk) for volumetric calculations.
Figure 14: Screencapture of side-by-side baseline (left) and 20-week (right) scan.

Figure 15: Example of selected volume of interest (VOI) on STL file. Left: Buccal view of baseline VOI (right) and 20-week (left). Right: Occlusal view of baseline VOI (right) and 20-week (left).
**Histomorphometric Analyses**

The bone core biopsies obtained at visit 7, as previously described, were demineralized in HCL solution and processed in routine overnight schedule on tissue processor, which dehydrates the tissue with gradient alcohol and fills it with paraffin. Then the tissue was embedded in paraffin blocks and sectioned longitudinally in a vertical plane to slices of 5 microns in thickness. The samples were mounted onto glass slides and dried overnight, then stained with Hematoxylin and Eosin for analysis under a light microscope (Zeiss Primo Star). Photographs of the slides were taken to capture the entire length of the specimens by examiner GAO. The analysis of these samples was performed on a fixed length (2mm) of the bone at the coronal end, so as to standardize the area to be analyzed among samples of varying lengths. Using ImageJ software, the total areas of remaining allograft and mineralized tissues were quantified based on appearance and expressed as a percentage of the total area. The remaining area in the sample was categorized as non-mineralized tissue. The histomorphometric analyses of all samples were performed by a single examiner (MA).
Figure 16: Example photo of entire bone core biopsy section (left) and cropped portion of the same sample, for use in the ImageJ analysis (right).
STUDY TIMELINE

Figure 17: Graphic of Timeline
## EVENTS SCHEDULE

### Table 4: Summary of Study Events

<table>
<thead>
<tr>
<th>Visit</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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</thead>
<tbody>
<tr>
<td><strong>Visit Description</strong></td>
<td>Screening</td>
<td>Tooth Extraction (Intervention)</td>
<td>Postop</td>
<td>Postop</td>
<td>Postop</td>
<td>Follow-up &amp; 2nd CBCT</td>
<td>Implant Placement (Intervention)</td>
<td>Postop (Final Visit)</td>
</tr>
<tr>
<td>Visit Chronology &amp; Time Window</td>
<td>No more than 10 weeks prior to TE</td>
<td>TE</td>
<td>TE + 1 week (±7 days)</td>
<td>TE + 2 weeks (±14 days)</td>
<td>TE + 5 weeks (±21 days)</td>
<td>TE + 20 weeks (±42 days)</td>
<td>TE + 24 weeks (±84 days)</td>
<td>Implant Placement + 2 weeks (±14 days)</td>
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<td>Informed Consent</td>
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<td>-</td>
<td>-</td>
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<td>CBCT Scan</td>
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<td>-</td>
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<tr>
<td>Periapical Radiograph</td>
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<td>-</td>
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<td>-</td>
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<td>Visual Analog Scale</td>
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<td>-</td>
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<td>X</td>
<td>-</td>
<td>-</td>
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<td>Bone Core Biopsy</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Adverse Events / Adverse Device Effects</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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</tr>
<tr>
<td>Length of Visit (Estimated)</td>
<td>1 to 1.5 hours</td>
<td>1.5 to 2 hours</td>
<td>30 mins</td>
<td>30 mins</td>
<td>30 mins</td>
<td>1 hour</td>
<td>1.5 to 2 hours</td>
<td>30 mins</td>
</tr>
</tbody>
</table>
STATISTICAL ANALYSES

Power Analysis
Given the nature of this study (case series), no formal sample size calculation was conducted. The sample size was selected based on feasibility and clinical relevance.

Data Management and Statistical Methods
Using Statistical Analysis System from IBM (SAS 9.4, Cary, North Carolina, USA), the data was uploaded and descriptive statistics were found to make inferences on the distribution of age, BMI, and other recorded variables. A Shapiro-Wilk test was performed to confirm that the data follows a normal distribution and a false discovery rate was performed to correct for multiple comparisons. Then, a one sample t-test was completed to determine whether the differences in buccal or lingual bone heights and the volumetric changes in the ridge, both at the hard [CBCT] and soft tissue [STL] level, were significantly different than zero. Alpha was set to 0.05.

The amount of residual grafting material, new mineralized tissue and non-mineralized tissue were evaluated on the histologic samples using ImageJ Software (Schneider, Rasband et al. 2012). The results were presented as a percentage of the total area of the section analyzed and were used in a linear model to observe if the dehiscence defect dimensions predicted the histologic outcomes including residual allograft [RA], mineralized tissue [MT], or non-mineralized tissue [NT].
RESULTS

A total of 23 subjects were screened and 21 subjects were enrolled in the study. Four of these subjects were excluded at the baseline surgery visit, lending a total sample size of 17 subjects. The study is currently ongoing with data available on 16 of these subjects through the 20-week follow-up period. Fourteen of the subjects have completed the study and have undergone the bone core biopsy and implant placement visit.

Demographic results

The study sample included 13 males and 4 females who were between 30-71 years of age, with a mean age of 51.8 years. The mean BMI of the participants was 29.23 and ranged between 16.4-49.1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
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</tr>
<tr>
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<td>Female n=4</td>
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<td>Diabetes</td>
<td>Yes n=5</td>
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<tr>
<td></td>
<td>No n=12</td>
</tr>
<tr>
<td>Smoking</td>
<td>Yes n=1</td>
</tr>
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<td></td>
<td>No n=16</td>
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<tr>
<td>Age</td>
<td>Mean 51.82 years</td>
</tr>
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<td>Range 30-71 years</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation 13.61 years</td>
</tr>
<tr>
<td>BMI</td>
<td>Mean 29.23 kg/m^2</td>
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<td></td>
<td>Standard Deviation 8.34 kg/m^2</td>
</tr>
</tbody>
</table>

Table 5: Baseline descriptive statistics for study sample.
<table>
<thead>
<tr>
<th>Ethnicity</th>
<th>Frequency</th>
<th>Percentage</th>
<th>Cumulative Frequency</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>African American</td>
<td>1</td>
<td>5.88</td>
<td>1</td>
<td>5.88</td>
</tr>
<tr>
<td>Caucasian</td>
<td>13</td>
<td>76.47</td>
<td>14</td>
<td>82.35</td>
</tr>
<tr>
<td>Guatemalan</td>
<td>1</td>
<td>5.88</td>
<td>15</td>
<td>88.24</td>
</tr>
<tr>
<td>Hispanic</td>
<td>1</td>
<td>5.88</td>
<td>16</td>
<td>94.12</td>
</tr>
<tr>
<td>Middle eastern</td>
<td>1</td>
<td>5.88</td>
<td>17</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Table 6: Ethnicity of the study participants.

Clinical measurements

More than half of the sites included in this study were maxillary central incisors [n=9/17] and most of the included sites were maxillary teeth [n=15/17].

<table>
<thead>
<tr>
<th>Tooth type</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxillary Central Incisors</td>
<td>9</td>
</tr>
<tr>
<td>Maxillary Lateral Incisors</td>
<td>1</td>
</tr>
<tr>
<td>Maxillary Canines</td>
<td>1</td>
</tr>
<tr>
<td>Maxillary First Premolars</td>
<td>2</td>
</tr>
<tr>
<td>Maxillary Second Premolars</td>
<td>2</td>
</tr>
<tr>
<td>Mandibular Second Premolars</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 7: Tooth types treated.

Probing depths measured at the baseline surgery visit ranged 1-12mm. See table below for site-specific information on probing depths.
Table 8: Baseline probing depths.

All subjects had at least one site of bleeding on probing around the tooth of interest, with the most common site for bleeding being the mid-buccal. See table below for comparison of sites that demonstrated bleeding on probing.

<table>
<thead>
<tr>
<th>Site</th>
<th>BOP positive [n]</th>
<th>Percentage of sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesiobuccal</td>
<td>6</td>
<td>37.5</td>
</tr>
<tr>
<td>Mid-buccal</td>
<td>11</td>
<td>68.75</td>
</tr>
<tr>
<td>Distobuccal</td>
<td>7</td>
<td>43.75</td>
</tr>
<tr>
<td>Distopalatal</td>
<td>9</td>
<td>56.25</td>
</tr>
<tr>
<td>Mid-palatal</td>
<td>5</td>
<td>31.25</td>
</tr>
<tr>
<td>Mesiopalatal</td>
<td>8</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 9: Bleeding on probing by site [n=16].
Mean recession on the buccal aspect of the teeth was 0.56mm and ranged -2-4mm (standard deviation of 1.46mm). At the midpalatal, the mean was -0.31 and ranged -3-1mm (standard deviation of 0.87mm).

<table>
<thead>
<tr>
<th>Site</th>
<th>Minimum (mm)</th>
<th>Maximum (mm)</th>
<th>Mean (mm)</th>
<th>StdDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midbuccal</td>
<td>-2</td>
<td>4</td>
<td>0.56</td>
<td>1.46</td>
</tr>
<tr>
<td>Midpalatal</td>
<td>-3</td>
<td>1</td>
<td>-0.31</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Table 10: Mean baseline recession at midbuccal and midpalatal sites.

All sites demonstrated adequate width of keratinized gingiva at baseline, with a range of 2-12mm and a mean width of 5.03mm. Tissue thickness measured at the mid-buccal aspect, roughly 1mm from the gingival margin was 1.37mm, ranging 1-3mm. At the midpalatal aspect, the mean was 1.74mm, ranging 1-2.5mm.

<table>
<thead>
<tr>
<th>Tissue Thickness at Midbuccal</th>
<th>Mean</th>
<th>1.38 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard Deviation</td>
<td>0.57 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tissue Thickness at Midpalatal</th>
<th>Mean</th>
<th>1.74 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard Deviation</td>
<td>0.46 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Keratinized Gingiva Width</th>
<th>Mean</th>
<th>5.03 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard Deviation</td>
<td>2.29 mm</td>
</tr>
</tbody>
</table>

Table 11: Mean baseline tissue thickness and keratinized gingiva width.

The mean dehiscence defect size in an apico-coronal dimension, as measured clinically, was found to be 7.68mm, with a range of 3-14mm. The mean mesio-distal dimension of the dehiscence was 4.34mm, with a range of 2-8mm.
Dehisence defect size – Apico-coronally [DDS-AC]  
Mean 7.68  
Standard Deviation 4.32  

Dehisence defect size – Mesio-distally [DDS-MD]  
Mean 4.34  
Standard Deviation 1.62  

Table 12: Dimensions of the baseline dehiscence defect, as measured clinically (mm).

A significant difference was noted in the amount of bucco-lingual membrane exposure over time, with a significant increase in the mean value noted at week 5 over the baseline value, an average increase of 0.88mm, p=0.0083.

<table>
<thead>
<tr>
<th></th>
<th>Baseline (mean)</th>
<th>Week 5 (mean)</th>
<th>Difference (P-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ME-BL</td>
<td>5.62</td>
<td>6.5</td>
<td>0.9063 (.0083)</td>
</tr>
<tr>
<td>ME-MD</td>
<td>4.53</td>
<td>4.41</td>
<td>0.0313 (0.4824)</td>
</tr>
</tbody>
</table>

Table 13: Mean membrane exposure at baseline versus at week 5, both buccolingually [ME-BL] and mesiodistally [ME-MD] (mm).

The modified wound-healing index value was measured at each follow-up visit. The value ranged 1-2, with the exception of one site at the 2-week follow-up on a subject who had removed the d-PTFE membrane prior to the visit, reporting that the membrane was bothersome. The mean values are shown in the table below, ranging 1-1.52 and generally decreasing over the follow-up period.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 week</td>
<td>1.53</td>
<td>0.51</td>
</tr>
<tr>
<td>2 weeks</td>
<td>1.19</td>
<td>0.54</td>
</tr>
</tbody>
</table>
Table 14: Modified Wound Healing Index [MHI] measured at follow-up visits.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 weeks</td>
<td>1.12</td>
<td>0.33</td>
</tr>
<tr>
<td>20 weeks</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>2 weeks following implant surgery</td>
<td>1.15</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Linear radiographic outcomes

As measured radiographically on the CBCT scans, the average distance from the neighboring CEJ to the coronal extent of the buccal bone was 8.67mm at baseline; this decreased to 3.8mm at the 20-week period, indicating an average gain of 4.87mm in buccal bone height. This was found to be statistically significantly different than zero using the one sample t-test with a sample size of 16 and an alpha level of 0.05 [p-value = .0002]. On the other hand, the t-test returned a non-significant difference for the lingual bone height change as the mean difference between week 20 and baseline was -0.1413mm, indicating a small loss in lingual bone height, as shown in table 5.

<table>
<thead>
<tr>
<th>Variable</th>
<th>T-Test Mean Difference (SD)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buccal bone height</td>
<td>4.87 (4.3200)</td>
<td>.0002</td>
</tr>
<tr>
<td>Lingual bone height</td>
<td>-0.1413 (1.4653)</td>
<td>0.6474</td>
</tr>
</tbody>
</table>

Table 15: Change in buccal and lingual bone heights, respectively, from baseline to week 20 as evaluated on CBCT scans.

Because of the large standard deviation of linear bone changes, the defects were grouped by severity to explore the relationship between initial defect severity and bone height changes. The sockets were grouped according to the classification system by Chu and
colleagues in 2015 which involve a subclassification of an earlier system proposed by Elian and colleagues (Elian, Cho et al. 2007, Chu, Sarnachiaro et al. 2015). According to this system, a Type 1 socket has an intact labial bone plate and soft tissues whereas Type 2 sockets have a dehiscence defect in the labial bone plate and Type 3 have both a loss of hard [dehiscence defect] and soft tissues [mucogingival recession]. Type 2 defects are then subclassified based on the apico-coronal extent of the dehiscence defect. Type 2A includes a defect that involves the coronal one-third of labial bone plate, 5-6mm from the free gingival margin; Type 2B involves the middle to coronal two-thirds, about 7-9mm from the free gingival margin; and Type 2C involves the apical one-third, about 10mm or more from the free gingival margin. Accordingly, 5 of the sites treated in this study can be classified as Type 2A, 6 as Type 2B and 6 as Type 2C. Indeed, the morphologic characteristics of the socket, as classified by this system, appear to have a significant effect on the change in buccal bone height. Sockets having greater dehiscence defect heights exhibited greater gain in buccal bone height. Specifically, those in subclass C had an average of 7.82mm more gain in buccal bone height than those in subclass A (p-value <0.0001) and 5.3mm more than those in subclass B (p-value=0.0096).

<table>
<thead>
<tr>
<th>Subclassification Comparison</th>
<th>Estimate difference</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (n=7) vs B (n=2)</td>
<td>5.3321</td>
<td>0.0096</td>
</tr>
<tr>
<td>A vs C (n=7)</td>
<td>7.8186</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>B vs C</td>
<td>2.4864</td>
<td>.1806</td>
</tr>
</tbody>
</table>

Table 16: Relationship between socket classification and change in buccal bone height.

**Volumetric outcomes [radiographic and intraoral scan data]**

An average loss in ridge volume using the CBCT scan was 1.69% and the loss in volume using the intraoral scan, which included the soft tissue component of the ridge, was 12.15%. Only the latter was found to be statistically significantly different than zero with a p-value of 0.0032 as shown in table 12.
Linear regression models were performed to determine whether a relationship existed between soft tissue thickness, either at the mid-buccal or mid-palatal and volumetric changes. No significant relationships were found.

<table>
<thead>
<tr>
<th>Covariate</th>
<th>Outcome</th>
<th>Mid-buccal tissue thickness</th>
<th>Mid-palatal tissue thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent change in volume using STL data</td>
<td>0.08889 (p-value = 0.1515)</td>
<td>0.05604 (p-value = 0.4844)</td>
<td></td>
</tr>
<tr>
<td>Percent change in volume using CBCT data</td>
<td>-0.00675 (p-value = 0.9294)</td>
<td>-0.09826 (p-value = 0.2970)</td>
<td></td>
</tr>
</tbody>
</table>

Table 19: Linear Regression models with the covariate estimates and the p-value for the test to see if the estimates are significantly different than zero.

At the time of the bone core biopsy and implant placement visit, the subjective assessment of bone quality was determined by the same examiner performing the interventional surgeries (MA). Most sites had bone densities between D1-D3, while only one site demonstrated a poorer bone density that can be categorized as D4.
<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>3</td>
<td>21.43</td>
</tr>
<tr>
<td>D2</td>
<td>7</td>
<td>50</td>
</tr>
<tr>
<td>D3</td>
<td>3</td>
<td>21.43</td>
</tr>
<tr>
<td>D4</td>
<td>1</td>
<td>7.14</td>
</tr>
</tbody>
</table>

Table 20: Tactile bone quality assessment using the Misch scale at the time of implant placement (n=14).

While half of the treated sites required additional bone grafting at the time of implant placement (n=7/14), all sites successfully underwent implant placement with adequate primary stability.

**Histologic outcomes**

Bone core biopsies were obtained on all subjects at 24 weeks during the time of implant placement. However, 5 of the 14 obtained samples were not analyzable due to insufficient size or incoherence of the sample. This lent a sample size of 9 for histologic analysis. Using the ImageJ software, a mean mineralized tissue area of 31.4%, residual allograft area of 17.7% and non-mineralized tissue area of 50.9% were calculated based on appearance, by the same examiner (MA). A model was performed to determine whether a relationship existed between these histologic outcomes and baseline dehiscence defect dimensions. This found no significant differences for the mesio-distal dimension of the dehiscence nor for the apico-coronal dimension, as shown in Table 8.

<table>
<thead>
<tr>
<th>Histologic outcome (Mean, SD)</th>
<th>DDS M-D (P-value)</th>
<th>DDS A-C (P-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual Allograft (17.731, 12.135)</td>
<td>0.3232(0.9140)</td>
<td>-0.2498 (0.8309)</td>
</tr>
<tr>
<td>Mineralized Tissue (31.403, 14.107)</td>
<td>-3.007(0.3807)</td>
<td>-0.3816(0.7788)</td>
</tr>
<tr>
<td>Non-mineralized Tissue (50.866, 8.674)</td>
<td>2.6795(0.1878)</td>
<td>0.6314(0.4407)</td>
</tr>
</tbody>
</table>

Table 21: The estimates (p-value) for the Dehiscence defect dimensions [DDS] both mesio-distally, M-D, and apico-coronally, A-C, modeled for the Histologic outcomes.
**Patient-centered outcomes**

Average pain scores remained relatively low and decreased over the follow-up following the baseline surgery, as shown in Table 10. The highest reported pain was following the extraction and ridge reconstruction visit, mean VAS of 19.06. Following this visit, and even following the implant surgery visit, the mean reported pain scores remained very low, ranging 3.12-19.06.

<table>
<thead>
<tr>
<th>Time Point</th>
<th>N</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 week</td>
<td>16</td>
<td>19.06</td>
<td>21.85</td>
<td>0</td>
<td>66.5</td>
</tr>
<tr>
<td>2 weeks</td>
<td>16</td>
<td>6.39</td>
<td>12.91</td>
<td>0</td>
<td>46.9</td>
</tr>
<tr>
<td>5 weeks</td>
<td>15</td>
<td>7.82</td>
<td>16.37</td>
<td>0</td>
<td>48.1</td>
</tr>
<tr>
<td>20 weeks</td>
<td>16</td>
<td>3.12</td>
<td>10.47</td>
<td>0</td>
<td>42.2</td>
</tr>
<tr>
<td>2 weeks following implant surgery</td>
<td>13</td>
<td>6.20</td>
<td>11.96</td>
<td>0</td>
<td>43.4</td>
</tr>
</tbody>
</table>

Table 22: Post-operative patient-reported discomfort score, measured using the VAS, at the follow-up appointments.

Patients were generally very satisfied with their participation in the study. An average patient-reported satisfaction level of 95.1% was recorded at the study’s termination.

<table>
<thead>
<tr>
<th>N</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>95.12</td>
<td>7.12</td>
<td>77.2</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 23: Patient satisfaction as measured by VAS [1-100].
DISCUSSION

This study aimed to assess the linear, volumetric, histomorphometric, and patient-centered outcomes following a minimally-invasive ridge reconstruction technique performed on non-intact sockets with buccal plate dehiscences. A total of 17 subjects were recruited and treated. The study is currently ongoing and near its completion. Overall, the technique employed demonstrated favorable results in each of the assessments performed.

The patients who were excluded at the baseline visit were originally enrolled on an intent-to-treat basis and were excluded when the presence of a dehiscence defect could not be confirmed clinically. As an example, one common etiology for dehiscence defects is a vertical root fracture; this condition can be challenging to diagnose clinically and radiographically with noninvasive measures and flap reflection is sometimes necessary to enable accurate diagnosis via direct visualization (Walton 2017).

The participants included subjects with controlled diabetes [n=4], prediabetes [n=1], and one smoker who reported smoking <10 cigarettes per day. This study may have benefited from stricter exclusion criteria as well as objective assessments of health rather than patient-reported data, as this form of data collections has its limitations. However, the inclusion and exclusion criteria were established, in part, for feasibility so that an adequate number of subjects may be recruited given that a very specific clinical scenario qualified for study inclusion.

Most of the sites that were included in the study were maxillary teeth, and many of these were maxillary central incisors. This is not surprising as these sites are more likely to match the study’s inclusion criteria. Post-extraction dehiscence defects have been found to be fairly common in the anterior maxilla, with a reported prevalence of 26.5% (Chen and Darby 2017). Being that most included teeth were maxillary, which have been demonstrated to have the greatest width of attached gingiva (Bowers 1963), it is not surprising that the average keratinized gingival width was 5.03mm and that all treated sites had adequate widths of keratinized gingiva of 2mm or greater. This is important as keratinized gingiva width has been shown to be protective against inflammation, especially around implants (Lang and Loe 1972, Bouri, Bissada et al. 2008).
The average baseline buccal-lingual tissue thickness was 1.37mm at the mid-buccal and 1.74mm at the mid-palatal. A large number of maxillary anterior teeth were included, which have been described to have the second greatest buccal-lingual tissue thickness, second only to maxillary third molars (Muller, Schaller et al. 2000). However, while the tissue thickness averages reported in this study are in line with previously reported averages (Goaslind, Robertson et al. 1977, Muller, Schaller et al. 2000), the mean thickness of the buccal tissue would still fall under the thin tissue biotype category, as described by Claffey and Shanley, as it is less than 1.5mm (Claffey and Shanley 1986).

Only four of the seventeen study sites could be categorized as thick, having a midbuccal tissue thickness of 2mm or greater. This is important to note as it has been well-documented that thicker tissues are associated with superior outcomes in soft and hard tissue grafting procedures around teeth (Anderegg, Metzler et al. 1995, Baldi, Pini-Prato et al. 1999, Chambrone and Tatakos 2015). Interestingly, however, volumetric changes in this study were not found to relate to initial tissue thickness, neither at the mid-buccal nor the mid-palatal. Though it is expected that greater baseline tissue thickness would be associated with greater maintenance in ridge volume, it is not surprising that no difference was detected given the study’s small sample size and the often-minute differences in tissue thicknesses between samples. Larger studies are needed to detect and establish such a relationship.

The apico-coronal dimension of the dehiscence defects treated in this study ranged 3-18mm, with an average defect height of 7.68mm. The defects were grouped by severity into Type 2A [n=7], Type 2B [n=2] and Type 2C [n=7], according to the system described by Chu and colleagues in 2015 (Elian, Cho et al. 2007, Chu, Sarnachiaro et al. 2015). Although developed to help in the decision-making when considering immediate implant placement, this classification system was employed in this study to aid in identifying patterns in the outcomes. It is important to note that the radiographic measurements used to classify the treatment sites involved a measurement from the adjacent CEJ to the bone plate, while the classification system is based on a distance from the gingival margin to the bone crest. Still, both respective distances adequately reflect defect severity. Indeed, when the sites treated in this study were grouped by this classification, it became evident that those sites with greater severity demonstrated
significantly greater gain in buccal bone height. This finding is to be expected as those defects with greater apico-coronal severity had a greater tenting effect produced by the membrane and had greater potential for bone regeneration. One technicality that is also worth mention, is that those defects that were larger in dimension were more amenable to overbuilding in a bucco-lingual dimension with an intrasocket approach. In accordance with the methodology, no attempt was made to overbuild any site with an extrasocket approach; thus, the larger defects may have had an advantage over the smaller defects with respect to the amount of bone grafting achievable. These findings highlight the importance of defect characteristics and morphology for bone regenerative capacity.

The increased membrane exposure noted over time may indicate that the membrane was not biocompatible with the soft tissues, resulting in a migration of the tissues away from the membrane. While histologic evidence of biocompatibility has been demonstrated in rats with a closed surgical technique (Monteiro, Macedo et al. 2010), it may be that because primary closure was not achieved nor intended in this study, that the exposure to the oral environment played a role in allowing bacterial accumulation particularly in those patients who were less compliant with oral hygiene measures, resulting in subsequent inflammation and tissue retraction over time. These findings imply that careful trimming of this membrane is important to avoid overextension and resulting recession. While increased membrane exposure was noted, most patients in this study maintained adequate oral hygiene and displayed minimal inflammation, as evidenced by the low modified wound healing indices recorded at follow-up visits.

Based on measurements obtained from the CBCT scans, an average gain in buccal bone height of 4.87mm and an average loss in lingual bone height of 0.1413mm was noted in this study, with only the gain in buccal bone height being statistically significant. These outcomes are very encouraging and validate the technique’s success in both reconstructing the deficient buccal bony plates and maintaining ridge height at the non-deficient lingual aspect of the socket. Systematic reviews evaluating the average loss in alveolar ridge height following alveolar ridge preservation report means ranging 0.96-2.07 (Vignoletti, Matesanz et al. 2012, Vittorini Orgeas, Clementini et al. 2013, Avila-Ortiz, Elangovan et al. 2014). The outcomes of these systematic reviews, however, have
limited application to this study as the included outcomes were not specific to non-intact sockets. As well, study heterogeneity should be considered as the studies employed a variety of techniques [flap, flapless, primary closure verses open] using a variety of materials and combinations of materials [bone graft alone or in combination with a membrane, membrane alone, different types of membranes and bone grafts, etc.] on both molar and non-molar sites. A recently published study on ridge augmentation of compromised sockets with buccal bone deficiencies similarly reported a significant average gain of 2.5mm in buccal bone height and minimal changes to lingual bone height (Aimetti, Manavella et al. 2018). Note, however, that this study was performed on subjects with periodontitis and the follow-up time was 1 year, as compared to 5 months in this study. As well, the researchers employed a slightly different technique that involved the use of different materials, including a resorbable collagen membrane secured with tacking screws and bovine bone graft. Overall, however, it may be concluded that the vertical linear outcomes in this study compare very favorably to the outcomes reported in the literature.

A similar study was published recently that reports buccolingual ridge changes after employing a very similar technique using similar biomaterials on sockets with buccal bone deficiencies. The technique was found to be successful in achieving reconstruction of the buccal plate and minimizing buccolingual ridge resorption. They report an average horizontal crestal ridge reduction of only 0.19mm as measured surgically, from the inner aspect of the reflected buccal flap to the inner aspect of the palatal flap (Luongo, Bianco et al. 2017). These findings support the use of this technique in similarly deficient sockets. Note, however, that radiographic buccolingual ridge width measurements could not accurately be performed in our study given the characteristic absence of the buccal plate in the sites treated, hence their absence in this study’s conducted measurements. Future studies conducting linear radiographic measurements on similarly deficient sockets may consider obtaining baseline CBCT scans immediately following tooth extraction, if feasible.

The volumetric changes observed in this study also compare favorably to published outcomes, though limited data on this assessment is available in the literature. The treated
sites demonstrated very minimal loss in bone volume, a mean of 1.7% loss, as measured on the CBCT scans. In comparison, the study previously quoted by Aimetti and colleagues reported an average 9.14% reduction in bone volume. A limitation to the volumetric measurements performed on the CBCT scans in this study, however, was that there were minor positional variations in the subjects’ orientation at the time the two scans were taken. Albeit minor, these differences may have affected the measurement’s precision.

Using the volumetric measurements performed on the STL files, which included both hard and soft tissue components, a mean 12.1% loss in volume was noted. Note that a portion of this change is owed to the presence of interproximal papillae on the initial scans when the tooth was present, and their absence on the scans performed at 20 weeks. Another explanation for the higher magnitude of change observed in comparison to the CBCT data may be that many of the treated sites required sharp dissection of the soft tissues associated with the defects to remove inflammatory granulation tissue present in the resorptive lesions. Thus, there was a resulting decrease in soft tissue volume, and this decreased volume occurred after the baseline intraoral scan and CBCT scan had already been collected, potentially resulting in an underestimation of the effectiveness of the treatment when evaluating the intraoral scan data. One of the strengths of this study which enabled such a distinction, is that volumetric assessments were performed both on the hard tissues alone via the CBCT scan data, and on the combined hard and soft tissue ridge via the intraoral scan data. However, because the pre-operative scans involved manual removal of the tooth’s crown prior to the measurement of the pre-operative ridge volume, some degree of estimation, and therefore human error, may have led to minor discrepancies in the accuracy of the pre-operative volume render.

The use of the nonresorbable dPTFE membrane, which maintains its structural integrity, likely played an integral role on the successful outcomes observed. Though some evidence on ridge preservation of intact sockets indicates that there is no difference in outcomes with the use of nonresorbable PTFE membranes versus resorbable collagen membranes (Arbab, Greenwell et al. 2016), the use of a nonresorbable membrane
becomes arguably significantly more impactful in the case of nonintact sockets, as long-term space maintenance is more critical in these cases.

In the 24-week histomorphometric analysis, an average mineralized tissue area of 31.4%, residual allograft area of 17.7% and non-mineralized tissue area of 50.9% were found. These results are similar to previous ridge preservation studies (Borg and Mealey 2014, Arbab, Greenwell et al. 2016). Because no significant relationship was observed between defect severity and histologic outcomes, it can be supposed that the healing time was likely sufficient for adequate bone regeneration in even those sites presenting with large deficiencies.

Patient-related outcomes included subjective pain assessment and satisfaction. The VAS scores for pain remained relatively low throughout the procedure, with the highest reported score being 19.06%, 1 week following the baseline surgical procedure. Patient satisfaction was 95% at the study’s completion. While subjective, these assessments may reflect the minimally invasiveness of the technique employed as well as its effectiveness in permitting implant placement without need for the patient to undergo an additional surgery.

Arguably the most clinically relevant finding in this study is that all sites underwent successful implant placement without need for site development procedures and all implants demonstrated adequate primary stability in mostly types 2-4 bone [13/14 sites], as described by Carl Misch (Misch 1990).

In conclusion, the procedure employed was both effective and predictable in rebuilding ridge deformities, preserving ridge volume, and optimizing future implant placement while being patient-friendly, with low reported post-operative pain scores and very high patient satisfaction. Future studies should include larger sample sizes, involve only objective assessments for eligibility criteria, and evaluate esthetic outcomes including gingival recession and papilla indices following the application of this treatment technique.
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