PERIODONTAL REGENERATION OF MOLARS WITH FURCATION DEFECTS UTILIZING A VIDEOSCOPE-ASSISTED MINIMALLY INVASIVE SURGICAL APPROACH

A Thesis

by

JOHN CLAYTON TUNNELL

Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Chair of Committee,	Harvey P. Kessler
Co-Chair of Committee,	David G. Kerns
Committee Member,	Jeffrey A. Rossmann
Head of Department,	Larry L. Bellinger

May 2016

Major Subject: Oral Biology

ABSTRACT

The aim of the current prospective, outcomes-based case series was to evaluate the potential of videoscope-assisted minimally invasive surgery (V-MIS) in the regenerative treatment of maxillary and mandibular molars with Degree II furcation involvement. Fifteen consecutively treated patients providing 12 interproximal maxillary and 3 buccal or lingual mandibular sites were included in the study. Treatment consisted of V-MIS in conjunction with 24% ethylenediaminetetraacetic acid (EDTA) for root biomodification, enamel matrix derivative (EMD) and bone grafting with cortical demineralized freeze-dried bone allograft (DFDBA). Final measurements were made 6 months post-operatively. Overall results revealed statistically significant mean improvements in probing depth of 2.667 ± 2.067 mm, clinical attachment level of 2.167 ± 2.209 mm, and vertical probing depth of the furcation as measured via bone sounding of 0.967 ± 1.494 mm. No statistically significant mean changes in the soft tissue parameters of gingival recession and papilla height and width were noted. The results of this study demonstrate that V-MIS and combination grafting with DFDBA and EMD may result in clinically and statistically significant improvements in probing depth, clinical attachment level, and vertical probing depth of the furcation with non-statistically significant changes in gingival recession and papilla height and width in the treatment of maxillary and mandibular Degree II furcation defects. Furthermore, these improvements may result in a statistically significant improvement in prognosis as determined by the Miller-McEntire Score.

DEDICATION

To my wife, Jade, and our son, Clayton

ACKNOWLEDGEMENTS

I would like to thank Stephen Harrel, David Kerns, Jeffrey Rossmann, and Harvey Kessler for their mentorship during this process. I would also like to thank Eric Solomon for providing statistical support, William Wathen for his aid with patient recruitment, Janet Vielma for her help in scheduling of patients, and Angela Lee-Noles for her assistance during the study. Finally, I would like to thank my family for their support through out this process. Without their help, this work would not be possible.

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CHAPTER I

INTRODUCTION AND REVIEW OF THE LITERATURE

Periodontitis is an inflammatory condition affecting the supporting structures of the teeth. It is usually a progressive process beginning with gingival inflammation that extends into underlying structures, resulting in destruction of the alveolar bone and periodontal ligament. Untreated and unaltered periodontal disease in molars often results in loss of periodontal support, thereby exposing the area in which the roots diverge from the crown, known as the furcation. This results in the development of a furcation invasion defect, defined as the pathologic resorption of bone within a furcation (AAP, 2001). These defects have been associated with a deteriorating prognosis and, without treatment, may result in ultimate loss of the involved tooth (Miller et al., 2014, Hirschfeld and Wasserman, 1978, Becker et al., 1984, McFall, 1982). However, while negatively affecting the prognoses of these teeth, several studies have shown that molars with furcation defects can be effectively treated and survive in health for a number of years (Miller et al., 2014, Salvi et al., 2014, Becker et al., 1984).

While various classification systems designate the severity of a furcation defect, it is generally agreed upon that the more severe the defect, the worse the prognosis. Generally, these classification systems are designed to provide some prognostic value to a furcation defect and to aid the clinician in determining an appropriate course of treatment. Glickman and Hamp, Nyman, and Lindhe developed two of the most popular classification systems for furcation defects. In Glickman's system, Grade I defects involve only the fluting of the furcation, Grade II defects have distinct horizontal destruction resulting in a "cul de sac" extending to any depth within the furcation without through and through involvement, Grade III defects have destruction extending all the way through the furcation that are not visible due to gingival coverage, and Grade IV defects have destruction visible to the eye that extends all the way through the furcation (Glickman, 1958). Later, Hamp *et al* characterized furcation defects using quantifiable measurements to describe the degree of destruction. They defined Degree I defects as horizontal loss of periodontal tissue support less than 3 mm, Degree II defects as horizontal loss of support exceeding 3 mm but not encompassing the total width of the furcation, and Degree III defects as horizontal "through and through" destruction of the periodontal tissue in the furcation area (Hamp et al., 1975). While Hamp *et al* described the severity of furcation defects using "Degree", other authors using their classification system since publication of the original report commonly substitute the word "Class" for "Degree" and use the two phrases interchangeably.

Since these two systems classified furcation defects on the basis of horizontal attachment loss, Tarnow & Fletcher created a subclassification system measuring vertical bone loss from the roof of the furcation to the apical extent of the bony crest. In their system, Subclass A designates 0 to 3 mm of vertical probing depth, subclass B designates 4 to 6 mm of vertical probing depth, and subclass C designates 7 mm or greater of probable vertical bone loss (Tarnow and Fletcher, 1984). Thus, Tarnow &

Fletcher's system could be used in conjunction with Glickman or Hamp's classification system to describe both the horizontal and vertical component of a furcation defect.

As previously stated, furcation involvement in molars with a current or past history of periodontal disease is a relatively common finding. To describe the frequency and nature of furcation involvements in maxillary and mandibular teeth, Thompson & Ross examined 615 molars in 72 patients with generalized chronic periodontitis both clinically and radiographically for evidence of furcation involvement. Ninety percent of the 303 maxillary molars had clinically or radiographically detectable furcation involvement while 35% of the 312 mandibular molars had furcation involvement. Of the maxillary molars with furcation involvement, these defects were detected 65% of the time with both clinical and radiographic examination, while 22% were detected only by radiographic exam and 3% were detected by clinical exam only. Of the mandibular molars with furcation involvement, these defects were detected 18% of the time by both clinical and radiographic exam while 8% were detected by radiographic exam only and 9% were detected by clinical exam only (Ross and Thompson, 1980). This study highlights three important concepts. First, furcation involvement seems to be more common in maxillary molars than mandibular molars. Second, furcation involvement is indeed a frequent occurrence in patients with periodontal disease, and third, these defects are relatively difficult to detect by clinical and/or radiographic means.

With these findings and observations in mind, several clinicians attempted to increase the reliability of clinical detection of furcation defects. Mealey *et al* examined 102 teeth with 274 furcations in 67 patients requiring surgery for moderate to advanced periodontitis at three time points: before administration of local anesthetic, after administration of anesthetic using bone sounding and after surgical debridement. Measurements of the furcation defects were made with a straight UNC-15 probe and a curved Nabers probe. Generally, the authors found that pre-anesthesia measurements significantly underestimated the depth of the furcation whereas post-anesthesia bone sounding proved to be significantly closer to measurements obtained after surgical debridement (Mealey et al., 1994). The authors stated that bone sounding was a reliable way to determine furcation defect severity prior to surgical access.

Other studies attempted to further characterize the difficulty encountered in radiographic detection of furcation defects. Typically, radiographs are used in dentistry to aid in detection of pathology not easily found during routine clinical exam. While mandibular furcation defects are usually more obvious to detect on radiograph, maxillary molars present unique challenges due to their trifurcated root structure that often obscures radiographic evidence of mesial and distal furcation involvement. Hardekopf *et al* coined the term "furcation arrow" to describe the "small, radiographic shadow across the mesial or distal roots of some maxillary molars" that "may indicate the presence of a furcation defect". In a dry skull study, the authors found the furcation arrow was a relatively reliable diagnostic tool but stressed that the absence of a furcation arrow on radiograph did not always relate to the absence of furcation involvement clinically (Hardekopf et al., 1987).

Using an *in vivo* approach, Deas *et al* set out to determine the reliability of the radiographic furcation arrow as a diagnostic tool in patients with moderate to advanced periodontal disease requiring surgical treatment. They conducted a radiographic exam to detect furcation arrows on maxillary molars followed by a clinical exam to detect furcation involvement using the criteria proposed by Hamp *et al* (Hamp et al., 1975) with results recorded immediately prior to initiation of surgical treatment. Once surgical access had been achieved, the examiner again recorded the presence or absence of furcation involvement. Of 164 maxillary molars providing 328 interproximal furcations included in the study, 111, or 33.8% of furcations were determined during surgery to have Degree I or greater furcation involvements. Regarding clinical detection of furcation involvement before and after surgery, a 98.6% agreement was found for Degree 0, a 98.4% agreement found for Degree I, an 83.7% agreement found for Degree II, and a 0% agreement found for Degree III. Of the 111 surgically confirmed furcation defects, 38.7% of them were predicted by the presence of a furcation arrow by three of the five examiners. Of the 64 Hamp Degree I furcation invasions, 31.1% were determined to have a furcation arrow by 3 of the 5 examiners, while 23 of the 47 Hamp Degree II or III defects were determined to have a furcation arrow by 3 of the 5 examiners. Again using the criteria of agreement between 3 of the 5 examiners, the authors determined the presence of a furcation arrow as a diagnostic marker had a sensitivity of 38.7% and a specificity of 92.2%. Further, the positive predictive value for a furcation arrow was 71.7% while the negative predictive value was 74.6%. The implications of these findings were that a large number of actual furcation invasions were not detected by the presence of furcation arrows on a radiograph. On the other hand, it seemed that when furcation arrows were not visible on a radiograph, it was more likely that an actual furcation defect was not present. Ultimately, the presence of a furcation arrow on radiograph predicted the presence of an actual furcation defect approximately 70% of the time, which, as the authors concluded, provided a somewhat limited diagnostic value for their use in clinical assessment of a patient (Deas et al., 2006). Taken together, the radiographic studies on furcation arrows by Hardekopf *et al* and Deas *et al* suggested that the presence of a furcation arrow often denoted the presence of a furcation defect clinically. However, the absence of a furcation arrow did not always relate to the nonexistence of clinical furcation involvement.

As several methods exist to detect and diagnose furcation involvement, some authors questioned the reliability of these clinical and radiographic measurements in evaluating the success or failure of periodontal therapy as it relates to furcation defects. Renvert *et al* examined this important question in a study comparing 4 different methods of healing evaluation following surgical treatment of intraosseous defects a sample of 13 patients with 33 interproximal, intraosseous defects. Methods utilized to evaluate the healing response included probing attachment level, probing bone level, a surgical reentry procedure, and radiographic evaluation. Probing depths, bone sounding measurements, and radiographs were taken pre-operatively. The surgical procedure consisted of flap surgery with scaling and root planing of affected teeth followed by root conditioning with citric acid. The alveolar bone height of the defect was recorded during the surgery. After completion of the procedure, flaps were re-approximated and sutured into place. Measurements for probing depths and probing bone levels were taken 32 weeks after surgery along with post-operative radiographs. Measurements of bony defect height were taken during a surgical re-entry procedure conducted 1 week later. In their results, they found a close correlation with probing bone levels and intra-surgical bone height measurements. Additionally, they found a good correlation between bone probing levels and clinical attachment measurements. Probing depths and radiographic measurements showed a weaker correlation. The finding that bone sounding and intra-surgical measurements were equally useful to determine the height of the alveolar bone suggested that reentry procedures for the purpose of taking post-surgical measurements may be omitted if careful bone sounding was done in its place. Further, it seemed clinical attachment levels and bone sounding may be used together to thoroughly evaluate the soft tissue and bony contour for pre and post-surgical measurements. Thus, the authors concluded that "probing attachment levels, possibly combined with probing bone levels, are the parameters of choice… for studies evaluating the effect of reconstructive periodontal therapy" (Renvert et al., 1981).

While these methods aid in detection and diagnosis of furcation involvement, the etiology for their occurrence must be established and addressed prior to determination of an effective treatment plan. In addition to periodontal disease initiated by bacterial plaque and the host immune response, several other factors exist that may trigger inflammatory disease. Simon *et al* described the correlation between endodontic and periodontic pathologies that commonly result in a combined perio-endo lesion (Simon et al., 1972). Gutmann found that approximately 30% of maxillary and mandibular molars have patent accessory canals extending into the furcation region, providing a possible endodontic etiology for furcation involvement (Gutmann, 1978). These endo-perio lesions can be difficult to accurately detect and diagnose, complicating determination of prognosis and an appropriate treatment plan (Simon et al., 1972, Gutmann, 1978). Thus, endodontic involvement impacts treatment of periodontitis and must be addressed and eliminated if resolution of disease is desired.

Additionally, other authors have attempted to characterize the effect occlusal trauma has on loss of periodontal tissue, making the case that occlusion plays a role in the periodontal destruction that results in furcation defects (Glickman, 1963, Pihlstrom et al., 1986, Jin and Cao, 1992, Nunn and Harrel, 2001, Harrel and Nunn, 2001). Occlusal discrepancies must be diagnosed and managed prior to further treatment of periodontally diseased molars.

Following detection, diagnosis, and determination and address of the etiologies of disease, the complex anatomy of the furcation regions in molars must be considered prior to and during treatment. Bower described this complicated anatomy in a series of studies that examined 114 maxillary and 103 mandibular extracted permanent first molars (Bower, 1979a, Bower, 1979b). The first study sought to determine whether or not furcation anatomy influenced the ability to instrument furcations using curettes. To investigate this relationship, he measured molar width mesiodistally, furcation entrance diameter, and the width of the blade face of several common curettes. When measured at the CEJ, the mean width of maxillary first molars measured 7.9 mm, while the mean width of mandibular molars measured 9.2 mm. Bower also found 63% of maxillary molars and 50% of mandibular molars had a furcation entrance diameter of 0.75 mm or less. For maxillary molars specifically, 85% of buccal furcations, 49% of mesiopalatal furcations, and 54% of distopalatal furcations were 0.75 mm or less. In mandibular molars, 63% of buccal furcations and 37% of lingual furcations were 0.75 mm or less in width. Overall, 81% of maxillary and mandibular molar furcation entrance diameters were 1.0 mm or less whereas 58% were 0.75 mm or less. In order to illustrate the difficulty encountered in accessing and treating these molar furcations, Bower measured the blade face width of several commonly used curettes from 4 different manufacturers and found that in all cases, blade width ranged from 0.75 to 1.10 mm (Bower, 1979a).

The second study aimed to determine which morphologic features might influence plaque control and root preparation of molar furcations. Using the same sample of extracted teeth as the first study, Bower took several additional measurements on maxillary and mandibular molars. For maxillary molars, he measured the concavities of the furcal aspect of the mesiobuccal root, the distobuccal root, the palatal root, and the angle formed by the buccal roots at the coronal aspect. For mandibular molars, he took similar measurements of the concavities of the furcal aspects of the mesial and distal roots, the minimum mesiodistal distance between the furcal aspects of the roots in the buccal half and the lingual half of the furcation, and the maximum mesiodistal dimension of the furcation. In summarizing his findings, Bower reported that in maxillary first molar teeth, 94% of mesiobuccal roots were concave at the furcal aspect while 31% of distobuccal and 17% of palatal roots had concavities, the deepest concavity was found on the mesiobuccal root with an average depth of 0.3 mm, and finally that the furcal aspects of the buccal roots diverged towards the palate in 97% of teeth with a mean divergence of 22^{o}. For mandibular first molars, 100% of mesial roots and 99% of distal roots had concavities with the mesial root concavity being slightly deeper at 0.7 mm compared to 0.5 mm on the distal root, the mean internal mesiodistal dimension of the furcation was larger than the mean mesiodistal root separation by a mean of 1.2 mm, and a wider root separation was associated with larger furcation entrance diameter. For the second part of the study, Bower measured the effect of cemental thickness on root concavity depth. He reported that cementum was not uniform in thickness, being thicker in the concavities than on the convexities of the root surfaces, and that a greater concavity of the dentinocemental junction was associated with an increased net reduction of concavity depth due to the presence of additional cementum (Bower, 1979b).

These studies are significant in that that they emphasize the difficulties encountered when attempting to treat molars with furcation involvement. The finding that 81% of maxillary and mandibular molars had a furcation entrance width of 1.0 mm or less, which was approximately the same size as the width of most common curettes used in scaling and root planing, suggested that curettes were not capable of accessing the intrafurcal root surfaces during debridement. Fifty eight percent of molar furcations were found to be less than 0.75 mm, which would effectively exclude all available curettes from reaching the furcation areas in these teeth. Furthermore, 94% of mesiobuccal roots of maxillary molars had concavities while the mesial and distal roots of almost all mandibular molars had concavities. These concavities serve as a haven for accumulation of bacterial plaque and calculus that can further exacerbate periodontal disease. Bower also found that these concavities had at their depth thicker cementum than was present on root convexities. The cementum of periodontally-involved root surfaces has been shown to harbor microbial deposits and lipopolysaccharide, both of which have been implicated in the pathogenesis of periodontal disease (Daly C.G., 1982). Thus, even in teeth with wide furcation entrances that were accessible to common curettes, the presence of these root concavities and thicker, potentially diseased cementum makes thorough debridement and root planing of the involved surfaces significantly more difficult.

Similar findings on furcation anatomy were reported by Chiu *et at* and Hou *et al* in Chinese molars with little differences noted compared to Bowers' study (Chiu et al., 1991, Hou et al., 1994). Together, these studies stressed the difficulties encountered in accessing and instrumenting molar furcations for effective debridement, thus presenting increased challenges in the treatment and maintenance of these important teeth.

Additional anatomical considerations involving molars include root trunk lengths, root concavities and cervical enamel projections. Kerns *et al* examined 412 extracted multi-rooted teeth and measured root trunk dimensions and the prevalence of root grooves. For maxillary first molars, they found the average length of the buccal root trunk to be 4.11 ± 0.99 mm, 4.66 ± 1.11 mm for the distal root trunk, and 4.73 ± 1.08 mm for the mesial root trunk. For maxillary second molars, they found average length for buccal root trunks to be 4.29 ± 0.95 mm, 4.83 ± 1.21 mm for distal root trunks, and 6.40 ± 1.66 mm for mesial root trunks. For mandibular first molars, the mean length of the buccal root trunk measured 3.27 ± 0.70 mm while the lingual root trunk measured 4.28 ± 0.78 mm. In mandibular second molars, the average buccal root trunk length measured 3.28 ± 0.85 mm and the average lingual root trunk length measured 3.83 ± 0.70 mm (Kerns et al., 1999). These differences in root trunk length are important in that furcation defects arising on the mesial of maxillary second molars, for example, may be more difficult to access and treat due to the depth at which the furcation entrance may be located. Conversely, buccal furcations of all molars may be easier to access and treat due to shorter root trunk length.

Root grooves were found in 64.4% of extracted multi-rooted teeth with at least one root groove present in 53.3% of maxillary first molars, 89.5% of maxillary second molars, 61.2% of mandibular first molars and 98.1% of mandibular second molars. They also found that, when present, these root grooves were located within 2 mm of the CEJ 86% of the time (Kerns et al., 1999). An earlier study by Leknes *et al* demonstrated that the presence of root grooves in anterior and premolar teeth significantly enhanced periodontal attachment loss (Leknes et al., 1994). It appears that the high frequency of root grooves reported by Kerns *et al* in molar teeth was significant in that these teeth may be even more prone to periodontal attachment loss than teeth without such grooves.

Grewe *et al* examined over 5000 extracted maxillary and mandibular molars for prevalence, location, and extent of cervical enamel projections (CEP). They found that approximately 16% of maxillary molars and 25% of mandibular molars had CEP's. They also concluded that maxillary second molars and mandibular first and second molars had a statistically significant relationship between periodontal involvement and presence of CEP's (Grewe et al., 1965). The incidence of CEP's noted by Grewe *et al* proved to be similar to results reported by Masters & Hoskins, who found 28.6% of mandibular molars and 17% of maxillary molars in a sample of 474 extracted teeth presented with CEP's. Additionally, the authors stated that "clinical observations seem to associate this cervical enamel projection with approximately 90% of isolated bifurcation involvements" (Masters and Hoskins, 1964). Thus, CEP's appear to be a common finding in furcation-involved molars. As such, the presence of cervical enamel projections complicates periodontal treatment and response to therapy even further, perhaps necessitating their removal during periodontal procedures.

With these complex anatomical considerations and limitations, it becomes more difficult to appropriately treat and maintain teeth with furcation defects. From the studies by Bower, Chiu *et al*, and Hou *et al* (Bower, 1979a, Bower, 1979b, Chiu et al., 1991, Hou et al., 1994), it has been shown that the width of molar furcations may limit the access to hand instruments for thorough debridement. To clinically confirm the difficulty encountered in treating furcation-involved teeth with hand instruments, Leon and Vogel examined the effectiveness of hand scaling versus ultrasonic instrumentation of furcations in relation to plaque index, gingival crevicular fluid flow, and microbial analysis with darkfield microscopy. Ultimately, they found that ultrasonic instrumentation was more effective than hand instruments in changing gingival crevicular fluid flow and altering the bacterial population to a flora more associated with gingival health, especially in deeper Class II and Class III furcations (Leon and Vogel, 1987). Another study by Matia *et al* divided patients with severe periodontitis and furcation-involved mandibular molars into five groups. Twenty teeth were cleaned with curettes, with 10 molars curetted before surgical exposure and 10 molars curetted after surgical exposure. Similarly, 20 teeth were cleaned with ultrasonic instrumentation, with 10 teeth cleaned before surgical exposure and 10 teeth after surgical exposure. Teeth in the control group were not cleaned at all. All test teeth were extracted immediately after cleaning and examined for the effectiveness of calculus removal in the furcation area. It was found that calculus removal was inadequate in both treatment groups without surgical exposure. With surgical exposure, ultrasonic instruments were more effective in debridement of the furcation area in narrow furcations whereas curettes and ultrasonic scalers were equally effective in calculus removal in wide furcations (Matia et al., 1986). Combined, these studies illustrate two important points. First, ultrasonic instruments appear to be more effective in the debridement of furcation-involved molars. Second, surgical exposure of the furcation allows for more effective debridement, especially in narrower furcations. Thus, in deeper, more severe furcation defects, surgical therapy appears to be the preferred method of treatment resulting in improved outcomes.

Studies have shown non-surgical therapy to be effective in the management of less-severe furcation defects (Bowers et al., 2003). However, as these defects become more severe, non-surgical therapy becomes less effectual and surgical periodontal therapy becomes the preferred method of treatment. Several surgical approaches to furcation defect management have been proposed. Some of these approaches were evaluated by Kalkwarf *et al*, who treated 1394 furcation sites associated with 556 first and second molar teeth in 82 patients with one of four treatment modalities: coronal scaling only, scaling and root planing only, modified Widman flap surgery, or flap with osseous surgery. During phase I therapy, all groups received scaling and root planing except the coronal scaling group who received supragingival scaling only. Four weeks later, surgery was scheduled for modified Widman flap and osseous surgery sites that had residual 5 mm probing depths or greater. During phase II, the coronal scaling group continued to receive coronal scaling, the scaling and root planing group had treatment when necessary, and the modified Widman flap and osseous surgery groups were treated as indicated. Following surgery, patients were enrolled in a 3-month periodontal maintenance program. While all types of treatment were effective in reducing probing depths, the osseous surgery group had the greatest probing depth reduction followed by the modified Widman flap group, followed by the scaling and root planing group, and lastly the coronal scaling only group. However, this reduction in probing depths was generally accompanied by significant gingival recession. As such, in regards to clinical attachment levels, the osseous surgery group experienced loss in both vertical and horizontal probing attachment while the other groups had a small gain in attachment levels. Improvements over preoperative results were seen within the first year post-surgically, but attachment levels tended to decline during the second year of maintenance regardless of the type of therapy employed (Kalkwarf et al., 1988).

Hamp *et al* utilized furcation operations, consisting of debridement, odontoplasty and/or osteoplasty for Degree I defects and root resection, tunnel preparation, and extraction of resected roots in more severe Degree II and III defects in the treatment of 310 furcation-involved molars. During the initial treatment period, 135 of these teeth were extracted, 32 were scaled and root planed only, 49 had furcation operations, 87 were root separated, and 7 received a tunnel preparation. After 5 years of follow-up, a mean gingival index score of 0.2 was found and only 16 of 175 furcation sites had probing depths greater than 3 mm (Hamp et al., 1975), showing these treatments to be effective in the long-term management of furcation invasion defects.

Basaraba introduced a technique along with indications and contraindications for root resection and hemisection of furcation involved molars in an effort to maintain these teeth long-term. Root resection was indicated when other therapeutic measures were not effective. Indications included severe vertical bone loss, furcation invasion that progressed to the point that odontoplasty was ineffective, root proximity to adjacent teeth that compromised the ability to maintain the interproximal area, caries or results of surgery that rendered the furcation impossible to maintain by the patient, teeth serving as abutments for fixed partial dentures that became periodontally hopeless, tooth or root fractures, dehiscence where the entire length of the root was involved, and incomplete endodontic therapy. Contraindications were presented as well which primarily involved avoiding root resection and hemisection if these procedures would reduce or eliminate the periodontal support for the retained tooth and avoiding these procedures if endodontic therapy cannot be successfully completed. In these instances, root resection or hemisection would decrease the long-term prognosis for the retained tooth (Basaraba, 1969). Klavan followed patients who had root resections using the technique outline by Basaraba in a case series with a follow-up period ranging from 11 to 84 months. Of 34 root-resected molars, one was extracted during the study. Of 33 remaining molars, 24 stood alone as individual units while the remaining teeth served as abutments for fixed partial dentures or removable partial dentures. The mean sulcus depth in the remaining teeth over the observation time was 2.6 mm. Only three out of the 33 teeth displayed some mobility, two of which served as abutments for removable partial dentures (Klavan, 1975). Thus, the majority of the teeth included in the study remained periodontally stable and functional.

Similarly, Erpenstein followed 34 molars in 28 patients who had hemisections over an average period of 3 years. Most of these teeth served as distal abutments for fixed partial dentures. Three of the 28 teeth were extracted during the follow-up period. He concluded that hemisectioned molars had a favorable prognosis and that, in this case, failures were due to endodontic, rather than periodontal reasons (Erpenstein, 1983). Hellden *et al* followed 156 teeth with "through and through" furcation involvement among 107 patients that had tunnel preparations with a mean follow-up time of 37.5 months. Over the follow-up period, 10 teeth were extracted and 7 were hemisected or root resected. Eleven teeth developed incipient caries and 12 had established carious lesions. The majority of sites had probing depths less than 3 mm. The authors reported minimal discomfort, gingival bleeding, and sensitivity to cold or warm temperatures based on a patient questionnaire. Thus, they concluded that, based on their findings, the prognosis of teeth with a tunnel preparation was significantly better than that reported by Hamp *et al* (Hellden et al., 1989).

The surgical techniques used to treat furcation defects in molars seem to be effective and offer an improved prognosis for these teeth. Still, complications exist. Most of these techniques are resective in nature and require some removal of periodontal support to aid in maintenance of the involved molar. The extensive loss of attachment that results leaves the remaining tooth roots exposed to the oral environment. Exposed roots are more prone to caries. Furthermore, while the periodontal prognosis seemingly remains unaffected, the reduced periodontal support may compromise these teeth when they serve as abutments for fixed or removable partial dentures. Additionally, while molars are located in the posterior of the mouth, the reduced support results in longer clinical crowns and exposed roots that become an esthetic compromise. Though odontoplasty, osseous surgery, root resection, hemisection, tunnel preparations, furcation operations, modified Widman flaps, and open flap debridement all play a role in appropriate and effective management of furcation involved molars, techniques that eliminate complications such as reduction of periodontal support, increased caries risk, and comprised esthetics are more desirable.

It seems, then, that treatment aimed at increasing, rather than reducing periodontal support would be ideal. The AAP Glossary of Terms defines regeneration as “reproduction or reconstitution of a lost or injured part” (AAP, 2001). When applied to periodontology, regeneration can be defined as regeneration of the tooth’s supporting structures, including alveolar bone, cementum and PDL (Garrett, 1996). This is in contrast to repair, which the AAP defines as “healing of a wound by tissue that does not fully restore the architecture or function of the lost part”. New attachment refers to “the union of connective tissue or epithelium with a root surface that has been deprived of its original attachment apparatus. This new attachment may be epithelial adhesion and/or connective adaptation or attachment and may include new cementum”. Bone fill, defined only as “the clinical restoration of bone tissue in a treated periodontal defect” (AAP, 2001), may represent repair or regeneration. Based on these definitions, therapy that may regenerate lost periodontium would eliminate the complications arising from resective surgery. While true and complete regeneration is most desirable, it is likely that clinical attempts at periodontal regeneration result in some combination of regeneration and repair (Garrett, 1996) that may or may not be clinically significant.. Nonetheless, when appropriately executed and expected results are obtained, regenerative treatment can increase periodontal support regardless of the true histologic nature of this attachment.

For historical perspective, Melcher is generally credited with first describing the processes by which periodontal regeneration may be possible following periodontal surgery. He emphasized the importance of cells from the periodontal ligament in allowing for this regeneration (Melcher, 1976). Citing previous studies completed by their group, Gottlow *et al* found that only cells from the PDL seemed to have the capacity to form a new attachment (Gottlow et al., 1986).

Seo *et al* conducted a study to examine this potential of PDL cells to serve as stem cells and to aid in periodontal regeneration. They isolated PDL stem cells from 25 surgically extracted human third molars. Once the viability of these cells was confirmed, they were transplanted to the dorsal surface of immunocompromised mice and to surgically created periodontal defects in immunocompromised rats. Additionally, the capacity of these PDL stem cells to differentiate into cementoblast-like cells, adipocytes, and collagen-forming cells was confirmed under defined culture conditions. In the immunocompromised rats, a typical cementum/PDL-like structure was regenerated, which appeared different than the bone and bone marrow tissue typically formed by bone marrow stem cells and from the dentin/pulpal tissue typically formed by dental pulp stem cells. Additionally, these transplanted PDL stem cells formed a dense type I collagen fiber, similar to those seen in the PDL. Furthermore, these newly-generated collagen fibers were able to connect to the newly formed cementum-like structure, simulating the attachment seen with Sharpey's fibers. The human PDL stem cells transplanted into the surgically created periodontal defects in rats integrated in to the PDL compartment and occasionally attached to the alveolar bone and tooth surface. Taken together, these findings suggest that human stem cells, isolated from the periodontal ligament, have the capacity to regenerate cementum and PDL-like tissue and thus play a critical role in periodontal regeneration (Seo et al., 2004). In vivo studies by Isidor *et al* corroborated these findings and advocated the importance of PDL cells in the formation of new attachment. Using 4 monkeys as test subjects, the authors observed the effects of placing tight (test groups) versus loose (control group) ligatures around the roots of teeth functioning as single-rooted teeth and associated with surgically created angular bony defects. These teeth were submerged and left to heal for 3 months when animals were sacrificed and specimens were processed for histology. Histological findings showed that new attachment in the form of new cementum and connective tissue attachment had formed coronal to the ligatures loosely tied around the roots in 10 of the 14 control group teeth while only 1 of the 18 test teeth had the same findings (Isidor et al., 1986). Thus, it seemed coronal migration of cells from the PDL was necessary for the formation of new attachment and, conversely, when coronal growth was inhibited, new attachment would not form.

While it has been shown that cells from the PDL have the capacity to aid in formation of a new attachment following periodontal disease destruction, down-growth of epithelium can interfere with this process and proves to be problematic in regenerative procedures. Caton *et al* described this problem in a study designed to determine the effect of periodontal regenerative procedures on the connective tissue attachment level in rhesus monkeys. Eight adult male rhesus monkeys with bilateral surgically-created periodontal defects were divided into four groups, with each pair receiving one of four treatments: modified Widman flap without osseous surgery, modified Widman flap without osseous surgery but with implantation of an autograft, modified Widman flap without osseous surgery but with the addition of beta tricalcium phosphate, and periodic root planing and soft tissue curettage. In each pair, the selected procedure was performed on one side of the jaws while the contralateral defect served as un-operated controls. The animals were sacrificed one year after treatment and histologic specimens were prepared from the tissue harvested from the surgical sites. Results showed that, in all specimens, the regenerative procedures resulted in formation of a long junctional epithelium with no new connective tissue attachment (Caton et al., 1980).

A follow-up, single case report study by Nyman *et al* sought to test whether enabling the cells of the periodontal ligament to populate a previously diseased root surface would allow for formation of a new connective tissue attachment. A 47-year-old male patient with advanced periodontal disease and a mandibular central incisor scheduled for extraction served as the test subject. The test tooth exhibited severe attachment loss and a vertical bony defect. After full-thickness flap reflection, the defect was cleaned and a Millipore® barrier membrane was placed between the underside of the flap and the tooth surface. Thus, bone, cementum, and PDL remained under the membrane while the connective tissue and epithelium of the flap remained outside the membrane. The tooth and surrounding periodontal support were removed *en bloc* 3 months after the procedure and the sample prepared for histology. New cementum with inserting collagen fibers were found on the root surface in addition to new bone formed at the apical portion of the bony defect (Nyman et al., 1982). The results of this study showed that regeneration of periodontal tissue was possible on a previously diseased root surface and that exclusion of overlying gingival epithelium is essential to this process.

In his 1983 paper, Prichard described another method of epithelial exclusion that allowed for periodontal regeneration. The procedure involved thorough debridement of an intrabony defect and the involved tooth, which he stated allowed for deposition of new cementum and connective tissue attachment to the root as long as epithelium was excluded from the wound site. If new cementum and connective tissue attachment were present, new bone would fill in the defect. The procedure was done by first removing the vestibular and oral margins of the gingiva up to the boundaries of the 3-wall intrabony defect and then by removing all granulation tissue and transseptal and alveolar crest fibers of the PDL. Next, calculus was eliminated from the root without removing all cementum. Finally, surgical dressing had to be excluded from the defect, which he accomplished by tenting a dry foil over the teeth and intrabony defect. Additionally, Prichard advocated for the use of antibiotics and occlusal adjustment following surgery and stressed that no pre-surgical scaling should be done on the affected roots. If all steps were properly followed, formation of new cementum and connective tissue attachment would result, with bony fill of the defect following. In cases that fail, Prichard stated “replacing the flaps over the orifice of the defect is probably the most common cause” since “epithelium grows faster than connective tissue, and growth of epithelium into the defect prevents new connective tissue attachment” (Prichard, 1983). The realization that epithelium must be excluded from the bony defect to allow for formation of new cementum, bone, and connective tissue attachment formed the rationale for other techniques aimed at periodontal regeneration.

Ellegaard *et al* described another procedure utilizing a free gingival graft to retard epithelial migration onto a treated root surface in the treatment of periodontal intrabony defects. In the procedure, split thickness flaps were elevated to access the defect, leaving the periosteum intact. Granulation tissue was removed and the affected tooth was scaled and root planned. The defect was grafted with autogenous cancellous bone and a free gingival graft, harvested from the palate, was placed to cover the site. The graft was sutured to the adjacent attached gingiva and periosteum and the surgical site was covered with a periodontal dressing that was removed one week later. In their paper, 88 intrabony defects were treated with this procedure and results evaluated at 3 and 6 months post surgery on the basis of pre-surgical versus post-surgical measurements. They reported a significantly greater amount of new attachment versus conventional flap procedures, with approximately 60% of defects exhibiting complete “regeneration”. They added that only 10% of the defects treated using this method had residual probing depths greater than 3 mm. They attributed the success of this procedure to the use of the free gingival graft used to cover the defect as opposed to the traditional replacement of the full thickness flap. The authors surmised that the time it takes for the graft to heal and reorganize, which occurs through a series of steps including desquamation of epithelium, revascularization of the graft, epithelial proliferation by 7 to 9 days postoperatively, and final healing by 2 to 3 weeks delays the apical migration of the epithelium and thus allows time for the development and organization of the granulation tissue near the root surface. Further, they discussed previous findings that three-walled defects appeared to be more amenable to new attachment procedures than one or two-walled defects, most likely because the additional bony walls were better able to support the flap and blood clot, thus allowing for more rapid granulation tissue fill. The use of a free gingival graft described in this procedure created a connective tissue wall, effectively turning one and two-walled defects into three-walled defects (Ellegaard et al., 1974).

These early studies on periodontal regeneration highlight the importance of epithelial exclusion from the wound site to allow for population of the previously diseased root surface with cells from the PDL. With this understanding, one group of authors set out to devise and describe a technique that prevented epithelial migration onto the root surface, in turn allowing for periodontal regeneration under the appropriate conditions. This technique, first described by Gottlow *et al*, was termed guided tissue regeneration (GTR) (Gottlow et al., 1986). Properly applied, GTR requires thorough debridement of the periodontal defect, often followed by grafting of the site with autogenous, allogeneic, or xenogeneic bone, and final application of a barrier membrane to exclude in-growth of the overlying epithelium that can inhibit periodontal regeneration (Garrett, 1996). The studies published by this group indicated that GTR allows for a predictable and stable means of regenerating lost periodontal attachment rather than reducing clinical attachment as occurs with resective surgery (Gottlow et al., 1986, Ochsenbein, 1986, Carnevale and Kaldahl, 2000).

In their classic case-series report introducing the GTR technique, Gottlow *et al* treated 12 teeth, 5 of which were scheduled for extraction, in 10 patients with advanced periodontal disease. Measurements were taken in all experimental teeth prior to surgery. In 4 out of 5 teeth scheduled for extraction, GTR was performed in conjunction with flap surgery of neighboring teeth. The fifth tooth served as an untreated control. The remaining seven teeth were treated with GTR but were not planned for extraction. For the surgical procedure, full thickness flaps were elevated, granulation tissue removed, teeth were scaled and root planed, and Teflon membranes were placed to cover the root surface in a way that would exclude gingival connective tissue and epithelium from coming into contact with the root surface. Flaps were then replaced and sutured. Three months after healing, the five teeth scheduled for extraction were removed *en bloc* and prepared for histology while membranes were removed from around the seven teeth scheduled to remain in function during a second surgery. Three months after the second surgery, final measurements were taken. While the results varied greatly between patients, using histology, they showed that a regenerative therapy based on the principles of GTR could predictably result in formation of a new attachment. Further, the authors stressed that vertical bony defects had greater regenerative potential than horizontal bony defects, which they attributed to greater availability of osseous surface area that had the potential to provide osteogenic cells. Additionally, they felt that the placement of the membrane on the outer surface of the remaining alveolar bone allowed both bone and PDL cells to migrate into the wound area without interference from the overlying epithelium (Gottlow et al., 1986). The use of a barrier membrane did not require a second surgical site as required in the technique presented by Ellegaard *et al*, and thus may be preferred by the patient in many circumstances. These important realizations would influence future approaches designed to address the limitations of their techniques and materials.

While early guided tissue regeneration studies had primarily been applied in the treatment of intrabony defects, limited studies existed that observed the potential of guided tissue regeneration in the treatment of furcation defects prior to a report published by Schallhorn and McClain in 1988. In their study, 95 periodontal defects consisting of 62 Grade II or III furcation defects and 33 dehiscences, horizontal bone loss, or wide intrabony defects were treated with e-PTFE membranes. Seventy-five of these sites also received bone grafting and citric acid root conditioning. Treatment consisted of full thickness flap reflection followed by thorough debridement of the defect. In sites selected to receive grafting, citric acid root conditioning was employed followed by grafting with a composite of autogenous bone and either tricalcium phosphate or decalcified freeze-dried bone allograft. In all cases, an e-PTFE membrane was then placed to cover the treated site and flaps were positioned to cover the membrane. Membranes were removed an average of 3 months post-operatively. Results showed that all sites treated with either membrane alone or with membrane, root conditioning and grafting showed improvement in clinical parameters of probing depth reduction, open and closed probing attachment levels, and partial or complete furcation fill. However, in all cases, sites treated with bone grafts did as well or better than the sites treated with membrane alone (Schallhorn and McClain, 1988). This study showed that the use of a barrier membrane over furcation defects in regenerative procedures resulted in improvement in clinical parameters. Additionally, the novel approach of using root conditioning with bone grafting resulted in further improvement over use of a membrane alone. Finally, this study demonstrated that furcation defects could be managed and treated with a regenerative approach.

Metzler *et al* compared the effectiveness of open flap debridement alone to open flap debridement combined with placement of an occlusive barrier membrane to treat maxillary furcation defects. Seventeen patients with a pair of comparable maxillary Class II furcation defects, consisting of 12 buccal and 5 interproximal pairs, were treated in a split-mouth fashion with experimental sites receiving open flap debridement in combination with placement of an e-PTFE membrane and control sites receiving only open flap debridement. Soft tissue measurements were taken during the hygienic phase and bony measurements were taken at the time of surgery. Patients were seen every week for the first month for prophylaxis and oral hygiene instruction and then monthly thereafter for periodontal maintenance. Membranes were removed 4 to 6 weeks post-operatively and reentry surgery was performed at 6 months post surgery when new soft and hard tissue measurements were taken. Both groups experienced approximately 0.7 mm of gingival recession. Experimental groups had an average probing depth reduction of 1.7 mm compared to 0.9 mm in control sites. Eleven experimental sites gained an average of 1.0 mm in clinical attachment whereas four control sites gained an average of 0.2 mm, though these differences were not statistically significant. For hard tissue measurements, alveolar crest resorption measured approximately 0.4 mm in the experimental group, which was not significantly different from 0.0 mm in the control group. Experimental sites had a statistically significant gain of vertical open probing attachment of 1.5 mm compared to 0.6 mm in the control group and a significantly greater gain in horizontal probing attachment of 0.9 mm compared to 0.3 mm in the control group. Metzler *et al* noted that GTR therapy in maxillary molars appeared to be of limited value as compared to open flap debridement alone. They also found recession to be a common drawback, occurring in about half of cases. Further, they noted that none of the experimental sites appeared to be “filled with bone”. They concluded that while experimental groups had a statistically significant improvement in healing compared to control groups, the clinical significance of these findings was unknown and further that results obtained in treating maxillary molar teeth with furcation involvement were unpredictable (Metzler et al., 1991).

In a series of two studies, Pontoriero *et al* tested the regenerative capacity of maxillary molar Degree II and Degree III furcations using guided tissue regeneration. In their first study, 28 patients with bilateral molars exhibiting Degree II furcation defects on one surface were treated with full thickness flap reflection, degranulation of the defect, placement of an e-PTFE membrane to cover the furcation entrance in test sites but not in control sites, and replacement and suturing of flaps to completely cover the defect and/or membrane. Membranes were removed after 6 weeks of healing. Measurements were recorded during the initial surgery and during a reentry procedure conducted 6 months later. Results in mesial furcations yielded a mean probing depth reduction of 1.6 mm in the test group and 1.3 mm in the control group. Mean probing attachment levels improved by 0.7 mm in test groups and 0.1 mm in control groups. Soft tissue recession was found to be 0.9 mm in the test group and 1.2 mm in the control group. Additionally, both groups failed to demonstrate a gain of bone height and minimal reduction of horizontal probing depths while only one furcation defect in the test group was completely filled with bone at the reentry procedure. In distal furcations, the authors noted a mean probing depth reduction of 1.3 mm in both groups. Mean probing attachment levels improved by 0.6 mm in the test group and 0.1 mm in the control group. Mean soft tissue recession was approximately 1.0 mm in both groups. Similarly, they noted no change in bone height, minimal improvements in horizontal probing depths, and found that no distal furcations were completely filled at reentry. In buccal furcations, mean probing depths improved by about 2 mm in the test group and 1 mm in the control group. No improvement in probing attachment levels was noted in control sites, but an improvement of 1.5 mm was noted in test sites. More recession was observed in control sites versus test sites. Again, no change in bone height was noted. However, they did record a horizontal probing depth reduction of 1.1 mm in test sites and 0.3 mm in control sites. Two buccal furcations in the test group and one in the control group exhibited complete fill at reentry. The authors concluded that, in maxillary molars with Degree II furcation defects, while GTR therapy enhanced the treatment outcomes in buccal furcations, no such benefit was noted in mesial and distal furcations (Pontoriero and Lindhe, 1995a).

In a follow-up study testing the effectiveness of GTR in maxillary molars with Degree III furcation involvements, 11 patients with bilateral “through and through” mesial-distal furcations, but uninvolved buccal furcations, were selected. Similar to their previous study, one site was randomly selected for GTR therapy with an e-PTFE membrane while the contralateral defect received open flap debridement. Membranes were removed after 6 weeks of healing and a reentry operation was performed at 6 months post-therapy to record final measurements. Comparisons of post-op measurements to intrasurgical measurements revealed a probing depth reduction of 1.7 mm in mesial furcations and 1.8 mm in distal furcations in the test group and 1.9 mm in mesial furcations and 2.0 mm in distal furcations in the control group. Probing attachment levels, however, only marginally improved. Regarding gingival recession, 1.6 mm in mesial furcations and 1.3 mm in distal furcations was noted in the experimental group versus 1.9 mm in mesial furcations and 1.8 mm in distal furcations in the control group. In both groups, height of bone remained unchanged at the reentry procedure and in a majority of defects in both groups, the distance between the CEJ to the base of the defect remained unchanged. These findings led the authors to conclude that GTR therapy had limited value in the treatment of maxillary Degree III furcation defects (Pontoriero and Lindhe, 1995b).

Caffesse *et al* used e-PTFE membranes to facilitate GTR in Class II furcation defects in mandibular molars. Here, 9 patients with 13 molars having Class II furcation defects were treated using open flap debridement followed by placement of the e-PTFE membrane over the furcation entrance in experimental teeth and open flap debridement alone with no membrane placement in control teeth. Patients were seen once a week for the first 4 weeks post-operatively, had membranes removed at 4 to 6 weeks post-op, and received periodontal maintenance at 3 months and 6 months post-operatively. The authors reported a mean probing depth reduction of 2.8 mm, a mean gain of clinical attachment of 1.8 mm, and a mean gain of 0.86 mm of horizontal attachment in experimental groups. The experimental sites outperformed the control sites at all time points and thus, the authors concluded that GTR produced better results in the treatment of mandibular Class II furcation defects than open flap debridement alone (Caffesse et al., 1990). While relatively small, featuring only 9 teeth in the experimental group and 4 teeth in the control group, this study showed that guided tissue regeneration in mandibular molars clearly produced shallower probing depths and increased attachment levels versus open flap debridement of the defect alone.

To further characterize the regenerative potential of Class II furcation defects in mandibular molars, Bowers *et al* conducted a 2-year prospective study to identify significant prognostic factors relating to the patient, the furcation, and the treatment. Qualifying patients presented with two or more Class II furcation defects and were treated either in a dental school or in a private practice setting. In total, 43 patients, 16 of whom were smokers, 27 who were non-smokers, were treated with combination GTR therapy using citric acid for root conditioning, demineralized freeze-dried bone allograft (DFDBA), and a non-resorbable e-PTFE barrier membrane secured over the furcation. Graft material was mixed with tetracycline and hydrated with sterile saline or local anesthetic. Patients were seen at 1, 2, 4, 6, 8, 10, and 12 weeks, then 6 months, 9 months, and 12 months for final evaluation. Barrier membranes were removed 6 to 8 weeks post-surgically and measurements were made at the time of membrane removal. Complete closure of the defect was obtained in 74% of cases. Further, 68% of residual defects were reduced to a Class I while only 8% of residual defects remained a Class II. As in most regenerative studies, smokers were found to have an inferior response compared to non-smokers. At the one-year evaluation, significant reductions were noted for mean gingival index and probing depths and an improvement in vertical probing attachment levels. Furcations with increased presurgical probing depth, increased horizontal probing attachment levels, especially those 5 mm or greater, increases in the distance from the roof of the furcation to the base of the osseous defect and to the crest of bone, increased root divergence, and increased distance from the CEJ to the newly formed tissue beneath the membrane were all associated with higher incidence of incomplete furcation closure. Teeth that had interproximal bone height at the same level or greater than the roof of the furcation tended to respond better to treatment. The authors make the general statement that “the less severe the defect, the greater the likelihood of achieving complete clinical furcation closure” and thus concluded that combination GTR therapy is beneficial in the treatment of mandibular Class II furcation defects (Bowers et al., 2003).

While several of these studies have confirmed that GTR with or without bone grafting can result in decreased probing depths and increased clinical attachment, the question as to whether results were due to bone fill or true regeneration had not been answered. To address this problem, Harris presented a small case report in which one patient with three mandibular molars with buccal Class II furcation involvement, including two third molars and one first molar, was treated with combination GTR therapy, including tetracycline root conditioning, bone grafting with DFDBA mixed with tetracycline, and coverage with a resorbable membrane. The three teeth were extracted 6 months post-operatively along with small pieces of tissue from the furcation and samples were prepared for histology. Measurements taken immediately prior to extraction showed that one of the third molars remained a Class II defect while the other third molar and first molar had been reduced to a Class I. Two of the molars saw attachment level gains of 1.0 mm while the other molar had an attachment level gain of 2.5 mm. Histologically, 2 of the 3 treated molars demonstrated varying levels of regeneration, with formation of new cementum, bone, and PDL (Harris, 1999). This important study showed not only successful GTR therapy using DFDBA and resorbable barrier membranes in hopeless teeth scheduled for extraction, but also proved, with human histology, that periodontal regeneration in furcation defects is possible.

While success has been noted using the principles of guided tissue regeneration in furcation defects, especially in mandibular molars, the difficulty in manipulating barrier membranes as well as the consequences that arise when these membranes become exposed during healing has resulted in surgeons seeking alternative treatments to achieve periodontal regeneration. One such alternative involves the use of enamel matrix derivative (EMD) with or without a barrier membrane and/or bone grafting. In fact, a number of authors have reported successful treatment outcomes in periodontal defects using EMD without a barrier membrane resulting in periodontal regeneration comparable to the traditional GTR approach (Sculean et al., 2003, Crea et al., 2008, Cortellini and Tonetti, 2005).

To assess the effectiveness of using EMD in Class II-involved mandibular furcation defects, Jepsen *et al* conducted a split-mouth, randomized, multicenter study in 45 patients comparing furcations treated with EMD versus those treated with a resorbable barrier membrane as the control. Clinical outcomes were evaluated the day of surgery, at 8 months, and at 14 months when surgical reentry was performed. To be included in the study, patients had to have full mouth plaque and bleeding scores of < 25% at baseline and bilateral mandibular molars with buccal Class II furcation involvements, have interproximal bone coronal to the fornix of the furcation, and at least 2 mm of keratinized tissue adjacent to the furcation defect. In both groups, buccal flaps that spared interproximal papillae were elevated and open flap debridement was performed. In experimental sites, 24% EDTA (PrefGel®, Straumann®) was then applied to the root followed by EMD application (Emdogain™, Straumann®). Control sites were not treated with EDTA and instead had the resorbable membrane adapted to the defect and sutured in place. Flaps were then replaced and sutured. Patients received supragingival cleaning at 1, 2, 3, 4, and 6 weeks, followed by periodontal maintenance at 3, 6, 8, and 14 months. At the 14 month post-operative appointment, both groups had significant improvements in the primary outcome of open horizontal furcation depth, with a mean reduction of 2.6 ± 1.8 mm in test sites versus 1.9 ± 1.4 mm in control sites. In experimental sites, 35 of the 45 defects were reduced, 8 of which were completely closed, while 9 defects did not improve and one actually deteriorated. In the control group, 30 of the 45 defects were reduced, 3 of which were completely closed. Eleven defects did not improve and 4 deteriorated. The authors concluded that while both treatments resulted in significant reduction in open horizontal probing depths, EMD alone was statistically significantly better than GTR alone in reducing horizontal furcation probing depth in mandibular Class II furcation defects (Jepsen et al., 2004).

Casarin *et al* conducted a 24-month study comparing open flap debridement with 24% EDTA (PrefGel®, Straumann®) for root conditioning in the control group to open flap debridement with 24% EDTA and enamel matrix derivative (Emdogain®, Straumann®) application in the test group in interproximal Class II furcation defects in maxillary molars with probing depths ≥ 5 mm and bleeding on probing after initial periodontal therapy. Twelve patients with bilateral maxillary interproximal Class II defects were enrolled in and completed the study. The authors measured full mouth bleeding and plaque scores, vertical probing depths, gingival margin position, relative vertical clinical attachment level, relative horizontal clinical attachment level, and vertical and horizontal bone sounding. After buccal and lingual full thickness flap reflection, the diagnosis of Class II furcation defect using Hamp's criteria was confirmed (Hamp et al., 1975). Teeth were randomly assigned to either test or control groups and the specified procedures were performed in a split-mouth manner. Flaps were replaced and sutured with modified mattress sutures. After 24 months, the authors found that patients maintained average full mouth plaque and bleeding scores of 20% or less through out the study, with 0% plaque scores noted at the surgical site at all time points, though plaque percentages increased as the study continued. Both groups had an average of 1.0 ± 1.0 mm of recession over the study period. They also noted a probing depth reduction of 1.0 ± 1.3 mm in the control group versus 1.9 ± 1.6 mm in the test group which, while showing a numerical difference, was not statistically significant. Both groups presented a slight gain in relative vertical and horizontal clinical attachment without a difference between groups. Neither group had a significant vertical gain in bone as measured via bone sounding, however, both groups presented a small horizontal bone gain of 0.6 ± 1.7 mm in the control group versus 1.0 ± 1.2 mm in the test group, though these differences were not statistically significant. After 24 months, 10 furcations in the control group were still diagnosed as a Class II furcation compared to 5 in the test group. Additionally, the test group had 2 closed furcations and 5 furcations that had been reduced to a Class I while the control group had only 2 furcations improve to a Class I at the 24-month follow-up (Casarin et al., 2010). Thus, while the majority of clinical parameters showed no statistical difference between test and control groups, the number of furcations that improved from a Class II to either completely closed or to a Class I was greater in the test group than the control group, showing that the addition of EDTA and EMD to open flap debridement in the treatment of maxillary interproximal Class II furcation defects proved beneficial over open flap debridement and EDTA application alone.

However, despite technique and material refinements, effective regeneration of molar furcation defects remains unpredictable (Bowers et al., 2003, McClain and Schallhorn, 2000, Caffesse et al., 1990, Metzler et al., 1991, Jepsen et al., 2004, Casarin et al., 2010). Though some degree of success has been achieved in treating mandibular molars, attempts at regeneration of maxillary furcation defects have produced mixed results (Pontoriero and Lindhe, 1995a, Pontoriero and Lindhe, 1995b, Donos et al., 2003, Kinaia et al., 2011, Avera et al., 1998). These findings were corroborated by the group of authors charged with evaluating the regenerative potential of furcation defects as part of the 2014 American Academy of Periodontology's Regeneration Workshop. In their report, the authors drew several important conclusions regarding the use of regenerative therapy in furcation defects. First, they found that "periodontal regeneration has been demonstrated histologically and clinically for the treatment of maxillary facial, mesial, distal, and mandibular facial or lingual Class II furcation defects", second that "although periodontal regeneration has been demonstrated histologically for the treatment of mandibular Class III defects, the clinical evidence is limited to one case report", third that "evidence supporting regenerative therapy in maxillary Class III furcation defects in molars and premolar furcation defects is limited to clinical case reports, which reported unpredictable outcomes" and fourth that "in Class I furcation defects, regenerative therapy may be beneficial in certain clinical scenarios, although most Class I furcation defects may be successfully treated with non-regenerative therapy" (Reddy et al., 2015).

As previously discussed, one of the primary concerns in treating furcation defects are the challenges that arise due to limited access (Bower, 1979a, Bowers et al., 2003, Chiu et al., 1991, Bower, 1979b, Hou et al., 1994). Limited access, at least in part, contributes to the unpredictable outcomes of treatment. To improve visualization, furcation defects have historically been accessed with a full thickness flap reflection that, due to the necessity of releasing enough tissue to visualize the affected site, often includes multiple sites of healthy teeth in addition to the diseased sites. Full thickness release compromises the blood supply to both the surgical site and healthy sites, resulting in impaired wound healing and gingival recession over time (Harrel, 1999, Donos et al., 2003, Sculean et al., 2003, Harrel and Rees, 1995).

To address these shortcomings, the concept of minimally invasive surgery (MIS) has been introduced in the periodontal literature as a surgical approach capable of reducing the drawbacks associated with traditional flap surgery (Harrel and Rees, 1995). MIS involves a very small incision design intended to maintain as much soft tissue and blood supply to the surgical site as possible (Harrel, 1999). In their original article, Harrel and Rees describe a “small incision periodontal surgical technique based on the use of the rotary degranulating instrument” that is “probably best described as a minimally invasive surgical technique”. They also stated, “the minimally invasive surgical approach is excellent for regenerative procedures, such as bone grafting and the use of guided tissue membranes in isolated periodontal defects”. They stressed the importance of making as small of an incision as possible, arguing “excessive reflection can damage the blood supply to the flap and can lead to increased tissue loss during initial healing” and that “maintenance of the blood supply to the flap and minimal trauma of the tissue are critical to the success of all regenerative surgical procedures”

(Harrel and Rees, 1995). This was one of the first articles published in the periodontal literature to report success in periodontal regenerative procedures using a minimally invasive surgical technique that reduced many of the limitations of traditional full thickness flap reflection.

While the previous paper alluded to the use of “small incisions”, Harrel and Rees did not thoroughly describe their minimally invasive surgical technique. Two follow-up papers by Harrel presented the technique in more detail, highlighting the use of MIS for periodontal bone grafting in addition to offering several observations made by the author during and after treatment. The author said the ideal situations for minimally invasive surgery include “isolated, usually interproximal defects that do not extend significantly beyond the interproximal site… a periodontal defect that borders on an edentulous area… and a defect that extends to the buccal and/or lingual from the interproximal area” and ideally, non-contiguous defects, even within the same quadrant. The incision design was described, which served to preserve as much of the soft tissue surrounding the defect as possible. After incisions are made, the tissue is “elevated utilizing sharp dissection only”. Sharp dissection for flap elevation minimizes “post surgical flattening of the papilla, interproximal cratering, and loss of soft tissue height”, thereby reducing gingival recession and preserving soft tissue esthetics. The defect can be visualized with magnification and a light source. Granulation tissue should be removed using curettes, ultrasonics, and a granulation tissue removal instrument in a way that prevents trauma to the flap. Following granulation tissue removal, “final root planing and smoothing is accomplished with a high speed surgical length finishing bur”. In these cases, the author advocated for the use of citric acid after thorough root planing followed by combination grafting with DFDBA mixed with tetracycline, hydrated with local anesthetic, and coverage with a surgical mesh. Finally, wound closure was accomplished with a single vertical mattress suture placed away from the papilla tips. Following, buccal and lingual papilla tips were gently compressed together with a wet gauze and finger pressure. According to the author, advantages of the MIS technique included improved "retention of soft tissue height and contour… patient acceptance" and less post-operative discomfort (Harrel, 1998, Harrel, 1999).

In the original case series on 10 consecutively treated patients who received the MIS treatment described and had post operative measurements taken an average of 25.1 months after surgery, Harrel reported a mean probing depth reduction of 4.1 mm and a gain in clinical attachment of 4.2 mm. Additionally, the author noted that "all teeth that were initially mobile showed improvement in mobility" and that no teeth were lost (Harrel, 1998). Thus, these results seemed consistent with the previously discussed results on combination GTR and bone-grafting studies utilizing traditional, full thickness flap reflection.

As advancements were made in the field of periodontal regeneration, Harrel *et al* published another case series in which EMD was used without a barrier membrane in conjunction with MIS to treat 160 sites in 16 patients. To qualify, patients had to have sites with a 6 mm or greater probing depth after initial non-surgical periodontal therapy. Following minimally invasive surgical access as previously described, defects were thoroughly debrided and teeth were root planed. Root surface modification was accomplished with either citric acid or 24% EDTA. After rinsing, EMD was applied in the defect and grafting with DFDBA followed. Flaps were replaced and sutured using a single suture and patients were enrolled in a 3-month periodontal maintenance program. Follow-up visits ranged from 11 to 24 months, when post-surgical measurements were made. At re-evaluation, mean probing depth reductions of 3.56 mm, mean clinical attachment level gains of 3.57 mm, and mean gains in gingival margin to CEJ measurement of 0.01 mm were noted. Interestingly, the authors drew a comparison between their results and the results summarized by Garrett (Garrett, 1996). In his review paper, Garrett summarized the results of several different authors in table format. Based on these findings, Harrel *et al* determined flap surgery resulted in a mean probing depth reduction of 2.70 mm, a CAL gain of 1.80 mm, and 0.90 mm of recession. Synthetic grafts resulted in a mean probing depth reduction of 3.02 mm, a CAL gain of 2.11 mm, and 1.00 mm of recession. Bone grafts resulted in a mean probing depth reduction of 2.40 mm, a CAL gain of 1.70 mm, and 0.70 mm of recession. Finally, guided tissue regeneration resulted in a mean probing depth reduction of 2.70 mm, a CAL gain of 2.20 mm, and 0.90 mm of recession. When compared to the results obtained by Harrel *et al,* it can be seen that MIS using combination EMD and DFDBA resulted in superior reductions in probing depths, CAL gain, and minimal to no recession as compared to flap surgery, synthetic grafts, bone grafts, or traditional GTR (Harrel et al., 2005). Further, the authors reported these improvements in clinical parameters remained virtually unchanged 6 years after treatment (Harrel et al., 2010).

Cortellini and Tonetti described a similar approach to periodontal treatment using small incision designs that they termed the minimally invasive surgical technique (MIST). They reported the advantages of MIST as being less traumatic, increased ease of flap and wound stability, better primary closure, faster completion of surgery, and minimization of patient discomfort during surgery and post-treatment (Cortellini and Tonetti, 2007).

With the MIS or MIST technique, access to the surgical site can be achieved while maintaining essential blood supply. In conventional MIS or MIST, surgeons utilized surgical telescopes (loupes), a fiber-optic endoscope, or a surgical microscope to visualize the treatment site (Harrel et al., 2005, Harrel et al., 2010, Cortellini and Tonetti, 2007). However, each of these methods presents their own set of challenges. Loupes often provide only limited magnification, the fiber optic endoscope quickly becomes contaminated with blood and debris as it is inserted into the surgical site which limits its effectiveness, and the surgical microscope is difficult to learn and utilize properly (Harrel et al., 2013). Thus, while the small incisions and minimal tissue reflection were likely responsible for the superior results obtained using these techniques, visualization remained a major drawback of minimally invasive surgery.

With traditional full thickness, multi-tooth flap reflection, defects can be seen with more ease than with conventional minimally invasive access. Recently, an approach to MIS that resolves many of the difficulties in visualization has been introduced. Harrel *et al* described a videoscope that can be used in MIS periodontal regeneration. The videoscope is a high definition digital camera placed on the end of a flexible tube 2.7

mm in diameter. Additionally, the videoscope contains a gas-shield that prevents blood and contamination from obscuring the camera, allowing improved visualization of the defect once inserted into the surgical site. A carbon fiber retractor on the end of the flexible tube may be rotated to aid in flap reflection. Using this videoscope, Harrel *et al* presented a case series in which the videoscope was used in the treatment of periodontal defects. Preliminary results indicated significant reduction of probing depths with minimal to no recession and even an improvement in root coverage in some cases (Harrel et al., 2013).

Later, Harrel *et al* published results of one-year follow-up data in this prospective cohort clinical outcomes study. To qualify for inclusion, patients had to have an isolated interproximal area of periodontal destruction with a probing depth of at least 5 mm, CAL of at least 2 mm, and radiographic evidence of bone loss on periapical radiographs following initial non-surgical therapy. After screening, 30 patients with 110 qualifying sites were treated with MIS utilizing the videoscope for visualization as described in the 2013 paper. The authors obtained minimally invasive surgical access, debrided the sites and planed the roots, biomodified root surfaces with 24% EDTA application, and grafted the sites with EMD mixed with DFDBA. As before, flaps were repositioned and sutured using a single resorbable vertical mattress suture. Digital pressure was then applied to the papilla tips to ensure closure. Surgical sites were re-evaluated 6 months post-operatively. Findings revealed a mean probing depth reduction of 2.07 mm, a 0.20 mm gain of gingival margin to CEJ measurements, and a CAL gain of 2.28 mm. Further, all sites had a post-surgical probing depth less than 3 mm (Harrel et al., 2014).

Despite the success of the MIS approach using the videoscope, the same surgical protocol has not yet been studied for the treatment of furcation invasion defects. Thus, our purpose is to conduct an outcomes-based study determining the effectiveness of periodontal regeneration of maxillary and mandibular first and second molars with Degree II furcation defects by utilizing a videoscope-assisted minimally invasive surgical approach.

CHAPTER II

BACKGROUND AND PURPOSE

The presence of furcation invasion defects in molars, defined as the pathologic resorption of bone within a furcation (AAP, 2001), has been associated with a deteriorating prognosis and, without treatment, may result in eventual loss of the involved tooth (Miller et al., 2014, Hirschfeld and Wasserman, 1978, Becker et al., 1984, McFall, 1982). However, while certainly affecting the prognosis of these teeth, several studies have shown that molars with furcation defects can be effectively treated and survive in health for a number of years (Miller et al., 2014, Salvi et al., 2014, Becker et al., 1984).

In general, regenerative procedures, such as guided tissue regeneration (GTR), are preferred in the treatment of furcation defects because they allow for a predictable means of regenerating lost periodontal attachment rather than reducing clinical attachment as occurs following resective surgery (Bowers et al., 2003, Gottlow et al., 1986, Caffesse et al., 1990, Carnevale and Kaldahl, 2000, Ochsenbein, 1986). Properly applied, GTR requires thorough debridement of the defect followed by application of a barrier membrane to exclude ingrowth of the overlying epithelium which inhibits periodontal regeneration (Garrett, 1996). Difficulty in manipulating these barrier membranes as well as the consequences that arise when membranes become exposed during healing resulted in surgeons seeking alternative treatments. One such alternative involves the use of enamel matrix derivative (EMD). A number of authors have used

EMD without a barrier membrane in the treatment of periodontal defects and reported results comparable to traditional GTR (Sculean et al., 2003, Crea et al., 2008, Cortellini and Tonetti, 2005).

However, despite technique and material refinements, the effective treatment of molar furcation defects with GTR (Bowers et al., 2003, McClain and Schallhorn, 2000, Caffesse et al., 1990, Pontoriero and Lindhe, 1995a, Pontoriero and Lindhe, 1995b) or EMD (Jepsen et al., 2004, Donos et al., 2003, Casarin et al., 2010) remains unpredictable. While several authors have achieved varying degrees of success in the treatment of furcation involvement in mandibular molars, similar success in maxillary molars remains elusive (Pontoriero and Lindhe, 1995a, Pontoriero and Lindhe, 1995b, Donos et al., 2003, Kinaia et al., 2011, Avera et al., 1998).

One of the unique challenges arising in the treatment of furcation invasion defects stems from the complex anatomy of the furcation area that limits surgical and visual access. Limited access contributes, at least in part, to the unpredictable outcomes of treatment (Bower, 1979a, Bowers et al., 2003). Without proper access and visualization of the affected site, complete debridement of the plaque, calculus and granulation tissue associated with these defects becomes difficult and the potential for effective treatment declines. As such, furcation defects are problematic and difficult to treat.

To improve visualization, furcation defects are traditionally accessed with a full thickness flap reflection that, due to the necessity of releasing enough tissue to visualize the affected site, often includes multiple sites of healthy teeth in addition to the diseased sites. Full thickness release compromises the blood supply to both the surgical site and healthy sites, thus contributing to gingival recession over time (Harrel, 1999, Donos et al., 2003, Sculean et al., 2003, Harrel and Rees, 1995).

The concept of minimally invasive surgery (MIS) was introduced in the periodontal literature as a surgical approach capable of reducing the drawbacks associated with traditional flap surgery (Harrel and Rees, 1995). MIS involves a very small incision design intended to maintain as much soft tissue and blood supply to the surgical site as possible (Harrel, 1999). Cortellini and Tonetti described a similar approach to treatment using small incisions that they termed the minimally invasive surgical technique (MIST). They reported the advantages of MIST as being less traumatic, increased ease of flap and wound stability, better primary closure, faster completion of surgery, and minimization of patient discomfort during surgery and post-treatment (Cortellini and Tonetti, 2007).

With the MIS or MIST technique, access to the defect can be achieved while maintaining essential blood supply thereby theoretically improving the capacity for wound healing. With conventional MIS or MIST, surgeons utilize surgical telescopes (loupes), a fiber-optic endoscope, or a surgical microscope to visualize the surgical site (Harrel et al., 2005, Harrel et al., 2010, Cortellini and Tonetti, 2007). However, each of these methods presents their own set of challenges. Loupes often provide only limited magnification, the fiber optic endoscope quickly becomes contaminated with blood and debris as it is inserted into the surgical site which limits its effectiveness, and the surgical microscope is difficult to learn and utilize properly (Harrel et al., 2013).

Recently, Harrel *et al* described a videoscope that can be used in MIS for periodontal regeneration that improves visualization of the surgical site while maintaining the potential for minimally invasive access. The videoscope is a high definition digital camera placed on the end of a flexible tube 2.7 mm in diameter. Additionally, the videoscope contains a gas-shield that prevents blood and contamination from obscuring the camera, allowing improved visualization of the defect once inserted into the surgical site. A carbon fiber retractor on the end of the flexible tube may be rotated to aid in flap reflection. Using this videoscope, Harrel *et al* presented a case series and follow-up data in which the videoscope was used to treat periodontal defects with a regenerative approach. Results indicated a significant reduction in probing depths, gain of clinical attachment, and minimal to no recession with some sites experiencing an actual improvement in root coverage (Harrel et al., 2013, Harrel et al., 2014).

Despite its success, videoscope-assisted minimally invasive surgery (V-MIS) has not yet been applied to the treatment of furcation invasion defects. Thus, our purpose is to conduct an outcomes-based study determining the effectiveness of V-MIS for periodontal regeneration of maxillary and mandibular first and second molars with Degree II furcation defects.

CHAPTER III

MATERIALS AND METHODS

Patient Selection

This study was designed as a prospective outcomes-based case series of 15 consecutively treated patients meeting defined inclusion criteria. After approval by the Texas A&M University Institutional Review Board (IRB Number: 2014-0219-BCD-FB), patients with existing periodontal destruction who were referred to the Department of Periodontics for management of furcation invasion defects were screened and evaluated for the following inclusion criteria: 1) completion of initial therapy consisting of oral hygiene instruction, scaling and root planing, occlusal adjustment as needed, and re-evaluation at 4 to 6 weeks post-therapy; 2) remaining isolated Degree II furcation defects (Hamp et al., 1975) on maxillary or mandibular first or second molars as determined with a Nabers furcation probe at the re-evaluation appointment, excluding the distal surface of second molars and all third molars; 3) maintenance of a modified O'Leary Plaque Index of ≥ 80% prior to surgery (O'Leary et al., 1972); 4) appropriate pre-operative radiographs of teeth to be treated; 5) be at least 18 years of age prior to surgery; 6) ASA class I or II. Patients were excluded on the basis of any of the following criteria: 1) current smokers (defined as those who have smoked more than 10 cigarettes in the past year); 2) patients with uncontrolled or poorly controlled diabetes mellitus, unstable or life threatening conditions, or other medical diagnosis or medication use that could negatively affect periodontal healing; 3) adjacent teeth with Degree II or III furcation defects such that the possibility of minimally invasive access would be compromised; 4) previous periodontal surgery in the same site within 6 months prior to enrollment; 5) non-English speakers; 6) ASA class III or greater. Patients meeting any of the exclusion criteria at any point during the study were immediately withdrawn and their care continued in the Department of Periodontics as needed.

After screening and obtaining informed consent, 15 patients who met the inclusion criteria (ages 32 to 73, 8 males and 7 females) were enrolled in the study. The patient population provided 15 furcation defects, with one treated site included in the study per patient. The breakdown of treated defects included 10 distal furcations of maxillary first molars, 2 mesial furcations of maxillary first molars, 1 buccal furcation of a mandibular first molar, 1 lingual furcation of a mandibular first molar, and 1 buccal furcation of a mandibular second molar.

Clinical Parameters & Patient-Based Outcomes

Following administration of local anesthetic and immediately prior to starting the surgical procedure, the following periodontal parameters were assessed by one of two experienced and previously standardized (Carney et al., 2012) periodontists (D.G.K. or J.A.R.) using a UNC-15 periodontal probe and a marked Nabers probe with all measurements rounded up to the nearest 0.5 mm: 1) probing depth (PD): measurement of the depth of the gingival sulcus made from the free gingival margin (FGM) to the depth of the sulcus; 2) gingival recession (GR): measurement of the distance from the CEJ to the FGM; 3) clinical attachment level (CAL): measurement of the level of soft tissue attachment to the tooth, calculated as the probing depth plus gingival recession; 4) bleeding on probing (BOP): recorded as a “yes” or “no” and evaluated approximately 10 seconds after gentle periodontal probing; 5) papilla height (PH): measurement of the height of the papilla associated with the furcation defect made by measuring the distance from the apex of the papilla, parallel to the long axis of the tooth, to the line used to measure the papilla width (defined below) as described by Saletta *et al* (Saletta et al., 2001); 6) papilla width (PW): a measurement of the base of the papilla associated with the furcation defect made by measuring the length of a line starting at a point formed by the intersection of the CEJ, the most apical portion of the gingival margin, and the most interproximal portion of the clinical crown on one tooth connecting to a similar point on the adjacent tooth as described by Saletta *et al* (Saletta et al., 2001); 7) vertical probing depth of furcation (VPDF): determined from the vertical depth of the furcation defect measured via bone sounding as the distance from the CEJ to the base of the defect using a UNC-15 probe as described by Mealey *et al* (Mealey et al., 1994); 8) horizontal probing depth of furcation (HPDF): determined from the horizontal depth of the furcation measured via bone sounding as the horizontal distance from the CEJ to the horizontal depth of the furcation using a marked Nabers probe as described by Mealey *et al* (Mealey et al., 1994); 9) mobility (M): measured using Miller’s classification of tooth mobility (Miller, 1950); 10) Miller-McEntire Scoring Index (M-M): recorded for each molar included in treatment as described by Miller *et al* (Miller et al., 2014). Measurements for PD, GR, CAL, BOP, VPDF, and HPDF were taken at the site of surgical access located at one of six points around the tooth (mesiobuccal, mid-buccal, distobuccal, distolingual, mid-lingual, or mesiolingual). Measurements for PH and PW were taken at the location of surgical access. For mandibular defects, PH and PW measurements were taken only at the mesial papilla since the treated tooth was the distal-most tooth in the arch in each case. When the CEJ was absent or indistinguishable, reproducible anatomic landmarks, such as a crown or restorative margin, were utilized as a reference point for measurements. To minimize variability in manufacturing, the same UNC-15 probe and Nabers probe were used to record all measurements.

To assess patient-related outcomes, patient satisfaction surveys were administered and filled out by the patient using a visual analogue scale (VAS) of 0 to 100 approximately 24 hours after surgery and at the 1 week and 6 month post-surgical appointments as described by Steffer *et al* (Steffer et al., 2013). As part of the 24-hour survey, patients were asked to rate their pain during and after the procedure, their ability to function regarding chewing, swallowing, and speaking, and finally their overall satisfaction with the procedure. As part of the 1 week and 6 months post-operative surveys, patients were asked to assess their current level of pain, their ability to function regarding chewing, swallowing, and speaking, their satisfaction with the appearance of the surgical site, and their overall satisfaction with the procedure.

Surgical Procedures

Prior to surgery, a review of the patient's medical history and assessment of vital signs were conducted. Patients were instructed to rinse with 0.12% chlorhexidine gluconate for one minute prior to administration of local anesthetic. Local anesthesia was achieved with 2% lidocaine HCL 1:100,000 epinephrine and/or 0.5% bupivacaine HCL 1:200,000 epinephrine. After confirmation of anesthesia, clinical measurements were obtained, including PD, GR, CAL, BOP, PH, PW, VPDF, HPDF, and M. The surgical procedure was completed as described by Harrel *et al* (Harrel et al., 2005, Harrel et al., 2013, Harrel et al., 2014). Incision design was modified based on the location of the furcation defect and the anatomy of the adjacent tooth. Mandibular furcations were accessed using sulcular incisions and minimal split-thickness dissection when appropriate without mesial and distal papilla release. Blunt dissection was avoided. Incisions and access were considered to be adequate when appropriate visualization of the defect could be achieved using the videoscope. Maxillary interproximal furcation defects were always accessed from the palate, using non-connecting intrasulcular incisions and a single horizontal incision at the base of the papilla, creating a small flap that left a majority of the interproximal tissue intact. Split-thickness dissection of the palatal flap was done to provide enough release to allow for visualization of the defect with the videoscope, again avoiding blunt dissection. When necessary, interproximal tissue was elevated by making buccal sulcular incisions, allowing for release of the tissue that could then be gently lifted or pushed through the contact to the buccal surface to allow for visualization of the surgical site. Visualization of the defect was confirmed by inserting the optical end of the videoscope into the accessed defect, allowing for 40 to 60 times magnification of the affected area as viewed on a surgical monitor. Once visualized, degranulation and debridement of the defect was completed using hand instruments, ultrasonics, and fluted finishing burs as necessary. The videoscope was utilized during this procedure by leaving it in place during instrumentation when possible or by taking it in and out of the defect when space was limited. Following debridement of the defect, careful root planing was completed and confirmed to be adequate using the videoscope. 24% ethylenediaminetetraacetic acid (EDTA; PrefGel®; Straumann®) was applied to the root surface and burnished with a sterile cotton pellet for approximately 2 minutes for removal of residual calculus and root biomodification. Reinsertion of the videoscope confirmed removal of any remaining remnants of calculus or root surface contaminant prior to grafting. Defects were dried with sterile gauze and EMD (Emdogain™; Straumann®) was applied directly into the defect. Cortical demineralized freeze-dried bone allograft (AlloGraft DGC; Straumann®) had previously been hydrated with sterile saline and gently dried with sterile gauze. The remaining EMD was then mixed with the DFDBA, placed into the defect and lightly condensed. Flap closure was then accomplished using either a single vertical mattress suture at the base of the papilla for interproximal furcation defects or a single sling suture for buccal or lingual defects using 4-0 chromic gut sutures. Following closure, gentle pressure was applied to the papilla tips using moistened sterile gauze to ensure proper adaptation. Oral and written post-operative instructions were given to the patient along with the 24-hour VAS survey to be returned at the one-week post-surgical appointment. Medically appropriate antibiotics were prescribed (either amoxicillin 500 mg t.i.d. for 7 days or minocycline 100 mg, taking two STAT, then b.i.d. for 7 days for patients unable to take amoxicillin) along with a twice-daily rinse of 0.12% chlorhexidine gluconate to be used the first week post-operatively. Patients were asked not to brush or floss the area during this time. Normal oral hygiene was resumed following the one-week post-op appointment with emphasis given to the use of good brushing and flossing technique with a soft toothbrush and the use of interproximal cleaning aids when indicated. Patients were seen 1 week, 4 weeks, 3 months, and 6 months following completion of the surgical procedure. Sutures were removed at the 1-week post-op appointment when necessary and patients were asked to return the 24-hour VAS survey and to complete the 1-week VAS survey during the appointment. Assessment of healing and light scaling of the surgical site was performed at each post-op appointment and thorough oral hygiene instruction was provided. Periodontal maintenance was performed at the 3 and 6-month post-operative visits using local anesthetic when required for patient comfort. At the 6-month post-surgical appointment, the same clinical measurements were assessed and recorded by either D.G.K. or J.A.R. and the final VAS survey was completed and turned in by the patient. Post-operative radiographs were taken when possible as part of routine periodontal maintenance procedures.

Statistical Analysis

A paired T test was used to compare changes that occurred from baseline to the 6-month post-operative visit using a significance of 0.05 for all testing. Responses for each question as a part of the VAS surveys were compiled and averaged to provide a mean response for each question in addition to a range of values.

CHAPTER IV

RESULTS

All 15 patients initially enrolled completed the study. The most common adverse event occurred intrasurgically when the papilla and associated interproximal tissues were inadvertently severed during flap reflection as occurred primarily with patient numbers 2, 4, 6, and 8. None of the patients presented with significant pain, discomfort, or evidence of post-surgical infection during the study. All patients were compliant with their 1 week, 1 month, 3 month, and 6 month post-operative visits and had undergone periodontal maintenance procedures at the 3 and 6 month visits.

All data collected from the study is presented in Table 1 and paired samples statistics for this data are presented in Table 2. Table 3 includes paired samples statistics for maxillary molar sites only. Table 4 includes the results of the VAS patient survey.

From Tables 1 and 2, it can be seen that statistically significant improvements in probing depth ($p < 0.001$), clinical attachment levels ($p = 0.002$), vertical probing depth of the furcation as measured via bone sounding ($p = 0.025$) and Miller-McEntire Index ($p = 0.001$) were noted. The mean probing depth at baseline of 6.470 ± 1.302 mm decreased to 3.800 ± 1.386 mm by the 6 month visit for a mean improvement of 2.667 ± 2.067 mm. Changes in gingival recession failed to reach statistical significance ($p = 0.051$), as a mean recession of 0.670 ± 0.900 mm at baseline increased to 1.167 ± 0.994 mm by 6 months for a mean increase in recession of 0.500 ± 0.906 mm. An improvement in clinical attachment levels of over 2 mm was also noted, as a mean attachment level of 6.930 ± 1.486 mm at baseline improved to 4.767 ± 1.438 mm by the 6 month post-op for a mean improvement of 2.167 ± 2.209 mm. When bone sounding was used to measure furcation dimensions, vertical probing depth had a statistically significant decrease from 7.130 ± 1.125 mm to 6.167 ± 1.644 mm for a mean improvement of 0.967 ± 1.494 mm while the horizontal probing depth improved from 7.233 ± 1.720 mm to 6.633 ± 2.191 mm for a mean change of 0.600 ± 3.048 mm, though this change was not statistically significant (*p* = 0.459). Finally, a statistically significant decrease in the Miller-McEntire score was noted, improving from a mean baseline calculation of 4.330 ± 0.724 to 3.200 ± 1.146 at 6 months for a mean improvement of 1.133 ± 0.990.

Also from Tables 1 and 2, it can be seen that measurements of soft tissue changes in response to V-MIS, including gingival recession (*p* = 0.051), papilla height (*p* = 0.209), and papilla width (*p* = 0.902) were not statistically significant. Additionally, at baseline, 5 patients had molars exhibiting Class 1 mobility. By the 6-month follow-up, 4 of these teeth no longer had clinically detectable mobility, one molar maintained Class 1 mobility, and another molar without clinical mobility at baseline became Class I mobile by the 6-month visit. Results for bleeding on probing were inconsistent and thus were not included for statistical analysis.

Paired samples statistics isolating the maxillary molar sites treated in this study are presented in Table 3. The findings reveal that, after removal of mandibular molars from statistical analysis, statistically significant improvements in probing depth (*p* = 0.002), clinical attachment levels (*p* = 0.023), and Miller-McEntire score (*p* = 0.005) were maintained. While a mean improvement in vertical probing depth of the furcation of 0.792 ± 1.499 mm was noted, this result was not statistically significant ($p = 0.095$). However, changes in soft tissue parameters of gingival recession ($p = 0.212$), papilla height ($p = 0.102$), and papilla width ($p = 0.896$) remained statistically insignificant. In fact, when only maxillary molars were considered, the mean gingival recession experienced was only 0.375 ± 0.980 mm, less than the 0.500 ± 0.906 mm of mean recession that occurred when maxillary and mandibular sites were considered together for statistical analysis.

Outcomes from the patient survey conducted as a visual analogue scale are presented in Table 4. The results primarily revealed that patients had minimal intra and post-surgical pain, minimal limitations in chewing, swallowing, and speaking, and high patient satisfaction with both the appearance of the surgical site and the results of the procedure itself.

CHAPTER V

DISCUSSION

The results of this study demonstrate that V-MIS may lead to clinically and statistically significant improvements in probing depth, clinical attachment level, and vertical probing depth of the furcation as measured via bone sounding with minimal, non-statistically significant alterations of soft tissue parameters including gingival recession and papilla height and width in the treatment of maxillary and mandibular molars with Degree II furcation involvement. Additionally, improvements in prognosis by approximately one point as measured via the Miller-McEntire score can be expected.

Twelve of the 15 sites treated in this study were maxillary Degree II interproximal furcation defects. It is known that furcation involvement is more common in maxillary than mandibular molars (Ross and Thompson, 1980). However, interproximal maxillary molar defects are generally more difficult to detect in the early stages of disease and thus may go unnoticed until reaching a more advanced stage of periodontal destruction. It has been shown that more severe furcation defects do not respond as well to treatment compared to less severe defects (Bowers et al., 2003). This may partially explain why several studies using GTR as a treatment in maxillary molar furcation defects found minimal improvements in clinical parameters (Metzler et al., 1991, Avera et al., 1998, Pontoriero and Lindhe, 1995a). These similarly designed studies reported changes in probing depth, gingival recession, and clinical attachment level following GTR of Degree II furcation defects in maxillary molars. Metzler *et al* treated buccal and interproximal furcations and found approximately a 1.7 mm mean reduction in probing depth, a mean of 0.7 mm of gingival recession, and a mean gain in clinical attachment of 1.0 mm (Metzler et al., 1991). Pontoriero *et al* treated buccal and interproximal furcations and found a mean probing depth reduction of 1.6 mm in mesial furcations and 1.3 mm in distal furcations, mean gingival recession of approximately 1.0 mm in mesial and distal furcations and a mean gain in clinical attachment of 0.7 mm in mesial furcations and 0.6 mm in distal furcations (Pontoriero and Lindhe, 1995a). Avera *et al* treated 8 patients with Class II furcation involvement of the mesial aspect of maxillary first molars in a split-mouth design using e-PTFE membranes with GTR in experimental sites compared to open flap debridement in control sites. Results reported 9 months after surgery revealed a mean probing depth reduction of 2.88 mm, mean gingival recession of 1.38 mm and mean gain of clinical attachment of 2.0 mm (Avera et al., 1998). Casarin *et al* used EMD after root conditioning with EDTA in the treatment of maxillary interproximal Degree II defects and also found minimal improvements, including a mean probing depth reduction of 1.9 mm, mean recession of 1.0 mm, and slight gains in horizontal and vertical probing attachment (Casarin et al., 2010). Thus, the results of the current study compare favorably to these previously published reports. When considering only maxillary molar sites, the 0.375 mm of recession noted using the V-MIS technique is less than the recession noted in all of the above studies. Minimal recession and a mean probing depth decrease of 2.0 mm resulted in gains of clinical attachment of 1.625 mm, providing superior results to all but the study by Avera *et al* when compared to both GTR (Metzler et al., 1991, Avera et al., 1998, Pontoriero and

Lindhe, 1995a) and to root conditioning with EMD and open flap debridement (Casarin et al., 2010).

The 3 mandibular furcations treated in this study also responded well, with improvements in CAL of 4 mm for patients 1 and 7 and 5 mm for patient 3. In addition, patient 1 experienced a reduction of 2 mm in vertical furcation depth and 3 mm for horizontal furcation depth while patient 3 had a 3 mm reduction of vertical depth and a 4 mm reduction in horizontal depth. Again, these results compare favorably and are superior in most cases to results obtained in the treatment of mandibular Degree II furcation defects using traditional GTR (Caffesse et al., 1990) and open flap debridement with root conditioning and EMD application (Jepsen et al., 2004).

The decrease in Miller-McEntire score of approximately 1 point, from an average of 4.33 to 3.20 represents an improved prognosis and survival probability of the furcation-involved molars included in this study. A score of 4 indicates a survival probability of 95% at 15 years and 85% at 30 years while a score of 3 indicates a survival probability of 96% at 15 years and 89% at 30 years (Miller et al., 2014). Therefore, if these patients are compliant with a suggested periodontal maintenance program and follow through with necessary treatment, they can reasonably expect to retain the involved molar in function for a number of years.

As previously mentioned, results for bleeding on probing were inconsistent and thus were not included for statistical analysis. Approximately half of the patients that had BOP at baseline did not have BOP at the 6-month follow-up and the other half of patients who did not have BOP at baseline developed BOP by the 6-month visit. While a plaque index was not specifically recorded for each patient during the course of the study, it appeared that a majority of patients who developed BOP were those whose oral hygiene deteriorated over the 6-month period, despite reinforcement at each visit. Thus, it seems likely that these patients developed active gingivitis during the healing period, thereby accounting for the appearance of BOP.

Perhaps one of the most significant benefits of the V-MIS technique is the minimal recession that arises post-surgically. In the present study, approximately 0.5 mm of recession occurred after a 6-month healing period. Harrel *et al* previously reported an actual mean gain in soft tissue height of 0.2 mm when treating interproximal intrabony defects using the V-MIS approach (Harrel et al., 2014). While a gain of 0.2 mm may not be clinically significant, the lack of recession is significant. Though only minimal recession occurred in the present study, it is possible that gains in soft tissue height were not seen due to the complex nature of treating furcation involvement in molars, which are known to respond less favorably to treatment than single-rooted teeth. Previous studies using traditional, larger flap reflection than is required by the V-MIS technique in the treatment of intrabony defects associated with both single-rooted and multi-rooted teeth reported recession ranging from 0.7 to 1.1 mm (Harrel et al., 2014, Garrett, 1996). Recession can lead to esthetic compromise, dentinal sensitivity from exposed root surfaces, and an inhibition of clinical attachment gain. Thus, a technique that minimizes these drawbacks, such as V-MIS, is desirable.

Another apparent advantage of the V-MIS technique is the ability to visualize remnants of calculus that are almost invisible to the naked eye, even when using loupes.

Studies have shown that the presence of subgingival calculus is usually associated with gingival inflammation (Wilson et al., 2008). Even after thorough scaling and root planing, calculus is commonly left behind on the root surface and likely contributes to the inflammatory response (Gellin et al., 1986, Kepic et al., 1990). The videoscope allows visualization and magnification of the subgingival environment in a way that has previously been impossible. In the current study, insertion of the videoscope into the surgical site after supposed complete instrumentation of the root surface confirmed residual calculus in almost all cases, especially at the base of the defect, on the roof of the furcation and in association with small anatomic variations on the root surface. Visualization of this calculus using the videoscope allowed the surgeon to thoroughly and completely debride the root surfaces in most cases. When small remnants of calculus could not be removed using hand instruments, ultrasonics, or finishing burs, application of 24% EDTA burnished against the root resulted in a surface virtually devoid of calculus as confirmed by use of the videoscope. Enhanced calculus removal undoubtedly contributes to the superior results achieved with V-MIS.

Another advantage to the V-MIS technique includes the minimal tissue manipulation required to appropriately visualize the surgical site. Several classic wound-healing studies have confirmed that stabilization of the blood clot and wound margins and maintenance of a periosteal bed and essential blood supply to the surgical site is fundamental to sound wound healing (Wilderman et al., 1960, Hiatt et al., 1968, Dickinson et al., 2013). A majority of the flap reflection required by the V-MIS technique is supra-crestal, leaving the periosteal bed intact. Additionally, the reflected flap is so small, usually involving only a single papilla that a majority of the tissue margins remain bound down to the underlying bone, thus resulting in a more stable wound site. These advantages probably explain the minimal patient discomfort and rapid wound healing that is evident following minimally invasive surgery.

As previously mentioned, one major complication occurring intra-surgically was the loss of the interdental papilla and associated interproximal tissue that occurred upon flap reflection. Minimally invasive access is typically obtained on the lingual or palatal surface by making non-connecting intrasulcular incisions on adjacent teeth extending interproximally with a horizontal incision at the base of the papilla. In cases involving an interproximal defect extending to the buccal, gently lifting the remaining interproximal tissue and pushing it through the contact improves visual access. In molar areas, this interproximal tissue is characteristically very narrow, especially in cases of close root proximity. Thus, when the tissue is lifted and pushed facially, it becomes weak and can sever, leaving the surgical site exposed and without soft tissue coverage. The lack of adequate wound closure in these cases results in loss of graft particles and non-ideal soft tissue healing. This situation arose during the present study in the treatment of patient numbers 2, 4, 6, and 8. As can be seen from the results, these patients experienced minimal improvements in clinical parameters. In the case of patient 2, loss of interproximal tissue and inadequate oral hygiene may partially explain the poor post-operative results. Further, this patient experienced generalized periodontal degeneration during the course of the study that was not isolated to the surgical site and thus may represent a downhill patient as represented in the literature (Hirschfeld and Wasserman, 1978, McFall, 1982).

To address the problem of severing the papilla, the incision design was modified, starting with patient 9, to include a horizontal incision made much closer to the contact near the apex of the papilla. This allowed adequate visualization of the interproximal defect without the need to reflect interproximal tissue and thus, only reflection of a palatal flap was required. This resulted in maintenance of the interproximal tissue in the remaining cases and improved stability of wound margins.

While the results of the current study are promising, several weaknesses should be addressed in future research. This study was designed as an outcomes-based case series to determine the potential of V-MIS to produce superior results in the treatment of Degree II furcation defects. Randomized controlled clinical trials, preferably in a split-mouth design comparing the present V-MIS technique to full thickness, long-span flap reflection are indicated. Further, while examiners were calibrated and standardized, the reproducibility of measurements in the current study may have been difficult. An acrylic stent could not be utilized due to difficulty in using the Nabers probe around the stent. Thus, a means to increase the reliability and accuracy of clinical measurements should be developed. Finally, without histological evidence of periodontal regeneration, it can only be assumed that some combination of bone fill and true regeneration occurred as a result of the procedure. Whether or not the type of healing that occurs in these defects has any clinical significance remains to be seen and may be better determined after long-term follow-up.

CHAPTER VI

CONCLUSION

It can be concluded that, within the limitations of the study, V-MIS using combination DFDBA and EMD may result in clinically and statistically significant improvements in probing depth, clinical attachment level, vertical probing depth of the furcation as measured via bone sounding, and improvements in Miller-McEntire score with statistically non-significant changes in soft tissue measurements of gingival recession and papilla height and width in the treatment of maxillary and mandibular Degree II furcation defects. Further study of the technique as part of a randomized controlled trial is indicated.

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APPENDIX A

Table 1 All Data

All Data																					
Pt #	**Site**	**PD 1**	**PD 2**	**GR 1**	**GR 2**	**CAL 1**	**CAL 2**	**BOP 1**	**BOP 2**	**PH 1**	**PH 2**	**PW 1**	**PW 2**	**VPD F 1**	**VPD F 2**	**HPD F 1**	**HPD F 2**	**M 1**	**M 2**	**MM S 1**	**MM S 2**
1	31B	8	3	0	1	8	4	y	y	2	3	3	4	6	4	8	5	0	0	4	2
2	3D	5	7	1	2	3	6	n	y	0	0	3.5	5	9	10	2.5	11	0	1	4	5
3	19L	8	2	0	1	8	3	y	n	2	2	4	3	7	4	8	4	1	1	4	3
4	3D	7	6	2	2	9	8	y	y	3	2	5	3	6	8	8	9	0	0	4	4
5	14D	5	2	2	1	7	3	n	n	1	0.5	4	3.5	8	4	9	6	1	0	5	3
6	3D	6	4.5	1	1	7	5.5	y	n	2	0.5	3	4.5	6	6	7	5	0	0	4	3
7	19B	8	3	1	2	9	5	y	y	2	2	3	3	6	6	8	7	1	0	5	2
8	3D	6	4	1	1	7	5	n	n	0	0	3	4	7	6	7	7	0	0	4	3
9	14D	7	3	0	0	7	3	y	y	2	2	3	3	7	6	7	3	0	0	3	1
10	3D	6	4	0	1	6	5	n	n	2	0	3	3	6	6	6	4	0	0	4	3
11	14M	9	4	-1	-1	8	3	y	y	3	2.5	4	3	9	8	7	8	1	0	6	5
12	3D	6	3.5	0	3	6	6.5	n	n	3	2	4	4	8	7	9	8	0	0	4	3
13	3D	5	3	1	1.5	6	4.5	n	y	1	2.5	3	4	6	5	5	6	0	0	4	3
14	14D	6	5	0	0	6	5	n	y	3	3	3.5	3.5	8	6	8	8	0	0	5	5
15	14M	5	3	2	2	7	5	y	y	2	1.5	4	3	8	6.5	9	8.5	1	0	5	3

Table 2 Summary Statistics: All Data

Summary Statistics: All Data				
Measurement	**Mean ± SD**	**SE of Mean**	**Range**	***p* Value**
Probing Depths				
Baseline	6.470 ± 1.302	0.336	5.000 to 9.000	
6 Months	3.800 ± 1.386	0.358	2.000 to 7.000	
Change	2.667 ± 2.067	0.534	-2.000 to 6.000	<0.001
Gingival Recession				
Baseline	0.670 ± 0.900	0.232	-1.000 to 2.000	
6 Months	1.167 ± 0.994	0.257	-1.000 to 3.000	
Change	-0.500 ± 0.906	0.234	-3.000 to 1.000	0.051
Clinical Attachment Level				
Baseline	6.930 ± 1.486	0.384	3.000 to 9.000	
6 Months	4.767 ± 1.438	0.371	3.000 to 8.000	
Change	2.167 ± 2.209	0.570	-3.000 to 5.000	0.002
Papilla Height				
Baseline	1.870 ± 0.990	0.256	0.000 to 3.000	
6 Months	1.567 ± 1.083	0.280	0.000 to 3.000	
Change	0.300 ± 0.882	0.228	-1.500 to 1.500	0.209
Papilla Width				
Baseline	3.533 ± 0.611	0.158	3.000 to 5.000	
6 Months	3.567 ± 0.651	0.168	3.000 to 5.000	
Change	-0.033 ± 1.026	0.265	-2.000 to 1.500	0.902
Vertical Probing Depth of Furcation				
Baseline	7.130 ± 1.125	0.291	6.000 to 9.000	
6 Months	6.167 ± 1.644	0.425	4.000 to 10.000	
Change	0.967 ± 1.494	0.386	-2.000 to 4.000	0.025
Horizontal Probing Depth of Furcation				
Baseline	7.233 ± 1.720	0.444	2.500 to 9.000	
6 Months	6.633 ± 2.191	0.566	3.000 to 11.000	
Change	0.600 ± 3.048	0.787	-8.500 to 4.000	0.459
Miller-McEntire Score				
Baseline	4.330 ± 0.724	0.187	3.000 to 6.000	
6 Months	3.200 ± 1.146	0.296	1.000 to 5.000	
Change	1.133 ± 0.990	0.256	-1.000 to 3.000	0.001

Table 3 Summary Statistics: Maxillary Molars

Summary Statistics: Maxillary Molars				
Measurement	**Mean ± SD**	**SE of Mean**	**Range**	***p* Value**
Probing Depths				
Baseline	6.080 ± 1.165	0.336	5.000 to 7.000	
6 Months	4.083 ± 1.395	0.403	2.000 to 7.000	
Change	2.000 ± 1.719	0.496	-2.000 to 5.000	0.002
Gingival Recession				
Baseline	0.750 ± 0.965	0.279	-1.000 to 2.000	
6 Months	1.125 ± 1.090	0.315	-1.000 to 3.000	
Change	-0.375 ± 0.980	0.283	-3.000 to 1.000	0.212
Clinical Attachment Level				
Baseline	6.580 ± 1.443	0.417	3.000 to 9.000	
6 Months	4.958 ± 1.499	0.433	3.000 to 8.000	
Change	1.625 ± 2.133	0.616	-3.000 to 5.000	0.023
Papilla Height				
Baseline	1.830 ± 1.115	0.322	0.000 to 3.000	
6 Months	1.375 ± 1.110	0.321	0.000 to 3.000	
Change	0.458 ± 0.891	0.257	-2.000 to 1.500	0.102
Papilla Width				
Baseline	3.583 ± 0.634	0.183	3.000 to 5.000	
6 Months	3.625 ± 0.678	0.196	3.000 to 5.000	
Change	-0.042 ± 1.076	0.311	-2.000 to 1.5000	0.896
Vertical Probing Depth of Furcation				
Baseline	7.330 ± 1.155	0.333	6.000 to 9.000	
6 Months	6.542 ± 1.559	0.45	4.000 to 10.000	
Change	0.792 ± 1.499	0.433	-2.000 to 4.000	0.095
Horizontal Probing Depth of Furcation				
Baseline	7.042 ± 1.889	0.545	2.500 to 9.000	
6 Months	6.958 ± 2.261	0.653	3.000 to 11.000	
Change	0.083 ± 3.154	0.910	-8.500 to 4.000	0.929
Miller-McEntire Score				
Baseline	4.330 ± 0.778	0.225	3.000 to 6.000	
6 Months	3.420 ± 1.165	0.336	3.000 to 5.000	
Change	0.917 ± 0.900	0.260	-1.000 to 2.000	0.005

Table 4 Patient VAS Survey Results

Patient VAS Survey Results*			
	24-Hour Post-Op	**1 Week Post-Op**	**6 Months Post-Op**
Pain During Procedure (0 = No Pain, 100 = Severe Pain)	7.667	N/A	N/A
Pain After Procedure (0 = No Pain, 100 = Severe Pain)	11.133	N/A	N/A
Current Level of Pain (0 = No Pain, 100 = Severe Pain)	N/A	2.333	0.000
Limitations of Chewing (0 = No Limitations, 100 = Severe Limitations)	12.000	4.000	1.667
Limitations of Swallowing (0 = No Limitations, 100 = Severe Limitations)	6.800	1.867	0.000
Limitations of Speaking (0 = No Limitations, 100 = Severe Limitations)	2.333	1.800	0.000
Satisfaction with Esthetics (0 = Displeased, 100 = Pleased)	N/A	98.867	100.000
Satisfaction with Overall Procedure (0 = Displeased, 100 = Pleased)	99.333	100.000	100.000
**Reported as a mean on a scale of 0 to 100*			

APPENDIX B

24-Hour Patient Satisfaction Survey

Patient Name:
Date:

Site(s) Operated On:

Please rate your level of pain during the procedure, with "0" being no pain and "100" being the worst pain imaginable:

0------------------------25-----------------------50-----------------------75------------------------100

Please rate your level of pain after the procedure, with "0" being no pain and "100" being the worst pain imaginable:

0------------------------25-----------------------50-----------------------75------------------------100

Please rate your ability to function (chew, swallow, speak) after the procedure, with "0" being no limitations and "100" being severe limitations:

Chewing
0------------------------25-----------------------50-----------------------75------------------------100

Swallowing
0------------------------25-----------------------50-----------------------75------------------------100

Speaking
0------------------------25-----------------------50-----------------------75------------------------100

Please rate your overall satisfaction with the procedure, with "0" being displeased and "100" being pleased:

0------------------------25-----------------------50-----------------------75------------------------100

One-Week Patient Satisfaction Survey

Patient Name:
Date:

Site(s) Operated On:

Please rate your current level of pain, with “0” being no pain and “100” being the worst pain imaginable:

0------------------------25-----------------------50-----------------------75-----------------------100

Please rate your ability to function (chew, swallow, speak) after the procedure, with “0” being no limitations and “100” being severe limitations:

Chewing

0------------------------25-----------------------50-----------------------75-----------------------100

Swallowing

0------------------------25-----------------------50-----------------------75-----------------------100

Speaking

0------------------------25-----------------------50-----------------------75-----------------------100

Please rate your satisfaction with the esthetic results (how it looks) of the procedure, with “0” being displeased and “100” being pleased:

0------------------------25-----------------------50-----------------------75-----------------------100

Please rate your overall satisfaction with the procedure, with “0” being displeased and “100” being pleased:

0------------------------25-----------------------50-----------------------75-----------------------100

Six-Month Patient Satisfaction Survey

Patient Name:
Date:

Site(s) Operated On:

Please rate your <u>current</u> level of pain, with “0” being no pain and “100” being the worst pain imaginable:
0------------------------25-----------------------50-----------------------75-----------------------100

Please rate your ability to function (chew, swallow, speak) after the procedure, with “0” being no limitations and “100” being severe limitations:

Chewing
0------------------------25-----------------------50-----------------------75-----------------------100

Swallowing
0------------------------25-----------------------50-----------------------75-----------------------100

Speaking
0------------------------25-----------------------50-----------------------75-----------------------100

Please rate your satisfaction with the esthetic results (how it looks) of the procedure, with “0” being displeased and “100” being pleased:
0------------------------25-----------------------50-----------------------75-----------------------100

Please rate your overall satisfaction with the procedure, with “0” being displeased and “100” being pleased:
0------------------------25-----------------------50-----------------------75-----------------------100