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ABSTRACT

Title: Evaluation of Periodontal Changes Adjacent to Extraction Sites Following Orthodontic Tooth Movement

Sarah Courtney, Master of Science, 2015

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There is an intimate relationship between orthodontic therapy and the periodontal changes that occur during tooth movement. Orthodontic therapy often includes premolar extractions to accomplish an ideal occlusion. The purpose of this study was to evaluate the impact on the periodontium of tooth movement through an extraction site. Subjects requiring premolar extraction prior to orthodontic tooth movement were selected. Periodontal clinical parameters and hard tissue measurements were completed. Pre- and post- treatment measurements were subject to paired t-test and multivariate analysis of variance. In the results, probing depth, recession and CAL were similar pre- and post-treatment. Pre and post treatment recession differences were noted between Asian, Hispanic and African American subjects. Overall, the findings support limited soft tissue changes following tooth movement into an extraction site. Soft tissue changes following tooth movement into an extraction site appear not detrimental to the periodontal tissues.

Evaluation of Periodontal Changes Adjacent to Extraction Sites Following Orthodontic Tooth Movement

by
Sarah L. Courtney

Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, Baltimore in partial fulfillment
of the requirements for the degree of
Master of Science
2015

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List of Abbreviations

Ext	Extraction
PD	Probing depth
GML	Gingival margin location
KT	Keratinized gingiva
CAL	Clinical attachment level
TGP	Transgingival probing
Pre-tx	Pre-treatment
Post-tx	Post-treatment
Post-ext	Post-extraction
mm	millimeters
CEJ	Cemento-enamel junction
CBCT	Cone beam computed tomography

INTRODUCTION

Considerable changes occur after a tooth is extracted. Extractions can occur for a variety of reasons, and the discussion of how the tooth will be replaced is an important decision between the clinician and the patient. A tooth may be removed due to caries, failing restorations, failed endodontic treatment, orthodontic therapy, or simply to create an ideal esthetic outcome. Often, a multidisciplinary approach is needed to attain ideal treatment to replace a missing tooth or teeth. Proper alignment of the dentition will facilitate an esthetic outcome.

Orthodontic therapy can often be a recommendation if there is malalignment of the teeth or improper contacts. Such movement can improve not only the space of the edentulous site, but also the occlusion of the entire dentition. In terms of orthodontic therapy, the tooth, often a premolar, is extracted if the space is inadequate to orthodontically move the dentition into an ideal arch form. Extractions for orthodontic considerations are treatment planned to improve the facial esthetics and the maintenance of a harmonious occlusion. This is a frequent scenario in the treatment plan of orthodontic therapy.

Within the orthodontic literature, Nance[1] in 1949 described second premolar extractions in an article, the Removal of Second Premolars in Orthodontic Treatment. "The orthodontist is confronted many times with cases of malocclusion that seems hopeless to solve without removing dental units", as stated by Schoppe[2] in 1964. There has been considerable discussion and controversy on premolar extractions and the decision of removing the first or second premolar. De Castro et al.[3] stated that when first premolars are removed the transitions are abrupt in the anterior segment, but when second premolars are removed, the transitions are gradual. Once the extractions are completed, orthodontic movement is initiated.

In orthodontic therapy, ideal occlusion is created and teeth are aligned properly for an esthetic outcome. However, discussion regarding changes of soft and hard tissue after premolar extractions and orthodontic movement come into question. How does the periodontium respond to the movement? What is the cellular response following premolar extraction and subsequent tooth movement? What is the impact on the gingiva and the keratinized tissue?

The literature has described the healing response and physiological changes that occur after a tooth is extracted. Numerous articles have demonstrated marked alterations of the alveolar ridge following tooth extraction.[2,4] Pietrokovski et al. concluded that the buccal bone in both the maxilla and mandible resorb more than the lingual/palatal bone. The center of the edentulous ridge, therefore, shifts lingually or palatally, so that the arch length is reduced in the edentulous region. Such dynamic changes are most significant in the first 6 to 12 months after tooth extraction. The authors also concluded the amount of buccal resorption was almost always greater than the lingual or palatal surface in both the mandible and maxilla.[4]

Amler et al.[5] described immediate changes that occur after tooth extraction, and described new tissue formation in fresh extraction sockets in human volunteers. It was summarized that a blood clot was formed on the same day of the extraction; granulation tissue forms within the socket, and then is replaced by connective tissue within 20 days. Osteogenic cells were recognized “at the peripheral or apical alveolus” by the 7th day with continuous mineralization by day 40 post-extraction. It is now known that the modeling and remodeling of the hard tissue continues well after the 40^{th} day of extraction.

Araujo[6] in 2005, demonstrated marked dimensional alterations that occurred during the early phase (8 weeks) following the extraction of mandibular premolars in mongrel dogs. The experiment confirmed that the inner portion of the extraction socket was occupied by coagulum, granulation tissue, provisional matrix and small amounts of newly formed bone. The inner surfaces of the socket were lined with bundle bone with occasional multinucleated cells observed on its surface. The woven bone was lined with densely packed osteoblasts and included a primitive bone marrow. An important finding was marked osteoclastic activity resulting in resorption of the crestal region of both the buccal and lingual bone wall. The reduction of the height of the walls was more pronounced at the buccal than at the lingual aspect of the extraction socket.

As described, the hard tissue alterations take place and the gingiva also remodels and heal after tooth removal. After tooth extraction Schropp[2] determined there were no appreciable soft tissue alterations at the mesial and distal aspects of the teeth adjacent to the extraction site. During the first 3 months following tooth extraction, pocket reduction of approximately 1mm was obtained. Mean gingival recession of 0.7mm occurred gradually during the 12-month healing period. These results indicate that periodontal health could be altered -gingival recession occurred at the teeth adjacent to an extraction site during the healing period.

Such examples convey the healing response after tooth extraction, but does not consider the outcome following continuous tooth movement through the extraction socket for space closure with orthodontic therapy. Once the premolar has been extracted, orthodontic therapy is initiated. Although both anecdotal data and results from clinical research have documented that most forms of orthodontic therapy are innocuous to the periodontium,[8,11] some patients respond with gingival recession and loss of attachment.[7,10]

Zachrisson[8] et al in 1972 described a presentation of generalized moderate gingivitis within one to two months after the placement of [orthodontic] appliances in spite of good oral hygiene. A control group was used to evaluate plaque accumulation and gingival condition in corresponding age groups who were not being orthodontically treated. Improvements in gingival health occurred only after band removal. A reduction in pocket depths after treatment was due mainly to shrinkage of hyperplastic gingivae. Hence, the gingival changes were transient and no permanent damage to the periodontal tissues could be demonstrated with the methods used. However, in such evaluations, the clinical indices recorded assessed the gingival tissue only. The clinical indices for their assessment of oral hygiene and gingival tissues used the criteria of the Plaque Index and Gingival Index.[9] Zachrisson examined alveolar bone loss via a radiographic technique in 1974.[10] In particular, the interdental alveolar crest heights in orthodontically treated and untreated individuals were examined. A statistically significant difference was measured ($P<0.001$) when comparing the average distance between the cemento-enamel junction to the alveolar crest (CEJ-AC). The mean CEJ-AC was 1.11 mm in the orthodontic patients and 0.88 mm in the reference group. The greatest values were noted in closed extraction spaces, and particularly, on the pressure side of the retracted canines. The orthodontic patients had significantly more alveolar bone loss radiographically than did the control subjects. However, such differences were small and it was stated that the figures on bone height "cannot be claimed to represent absolute values". The study was unable to determine if the results conveyed true bone loss or a change in the bone height. The authors also suggested that the extractions could have contributed to the alveolar bone loss in the orthodontically treated group.

There are conflicting reports regarding possible loss of crestal alveolar bone related to orthodontic therapy. Polson[11] in 1984, compared alveolar bone level in patients who had completed orthodontic therapy with a control group who had never had any orthodontic treatment. The mean age for the orthodontically treated group was 28.9 years group and controls was 29.8 years with an average of 13 years since completion of orthodontic therapy. Bitewing and periapical radiographs were evaluated to determine the crestal alveolar bone level adjacent to the interproximal surface of each tooth in the maxilla and mandible. When comparing location in the arch, tooth type and surface location for molar and premolar teeth, the results found no statistical significance between the crestal alveolar bone levels (crestal alveolar bone level study group = 1.12 mm; control group = 1.23 mm; p= 0.065). These findings imply a lack of effect of orthodontic treatment on crestal alveolar bone levels. The crestal alveolar bone level dimensions described as the relation of "the alveolar bone height to a fixed reference point on the tooth surface" as determined from the radiographs and results determined no statistical difference between the groups. The authors concluded orthodontic treatment during adolescence had no detrimental long-term effect upon crestal alveolar bone levels.

Healing of an extraction socket and the impact of orthodontic therapy on the periodontium are reported separately. Unknown are the potential changes to the teeth adjacent to extraction sites once moved through these sites. More specifically, observation of these hard and soft tissue changes relative to orthodontic therapy initiated shortly after premolar extraction. Potential risks and outcomes for the periodontium following space closure have not been described.

The healing response could be altered with the addition of orthodontic movement. How does the soft tissue heal? It was suggested that soft tissue and gingival contour often mimics the underlying hard tissue topography. Ochsenbein and Ross[12] conveyed this observation during classification of the phenotypic presentation of the soft tissue. Two main types of gingival anatomy, flat or highly scalloped, were described and associated with either square or tapered tooth form. Later Seibert and Lindhe[13] introduced the term "periodontal biotype" categorizing the gingiva into "thick-flat" and "thin-scalloped" biotypes. Cook, et al[14] evaluated the relationship between clinical periodontal biotype and labial plate thickness *in vivo.* Using CBCT scans and diagnostic casts of the maxillary anterior teeth, it was determined that periodontal biotype is significantly related to labial plate thickness, alveolar crest position, keratinized tissue width, gingival architecture, and probe visibility. In 1996, Kois et al.[15] introduced a classification system relating periodontal biotype to the relationship between the CEJ and the crest of bone. Three categories were defined: 1) normal crest: alveolar crest is 3mm apical to the CEJ (85% of the population), 2) high crest: alveolar crest is <3mm apical to the CEJ (2% of the population), and 3) low crest: alveolar crest is >3mm apical to the CEJ (13% of the population). Kois et al. described treatment outcomes in each of the three crestal positions and suggested that clinical outcomes were strongly related to the gingival/alveolar crest form. A 2010 publication by Fu et al.[16], using CBCT evaluation and cadaver heads, determined that the labial gingival thickness was moderately associated with the underlying bone thickness. The purpose of the study was to determine the thickness of both soft tissue and underlying alveolar bone and to establish the association between tissue biotype and the underlying bone morphology. The periodontal probe was used to determine the biotype by the method of probe transparency, and a caliper used to measure the hard tissue thickness. CBCT scans were also completed during the study. There were no statistically significant differences between radiographic and clinical measurements of both bone and labial soft tissue thickness except in the palatal soft tissue measurements. From this study it could be preliminarily concluded that CBCT measurements of both bone and labial soft tissue thickness are accurate when compared to the use of a periodontal probe and caliper. Using a direct measure with a periodontal probe of gingival thickness first described by Greenberg[17] in 1976, gingival tissue thickness or "vertical bone sounding" was defined as thick (biotype) when the thickness was ≥1.5 mm. When thickness was ≤1.5 mm, it was considered a thin tissue biotype. Transgingival probing, and bone levels measured at surgery on the buccal surfaces of 106 teeth, had similar results between the two methods of measurement[4].

It has been suggested that recession of the gingival margin frequently occurs in sites where teeth either lack or have a thin layer of buccal bone over the root surface. Dehiscences are commonly found at the malpositioned teeth.[19] Lang and Loe[20] suggested that at least 2mm of keratinized tissue (1mm of attached gingiva) was necessary to maintain clinical health. Recession may also occur during orthodontic therapy where an inadequate zone of attached and keratinized gingiva exists.[21]

Orthodontic movement of incisors and premolars may result in recession of the gingival margin and loss of connective tissue attachment. Five adult monkeys were evaluated for soft tissue changes following orthodontic movement.[7] The undesired side effects occurred in areas with gingivitis and in situations when the tooth was moved through the envelope of the alveolar process but appeared to be unrelated to the width of the zone of keratinized gingiva.

However, teeth that presented with no keratinized gingiva prior to orthodontic therapy may not change in dimensions at the completion of therapy.[22] The results by Coatoam et al. supported that the orthodontic therapy did not lead to a poor outcome. The study did mention an alteration of the soft tissue in some of the teeth described as a gingival cleft. Overall, the findings determined that mucogingival deformities noted after orthodontic therapy are often the result of a pre-existing mucogingival problem.

As suggested, potential periodontal outcomes of orthodontic therapy include bone loss, recession and/or apical migration of the gingival margin location. Additional soft tissue changes include gingival clefts, which were described as "a crease in the gingival tissue". Such a crease was demonstrated in the gingival tissue between the papilla on either side [of the premolar extraction site] and the compressed epithelium overlying the tooth socket[31]. Robertson et al.[23] in 1977, evaluated 40 active retention human subjects and reported the prevalence of infolding or invagination of the gingival tissue. This soft tissue invagination varied from a shallow groove to a definite cleft exceeding 1mm in depth. According to the definition by Robertson et al., gingival invagination is a linear invagination of the interproximal tissue with mesial and distal orientation. Fourteen out of the 40 orthodontic patients (35%) demonstrated interdental clefts associated with one or more of the bicuspid extraction sites. Approximately 78% were associated with the extraction site of a mandibular first premolar and of these, 70% were observed in the buccal interproximal area. Coatoam[24] in 1981 reported gingival clefts in two out of seven teeth that started with no keratinized gingiva.

Histologically, the invaginated gingival tissue consisted of fibrous connective tissue covered by a layer of stratified squamous epithelium. No clefts were noted in premolar areas of a comparable population without previous orthodontic treatment. The authors concluded that the presence of the gingival clefts appear to have clinical implications, both in orthodontic relapse and maintenance of gingival health. Gingival invaginations display hyperplastic changes including epithelial hyperkeratinization with pronounced depth proliferation at the edges of the invagination.[26] Adjacent to an invagination, marginal bone resorption was noted in the histologic evaluation. Few inflammatory cells were detected in the adjacent soft tissue. Results of the histologic evaluation corroborate with findings of Ronnerman et al.[26] and Kurol et al.[27] Ronnerman et al.[26] in 1980, obtained biopsy specimens and found hyperplasic tissue with increased metabolism in the invaginated epithelium after extraction of maxillary first premolars. It was concluded that stimulation from the orthodontic forces was responsible for the hyperplastic tissue reaction. A follow up study in 1982 published by Kurol et al.[27] conveyed that "the forces exerted by orthodontic appliances seemed to induce 'sublethal damage' to the gingival tissues in young humans, as reflected by epithelial hyperplasia, invaginations and the development of a connective tissue susceptible to inflammatory reactions." Malkoc et al.[28] attributed these histologic changes to the interruption of the continuity of the gingival fiber system and bone remodeling that occur

with destruction of the cortical plates, socket healing and root movement. Another suggested rationale is the displacement of the gingival fiber system with the resultant invagination due to passive folding of the gingival tissue.[30] The etiology of invaginations is not completely understood. Atherton et al.[30] in 1970, determined that if tooth movement is slow, the tissue is no longer "sunk beneath the general level of the gingiva." Therefore, calculated orthodontic movement could control gingival invagination.
Overall, the formation of a gingival cleft is recognized in the literature, and is noted in areas where space was closed after premolar extraction. Evaluation of possible gingival clefting associated with premolar extraction sites (both mandibular and maxillary premolars) after orthodontic space closure and soft tissue changes of the teeth moved through those extraction sites will be a focus of this the study.

Specific Aim of the Study

The specific aim of this study is to evaluate the impact of orthodontic tooth movement after premolar extraction through an extraction site on the periodontium. The focus considers the hard and soft tissue changes at the proximal surfaces of the adjacent dentition, and the observation of gingival invagination of the adjacent teeth of the extracted premolar.

The study will provide a detailed evaluation that may consider an unrecognized impact on attachment level, gingival height, and location of the gingival margin adjacent to extraction sites after space closure.

Participant enrollment

After approval of the protocol by the Institutional Review Board of the University of Maryland School of Dentistry, Baltimore, Maryland, 50 subjects (32 females and 18 males, aged 11 to 55 years; mean age: 18.18) who required premolar extraction with subsequent space closure for orthodontic therapy were selected from the Orthodontic clinic at the University of Maryland Dental School. Subjects were included in the study if they met the following criteria: 1) were beginning orthodontic therapy in the postgraduate department 2) treatment planned for bicuspid extraction with subsequent orthodontic space closure; 3) non-contributory medical history; 4) presented with permanent dentition. Patients were excluded from the study if they: 1) presented in the primary or mixed dentition stages; 2) significant medical history; 3) localized periodontal disease of the adjacent tooth sites.

Orthodontic evaluation and records, including models, lateral cephalometric radiograph, panoramic radiograph, and intra-oral and extra-oral photographs were obtained. Once the patients were enrolled and patient (or parent/guardian) had given written informed consent, a referral was completed for premolar extraction.

Extraction Procedure

Periodontal evaluation and subsequent extractions were completed in the postgraduate Periodontics department by periodontics residents. A review of post-extraction instructions were completed verbally and in writing with patient (and parent/guardian if appropriate). Examiners were calibrated for all periodontal measurements. Three examiners were calibrated, completed extractions as well as pre-extraction and immediate post-extraction measurements (SC, AH, RG).

Local infiltration was completed with the use of topical anesthetic. Once properly anesthetized, periodontal parameters were measured using a Moffit probe with Williams O markings, endodontic probe, and caliper (in millimeters). Periodontal probing depth (PD) measurements of the adjacent teeth were completed (6 sites per tooth; mesial-buccal, mid-buccal, distal-buccal, mesial-lingual/palatal, mid-lingual/palatal, and distal-lingual/palatal). Periodontal probing was completed three times at each site to ensure accurate charting. The measurements were than averaged. Keratinized tissue (KT) and gingival margin location (GML) was also measured at adjacent teeth. The location of the gingival margin was measured by calculating the distance from the free gingival margin to the cemento-enamel junction (FGG-CEJ). Transgingival probing (TGP) was also completed at both the buccal and lingual/palatal aspects of each tooth site to measure gingival thickness. Measurements were repeated after the extraction procedure and included probing depth, gingival margin movement (FGM-CEJ), width of keratinized tissue, and the presentation of gingival invagination. Post-measurements did not include transgingival probing or hard tissue evaluation.

Atraumatic, flapless extractions were completed using a periodontal periotome, 15 blade, extraction elevators and extraction forceps. Sockets walls and buccal plate were preserved during each extraction. Sockets were debrided with a bone curette, irrigated with sterile saline, and hemostasis was obtained with gauze and light finger pressure.

Immediate post-extraction measurements included socket distance (distance of space closure) in a mesial-distal direction. With a periodontal probe, the mesial aspect of the adjacent distal tooth and the distal aspect of the adjacent mesial tooth were measured. These include the 'inside sites' which are proximal to the extraction socket (Figure 1). The 'outside sites' were also measured and are illustrated in Figure 2. The 'outside sites' include the distal aspect of the adjacent distal tooth and the mesial aspect of the adjacent mesial tooth in relation to the extracted premolar. A metal caliper was used to measure the buccal plate thickness at the alveolar crest, 3mm apical to the crest, and 6mm apical to the crest. During use of the caliper to assess the labial plate thickness, there was no force being placed once the tips of the caliper where contacting tissue. Care was taken to not distort the tissue during use of the instrument. The periodontal probe was used to accurately measure the appropriate distance from the alveolar crest. The caliper was held in place between the labial gingiva and the buccal aspect of the internal socket wall to assess the thickness of the labial bone. Measurements were repeated three times and the mean calculated.

Orthodontic therapy began within weeks after the extractions. Once space closure at each site was attained as determined by the orthodontic resident, periodontal parameters were measured again at the teeth adjacent to the former extraction site. All post-treatment measurements were completed by a single examiner (SC). These measurements include periodontal probing depth (6 sites per tooth), gingival margin location (FGG-CEJ), and width of keratinized tissue. The interdental soft tissue was clinically assessed and evaluated for the presence of gingival invagination. Transgingival probing or hard tissue evaluation was not repeated post-space closure. A second examiner (RG) measured the severity of the gingival invagination using a classification founded by Reichert[5,6] in 2011. Categorizing the severity of the gingival defect was calculated by three planes of measurement (X, Y, Z), including width, height, and depth of the invagination, respectively. A code was formed to define severity of the gingival invagination in units of millimeters squared (mm^2). The severity of the gingival invagination is defined by the parameter 'Level of certainty'[32], LC^2 = (probing depth, vestibular)^2 + (probing depth, vertical)^2 + (probing depth, oral)^2. The periodontal probe was used to determine the three planes: vestibular orientation (parallel to the occlusal plane), oral orientation (parallel to the occlusal plane), and vertical orientation (90° to the occlusal plane).

Statistical Analyses

To evaluate the clinical parameters measured and the subject's demographic data, a multivariate analysis of variance was performed. A paired t-test was also completed to compare the clinical parameters by tooth site and to compare pre- versus post-treatment measurements. Data analyses were performed using statistical software, JMP10, Carey, NC, with a statistical significance of $p<0.05$.

Twenty-one patients completed the entire study, including premolar extraction, pre- and post-periodontal measurements, and orthodontic therapy. In total, 74 premolar teeth were extracted in preparation for orthodontic therapy. Of the 21 subjects, 12 were male and 9 were female. Subjects were also categorized by age. The majority of participants (90.5%) were below the age of 18 years. Only two subjects were in the age range between 19-55 (9.5%). Demographical data was categorized by race: Asian, African American, and Hispanic (Table 1).

The subjects who did not complete both pre and post-measurements were excluded from the statistical analysis. There were a large number of subjects excluded due lack of available measures. Two participates declined the initial treatment of premolar extractions, 3 patients delayed the scheduled extraction appointments, and 3 patients completed extractions under intravenous sedation and which did not permit measurements completion. In addition, multiple patients failed their follow up appointments for post-measurements. It is important to state that due to time limitations, not all space closures were complete at the time of the post-extraction measurement. Measurements were taken whether space closure was complete or not, but site closure was recorded. Out of the 21 subjects involved in the study, 15 of them had a total of 4 premolar extractions completed. One subject had 3 premolar extractions due to an unerupted maxillary canine, and 5 subjects had 2 premolar extractions completed in the study. Total number of teeth extracted by tooth number is reviewed in Table 2.

Table 1. Subject Population Demographic Data

	Total Subjects (N=21)	Proportion
Gender		
Male	12	57.1%
Female	9	42.9%
Age (years)		
11-18	19	90.5%
19-55	2	9.5%
Race		
Asian	4	19.0%
Black	12	57.1%
Hispanic	5	23.8%

Table 2. Total Number of Teeth Extracted by Tooth Number.

Tooth #	Total extracted
4	6
5	14
12	15
13	5
20	6
21	11
28	10
29	5

Soft and Hard Tissue Alterations

Keratinized tissue (KT) was measured at the buccal aspect of the extraction site immediately before premolar extraction. The post-extraction KT measurements of the teeth anterior and posterior to the extracted tooth had a statistically significant greater width ($p<0.05$) than that of the extracted tooth. The mean KT width was 3.7 mm ±1.3 prior to premolar extraction. The mean buccal KT width was 4.6 mm ±0.2 at the post-extraction exam. The posterior tooth had a mean buccal KT of 4.9 mm ±1.3 ($p=0.00$) and the anterior tooth presented with a mean KT of 4.3mm ±1.6 ($p=0.01$). Both post-extraction measurements were statistically significant when compared to the pre-treatment.

When comparing periodontal probing depth adjacent to the extraction site (inside sites) before and after premolar extraction, no statistically significant difference was found ($p > 0.05$). The mean probing depth of inside sites closest to the extraction socket was pre-extraction equal to 3.0 mm ±0.5mm and post-extraction was 2.8 mm ±0.6 mm, respectively. However, a trend was suggested of probing depth reduction post extraction. A larger study population may have recognized statistically significant data that was undetected in this sample size. Probing depth was also measured at the outer aspects of the adjacent teeth (distal aspect of the posterior tooth and mesial aspect of the anterior tooth). The mean probing depth of the outside sites pre-extraction site was 2.9 mm ±0.5 mm and post-extraction measurement was 2.9 mm ± 0.5 mm. No statistically significant differences were found for mean probing depth measurement between inside and outside sites before and after treatment.

Figure 1. Illustration of Inside Sites Measured

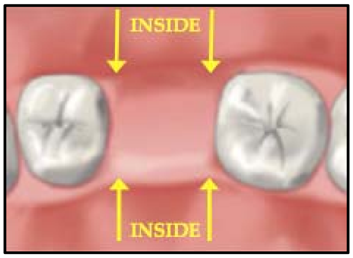
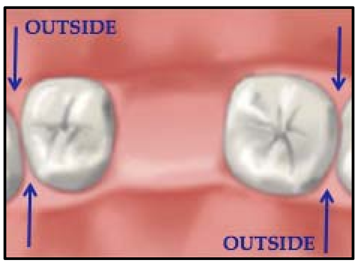


Figure 2. Illustration of Outside Sites Measured



Gingival margin location (GML) was measured at the neighboring teeth to the extraction site. The inside and outside sites were individually measured and compared between pre-extraction and post-treatment values. The inside sites had a pre-extraction GML value of -1.7 mm ± 0.9 mm, and an inside post-extraction mean GML value of -1.7 mm ± 0.7 mm (summarized in Table 3). Though there was a small decrease in gingival margin height, the results were not statistically significant. The mean pre-extraction GML of outside sites was -1.7 mm ± 0.8 mm and post-extraction was -1.6 mm ±0.7 mm. No significant differences were noted pre-extraction and post-extraction for mean GML ($p=0.10$) for gingival margin position adjacent to the extraction sites.

Mean clinical attachment level (CAL) was calculated at the inside and outside sites before and after the premolar extractions. The mean pre-extraction CAL for inside sites was 1.2 mm ±0.9 mm and a mean post-extraction measurement was 1.1 mm ±0.6 mm ($p > 0.05$). Therefore, no significant change in CAL measurement occurred at the sites adjacent to the premolar extraction site. The soft tissue clinical parameters measured are summarized in Table 3.

Table 3. Comparison of Mean Values in mm of PD, GML, & CAL for Inside and Outside Sites at Pre-Treatment & Post-Extraction

Clinical Parameter	Location	PRE-extraction	POST-extraction
PD	Inside	3.0mm ±0.5	2.8mm ±0.6
PD	Outside	2.9mm ±0.5	2.9mm ±0.5
GML	Inside	-1.7mm ±0.9	-1.7mm ±0.7
GML	Outside	-1.7mm ±0.8	-1.6mm ±0.7
CAL	Inside	1.2mm ±0.9	1.1mm ±0.6
CAL	Outside	1.2mm ±0.8	1.3mm ±0.6

No statistically significant differences were found between inside & outside sites, and between pre- and post- treatment measurements. p=0.05.

Clinical parameters and change for between pre-treatment and post-treatment was analyzed with respect to gender, race, and age. Subjects identified as Asian, Hispanic, and African American subjects were included in this analysis. When comparing periodontal probing depth, there were no significant differences between racial groups before or after the premolar extraction at the specific sites measured. There was mean PD change of 0.4 mm ±0.2 mm at the inside sites and a 0.3 mm ±0.2 mm at the outside location (F ratio=1.17, Prob>F=0.32). The mean change in probing depths for African American and Hispanic groups was a tenth of a millimeter or less when comparing pre- and post-treatment measurements (shown in Table 4). In addition, no significant differences were found when analyzing by race comparing the mean buccal or lingual probing depths of the adjacent to the extraction sites.

The change in gingival margin location relative to the CEJ (cemento-enamel junction) was evaluated at each site. The Asian group had statistically significant apical migration of the gingival margin relative to the CEJ at the post-extraction inside sites when compared to Hispanics and African Americans (Table 5 and Table 6). In the Asian population, post-treatment inside gingival margin measurement (GML) was compared with the inside pre-extraction, the overall change in the Asian subjects was 0.7 mm ±-1.1 mm (standard error) at the inside location and was statistically significant compared to the Hispanic population (-0.04 mm ±-0.4) and African American population (0.1 mm ±-0.1), as depicted in Table 5. The mean change of GML was statistically significant in the Asian population at the outside sites when comparing by race, which is demonstrated in Table 6.

Table 4. PD measured at inside & outside sites, Delta by Race

Race	Delta PD inside, pre versus post-tx (mean ± standard error)	Delta PD outside, pre versus post-tx (mean ± standard error)
Asian	**0.4 ± 0.2 mm**	**0.3 ± 0.2**
Hispanic	**0.1 ± 0.2 mm**	**0.0 ± 0.1**
African American	**0.1 ± 0.1mm**	**-0.0± 0.1**

Table 5. Comparison of GML Change at Inside Sites by Race.

Race (N)	**Mean change**	**SE (standard error)**
Asian (11)	-0.7 mm*	-1.1 mm
Hispanic (18)	-0.0 mm	-0.4 mm
African American (44)	0.1 mm	-0.1 mm

Table 6. Comparison of GML Change at Outside Sites by Race.

Race (N)	**Mean change**	**SE (standard error)**
Asian (11)	-0.8 mm*	0.2 mm
Hispanic (18)	-0.1 mm	0.2 mm
African American (44)	0.0 mm	0.1 mm

The mean GML change for the Asian subjects was -0.8 mm ±0.2 mm was statistically different when compared to Hispanic and African American subjects (-0.1 mm ±0.1, 0.0mm ±0.1mm, respectively). When comparing pre-extraction vs. post-extraction measurements, an apical migration of the gingival margin relative to the CEJ at the inside and outside sites of the extraction site was correlate with Asian race.

The transgingival probing (TGP) indicative of tissue thickness and patient biotype at the buccal aspect of the extraction site was also correlated with race. Soft tissue thickness at both the buccal and lingual aspects did not differ between groups. The mean TGP of the buccal aspect (immediately post-extraction) was 2.4 mm ±0.3 mm (standard error) in the Asian group, 2.6 mm ±0.2 mm in the Hispanics, and 2.9 mm ±0.2 mm in the African American group. Overall, gingival biotype or thickness measured by TGP was not statistically different when comparing race. There were no statistically significant changes when comparing the immediate post-extraction TGP value to Hispanics and African American subjects.

In addition, the bone thickness measurements were compared by race and no statistically significant differences were found. Bone level was measured at the crest (0 mm), 3 mm apical to the crest, and 6 mm apical to the crest. At the crest of bone, the Asian population had a mean thickness of 1.5 mm ±0.3 mm, the Hispanic subjects presented with a mean thickness 1.7 mm ±0.3 mm, and the African American study population had a mean thickness of 1.1 mm ±0.2 mm. The results are shown in Table 7. There were no statistically significant differences detected when comparing all three racial groups. The measurements taken at 3mm apical to the crest of bone did not have significant results, and all values were within 2.4 mm to 2.9 mm for all races. Both the

Asian and African American subjects had a mean 3mm buccal plate thickness of 2.4 mm. Lastly, the 6mm evaluation of buccal plate thickness was similar amongst racial groups; the values for each group were within less than one millimeter.

Table 7. Comparison by Race of Mean Buccal Plate Thickness

Bone level (mm)	Asian	Hispanic	African American
0 (crest)	1.5 mm ±0.3 mm	1.7 mm ±0.3 mm	1.1 mm ±0.2 mm
3	2.4 mm ±0.4 mm	2.9 mm ±0.3 mm	2.4 mm ±0.2 mm
6	3.5 mm ±0.4 mm	4.04 mm ±0.3 mm	3.8 mm ±0.2 mm

No statistically significant differences were found, $p \leq 0.05$.

Mean PD, GML, and TGP relative to gender was evaluated. No significant differences for these parameters were noted in the male population. However, in females differences for mean GML were found for female subjects. Asian males presented with mean GML at the pre-extraction exam of -1.8 mm, and a post-extraction value of -1.0 mm at both inside and outside sites (Table 8 and Table 9). Comparatively, Asian females presented with a mean GML value of -2.08 mm at pre-extraction, and a mean GML value of -1.66 mm at post-extraction inside site values (Table 8). Hispanic females had a mean GML value of -1.6 mm before the extraction and a post-extraction mean GML of -1.3 mm at the inside sites. Hispanic males displayed little change between pre- and post-extraction mean GML values (-1.7 mm, -1.9 mm, respectively). African American female subjects displayed a mean GML value at pre-extraction of -1.1 mm, and a post-extraction mean GML value of -1.7 mm. Lastly, the African American males showed little change when comparing pre- to post-extraction GML measurements (-2.0 mm, -1.9 mm, respectively). Similar results were detected at both inside and outside sites as depicted in Table 8 and 9.

Interestingly, there were no statistically significant differences by race for probing depth. However, when evaluating gender, a trend was noted for deeper probing depths in males than females at the inside and outside sites. At the pre-extraction examination, probing depth at the inside sites were greater for males compared to females. There were no racial differences for PD measurements. Comparative analysis of the post-extraction PD was similar for males and females.

Table 8. Comparison of Mean GML for Inside Sites by Race and Gender (mean ± SD)

Race	Asian		Hispanic		African American	
Gender	pre-tx	post-tx	pre-tx	post-tx	pre-tx	post-tx
Male	-1.8mm ±1.5mm	-1.0mm ±0.6mm	-1.7mm ±1.4mm	-1.9mm ±0.8mm	-2.0mm ±0.9mm	-1.9mm ±0.9mm
Female	-2.1mm ±0.3mm	-1.7mm ±0.3mm	-1.6mm ±0.6mm	-1.3mm ±0.2mm	-1.10mm ±0.3mm	-1.7mm ±0.4mm

Table 9. Comparison of Mean GML for Outside Sites by Race and Gender (mean ± SD)

Race	Asian		Hispanic		African American	
Gender	pre-tx	post-tx	pre-tx	post-tx	pre-tx	post-tx
Male	-1.7mm ±1.4mm	-1.0mm ±0.5mm	-1.7mm ±0.5mm	-1.7mm ±0.6mm	-1.9mm ±0.9mm	-1.8mm ±0.9mm
Female	-2.0mm ±0.3mm	-1.1mm ±0.1mm	-1.6mm ±0.6mm	-1.5mm ±0.3mm	-1.2mm ±0.3mm	-1.5mm ±0.2mm

Males had deeper mean PD post-treatment than females at the inside sites as well as the outside sites. Males had a greater PD (mean of 3.0mm) compared to females (mean of 2.8mm) of the four inside sites at the pre-extraction time ($p<0.05$). In addition, the average PD of the outside sites at post-extraction was statistically significant deeper probing depth in males versus females (3.1 mm vs. 2.6 mm, respectively). Overall, when relating gender, PD, and GML, female patients displayed greater apical movement of the gingival margin relative to the CEJ after premolar extraction than males. Males presented with deeper probing depths than females at both the inside and outside sites at pre- and post-extraction time points.

Gingival Invaginations

Gingival invaginations were recorded when present in this study. In total, seventy-four extraction sites were evaluated for gingival invagination formation during or after completion of orthodontic tooth movement. A gingival invagination occurred in 29.7% of the sites. Most gingival invaginations occurred in the mandibular arch (54.5%) at the first premolar site. The maxillary gingival invaginations were present in 45.5% of the sites (10 out of the 22 invaginations). The gingival defects were recognized more frequently in males (77.3%) than females. Out of the twenty-two gingival invaginations present, five of the sites remained open at the time of the post-treatment measurement. Therefore, 22.7% of the gingival invaginations present were not orthodontically closed.

Orthodontic therapy is a valued consideration in tooth movement for esthetics, ideal occlusion, but also for future site development for implant therapy. There are limited changes to the hard and soft tissue after premolar extraction and orthodontic tooth movement.

When evaluating the anterior and posterior teeth adjacent to the extraction sites, there were minor gingival changes that did not show statistical significance. Although trends in the tissue height change after the premolar extraction and initiation of orthodontic movement were noted. Overall, no harmful changes affected the gingival tissue. No loss of KT was noted when comparing buccal KT of the extracted premolar to the post-treatment KT of the adjacent teeth that there was not a loss of KT. The mean KT width was 3.7 mm prior to premolar extraction, and when compared to post-extraction mean buccal KT of the adjacent teeth statistically significant changes occurred. (4.6 mm at the posterior tooth, 4.3 mm at the anterior tooth) with $p<0.05$. Therefore, there was an overall increase in KT in the area of the extraction site after orthodontic movement.

As a study group, the subjects did not show significant soft tissue changes relating to GML, probing depth, and clinical attachment level. This occurred despite the likely occurrence of buccal bone resorption following tooth extraction. These results are in agreement with previous reports indicating orthodontic tooth movement has no obvious or injurious effects on gingival tissues. Reed et al.[36] demonstrated no significant difference in gingival margin location in a site of premolar extraction and orthodontic therapy. Orthodontic movement of teeth into extraction sites had no detrimental effect upon the adjacent periodontal status. The study found no significant difference for CAL and PD, but also supported no change in the gingival margin location. However, the study did not evaluate gender or race, and had a study population of twelve patients. In addition, Trossello et al.[46] compared patients with a history of orthodontic therapy (at least two years prior) with subjects who had no had any orthodontic experience. The findings suggested the effects of orthodontic treatment on the periodontium are for the most part, small. Trossello et al. reported tissue hyperplasia in the maxillary molar region suggesting increased PD, which can be harmful. In addition, the study described, "tissue bunching" that was most apparent in closed extraction sites. The study found this presentation to be most apparent in the mandibular incisor region. Overall, the study determined that the "net effect" of orthodontic therapy was relatively modest for the majority of patients although certain individuals exhibit larger changes. The changes conveyed "few hazards to the dentition and supporting structures".[46]

Though the changes were not harmful overall, when gender and race were considered, significant differences were observed. When comparing race, Asians presented with greater apical movement of the GML relative to the CEJ at the post-treatment examination. A statistically significant result of -1.20 mm apical migration of the GML was recognized when comparing Asians to Hispanics and African Americans. The negative values correlate with hyperplastic tissue, or a gingival margin coronal to the CEJ. Even with a shift to a more apical position adjacent the to the CEJ, there was no recession recorded in the mean values of the data. Nevertheless, the Asian population, especially females, is at greater risk of apical movement of the gingival margin when treatment planned for premolar extraction and subsequent orthodontic therapy.

Statistically significant differences were found based on gender for mean PD and GML. The findings support that males have deeper probing depths than females at both the inside and outside measurements in the post-extraction readings. There was an overall trend that the males had consistently deeper probing depths than females. Females tended to show greater apical GML values while males tended to show little to know gingival change before and after treatment.

Gingival Invaginations

Gingival invaginations were present in 29.7% of the study population. The gingival invagination revealed a folding or crease of the tissue. Figure 3 and 4 illustrate the remarkable soft tissue alterations that occur at the premolar extraction site after the initiation of orthodontic therapy. The prevalence of gingival invaginations found in this study is similar to that reported by Robertson et al.[23] who demonstrated that 35% of interdental clefts were associated with premolar extraction and subsequent orthodontic space closure. All subjects were in the retention phase of orthodontic therapy in the study. Therefore, all spaces were orthodontically closed.

Figure 3. Clinical Image of a Facial Gingival Invagination

Figure 4. Clinical Image of Gingival Invaginations Present Both in Maxillary and Mandibular Sites.

In the present study, five out of the twenty-two gingival invaginations detected were not orthodontically closed. Therefore these spaces were open in 22.7% of the total invaginations, which is significant and may have altered the final results of the study.

Roberston et al.[23] also demonstrated that the great majority of clefts were observed in patients with a history of first premolar extraction. It was found that no clefts were observed in premolar areas of orthodontic patients who did not require premolar extraction or in patients without previous orthodontic treatment. The publication also conveyed that the anatomical configuration of the cleft impaired the patient's ability to keep the area clean and the resultant plaque-induced gingival inflammation was significantly greater in areas manifesting clefts as compared to adjacent non-cleft areas in the same arch. The publication concluded that the presence of the cleft appeared to have clinical implications, both in terms of orthodontic treatment with a history of premolar extraction, and maintenance of the gingival health.

The invagination may impede oral hygiene[8] and prevent adequate plaque removal. Optimal brushing and flossing at the site, in addition to the orthodontic appliance, may create an environment for plaque accumulation. The known etiology of periodontal disease is bacterial plaque. Gingivitis is a prominent presentation in young patients, especially young orthodontic patients with poor oral hygiene. Factors that predispose the accumulation of will increase the risk of gingivitis. If gingival invaginations predispose, either directly or indirectly, plaque accumulation and hence gingivitis, their formation during and after orthodontic tooth movement could have an adverse effect on future periodontal health[29]. Similar to a food trap, the invagination allows predisposition of plaque accumulation and eventual inflammation. It is an important concept that the patient maintains a healthy periodontal status during orthodontic therapy, but also during the retention phase of orthodontic therapy. Overall, the gingival invagination could be a contributing factor in the disease process, with an adverse effect on the future periodontal status of the site.

A valid question to ask is, 'does the gingival invagination remain once the orthodontic appliances are removed?' A study evaluated 72 orthodontic patients and compared those who were in active treatment versus subjects who were in the retention phase for six months. The study revealed that gingival invaginations were present on the buccal and lingual alveolar surfaces, were more prominent on the mandible, and that the severity of the invagination decreased throughout the retention phase. The conclusion determined that time is the important factor in the resolution of these invaginations. However, many subjects still demonstrated invaginations months after completion of active treatment or discontinuation of all orthodontic appliances. The present study demonstrated a high percentage of gingival invaginations in patients who underwent premolar extractions with continuation of orthodontic therapy. Nevertheless, not all subjects in the study had completed active orthodontic treatment so proper follow up was not completed. The retention phase was not considered as many of the patients still presented with open contacts at the site of the premolar extraction. There may be alterations of the tissue and remodeling of the sites that may show gradual changes over time. Circuns et al.[29] reiterated the general trend of resolution of the defects over the six month retention period, but many invaginations did persist at the end of the study. The study supported that time is the important factor in the resolution of gingival invaginations.

Limitations of the Study

As stated, there were sites that had not completed orthodontic space closure at the time of post-treatment measurements. Out of a total of 74 sites measured, 17 of the sites had incomplete space. This results in 22.7% of the premolar extraction sites having open contacts at the time of the final exam. Due to this finding, the results of this study should be reviewed with caution.

Other limitations include a hard tissue evaluation in the post-treatment measurements. Anesthetizing patients for bone sounding and transgingival probing at the post-measurements would have been medically unnecessary and potentially harmful to the patient. In addition, cone beam computed tomography (CBCT) scans were not completed due to potential radiation exposure without patient benefit. Therefore, post-extraction and orthodontic movement measurements did not include hard tissue evaluation. The lack of data did not allow for proper comparison after premolar extraction and subsequent space closure.

There are other limitations within the study that are important to address due to the potential effect on the resulting outcomes. There were a number of patients that were lost throughout the study due to refusal of orthodontic therapy, failed appointments, or inability to complete measurements. The sample size of 24 was small in comparison to the original population study of 50 participants. Data may have shown statistical results and/or may have detected obvious trends if there had been a larger study population. Though there was an age range of 11-32 years, only 2 patients were over the age of 16 years. The mean age was 14.58 years old. Therefore, the study evaluated a younger age group and may have limited the potential outcomes. In addition, subjects were not matched by age or race. A proper evaluation of race would therefore require matched subjects to accurately compare the study population.

This young age group has greater frequency of poor plaque control and orthodontic appliances potentiates the shift of bacterial species form supragingival to subgingival microflora[7]. Diamanti-Kipioti, et al.[34] concluded that the placement of orthodontic bands in children (10-15 years old) in the absence of optimal oral hygiene will result in the formation of increased pocket probing depths concomitantly with an increase in the amount and shifts in the microbial composition of the subgingival plaque. A study published in 1992[8] compared the orthodontic effects between adolescents and adults. It was demonstrated that significantly higher mean values for Gingival Index, bleeding tendency, and pocket depth for both maxillary and mandibular molars when the adolescent group was compared to the adult group. Plaque indices were not measured in this study, but inflammation of the gingival tissue was a common clinical finding. The younger population in this study, and the increased risk of poor oral hygiene, may be at greater risk for gingival inflammation. Therefore, this may have affected the final results in the soft tissue measurements. Plaque indices nor was maintenance regimen recorded in this study.

The appliances not only may impede proper oral hygiene, but also create difficulty when measuring all clinical parameters. Such inflammation may induce hyperplasic tissue, which can further inhibit the ideal placement of the periodontal probe. The obstruction of the bracket could have altered an accurate measurement of the sulcus depth.

Orthodontic tooth movement occurred for all patients, but the type of movement, sequence of movements, and amount of space closure varied from patient to patient. Therefore, it can be assumed that different types of orthodontic tooth movements were initiated. Misaligned teeth were rotated, mesially-inclined, distally-inclined, and therefore, the type of movement altered the tension and compression surfaces. In addition, a limitation may also include accurate measurements due to delayed or altered passive eruption. Many of the subjects were in their teenage years, and complete eruption may not have occurred where the CEJ was not detected. Overall, there are limitations to the study that could have altered the results and therefore may have prevented detectable differences in the study population.

Future Considerations

There is a clinical consensus that a thin biotype is associated with a thin underlying labial plate and a thick or average biotype is associated with a thicker labial plate[16]. However, this report indicated no significant differences when assessing buccal plate thickness and gingival biotype (TGP).

De Rouck et al.[47] in 2009, evaluated gingival biotype in periodontally-sound maxillary central incisors and concluded that a thin, scalloped biotype was found in about one-third of the sample in mainly female subjects. Similarly, a thick gingiva was found in approximately two-thirds of the sample in mainly male subjects. The results considered tooth shape to be associated with gingival biotype. There was a trend that conveyed slender teeth to be associated with thin-scalloped type biotype, and quadratic teeth have a thick-flat biotype. The biotype (or TGP) was considered in the present study. However, the concept of tooth shape and size is a consideration for future studies.

Conclusion

In conclusion, the results convey that some patients may be at greater risk for apical migration of the gingival margin after premolar extraction with subsequent orthodontic therapy. There are limited but important changes that occur in the soft tissue during and after orthodontic therapy, including apical migration of the gingival margin relative to the CEJ in the Asian population. The results support that females may be at greater risk for apical movement of the soft tissue margin after therapy is complete. The results of the study convey that orthodontic movement after premolar extractions have statistically modest effects on the periodontium. Overall, the findings support that there are limited but important changes that could occur in the soft and hard tissue during and after premolar extraction and orthodontic therapy. Alterations of the tissues are not detrimental to the periodontal status during and after active orthodontic treatment.

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