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The Effect of Orthodontic Rotation and Proclination on Periodontium

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The Effect of Orthodontic Rotation and Proclination on Periodontium

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The Effect of Orthodontic Rotation and Proclination on Periodontium

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Abstract

Periodontium is defined as the tissues that surround and provide support to the natural dentition. Throughout orthodontic tooth movement, the forces on the teeth cause periodontal soft tissue and hard tissue remodeling. Degree of orthodontic rotation and proclination, keratinized tissue width (KTW), mid-facial recession, tissue phenotype and interdental papilla dimension are the main parameters of interest in this study as they affect the esthetic outcomes of not only orthodontic treatment, but also, other restorative dental procedures. Thus, the purpose of the study is to analyze the effect of orthodontic rotation and proclination produced by low levels of orthodontic force on the periodontium in the esthetic zone (canine to canine) during the first six months of treatment. This study is a prospective cohort study. Patients of the University of California, San Francisco (UCSF) postgraduate orthodontic clinic receiving orthodontic treatment with full fixed appliances or removable clear aligners are included. The variables measured for this study are the degrees of rotation of each tooth before and after orthodontic alignment, KTW, mid-facial recession, tissue phenotype and interdental papilla dimension. During the first six months of treatment, this study found: 1) An increase in orthodontic rotation is significantly correlated with a decrease in the alveolar housing width at the level of S1, or 3 mm apical to the cementum enamel junction (CEJ). 2) Orthodontic rotation has minimal impact on soft tissue changes in the anterior dentition. 3) Changes in degree of upper incisor inclination are correlated with an increase in papilla height and width, a decrease in midfacial recession, and a decrease in alveolar housing at the level of S1.

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1. Introduction

1.1 Background and Significance

Orthodontic tooth movement depends on the remodeling of the periodontium and alveolar bone. Orthodontic forces disrupt the periodontal space by altering blood flow and the electrochemical environment, which leads to periodontal tissue changes (d'Apuzzo et al., 2013). These tissue changes directly affect orthodontic outcomes because orthodontists must consider not only the position of the teeth, but also the periodontal tissues to achieve excellent smile esthetics. In addition to orthodontics, periodontal changes have great implications on the esthetic outcomes of restorative dentistry. In this study, keratinized tissue width (KTW), midfacial recession, papilla dimensions, soft tissue phenotype, and plaque index are the periodontal parameters of interest because of their importance in achieving a stable, healthy, and esthetic outcome.

KTW is an integral component of the periodontium and is clinically significant because decreased width is associated with poorer esthetic outcomes and has effects on long-term stability in restorative dentistry. In cases where there is minimal keratinized tissue, further loss of attached tissue may predispose the patient to further mucogingival problems. For example, teeth that erupt too labially or buccally have been shown to have thinner bands of attached tissue, which may predispose these teeth to recession either by plaque accumulation and traumatic tooth brushing during orthodontic treatment (Vijayalakshmi et al., 2009).

The presence of absence of Interdental papilla is well known to influence the likelihood of achieving an esthetic orthodontic outcome. Minimal papilla fill leads to black triangles, which are esthetic concerns of both patients and clinicians. Cunliffe and Pretty (2009) found that loss of papilla or "black triangles" ranked, as the third most disliked esthetic problem perceived by patients. The level of the crestal bone and the location of the contact point influence the degree of papilla fill and orthodontists routinely perform interproximal reduction or “stripping” between teeth to lower the contact the point and minimize black triangles. In fact, it is necessary to explain that once crowding is relieved, the patient can expect black triangles as a result of the contact points becoming more coronal than when the teeth were crowded. Kurth and Kokich (2001) reported that 15% of adolescent and 38% adult patients had black triangles post orthodontic treatment to alleviate crowding. In addition to the crestal bone and location of the contact point, embrasure dimensions such as the papilla height and base width also influence papilla fill. These dimensions of the papilla have not been widely studied during orthodontic treatment and may shed light on the dimensions of the unsightly black triangle.

A thin gingival phenotype may predispose the initiation and/or progression of mid-facial recession defects, which have clear deleterious effects on esthetics. A native thick tissue phenotype has been associated with more favorable clinical outcomes following long-term periodontal care. Since the periodontal soft tissues undergo a remodeling process throughout the orthodontic treatment, the investigation of the changes of tissue phenotype and mid-facial recessions is crucial to understand the significance of orthodontic alignment on these parameters.

It is well documented that fixed orthodontic appliances increase the risk of plaque accumulation due to retention of plaque around the appliances. Thus, fixed appliances in orthodontics often induce gingivitis if patients are not motivated to maintain good oral hygiene. It is of utmost importance that patients adhere to routine prophylactic schedules. Studying orthodontic effects on periodontal health is challenging because it is often difficult to discern if the perceived soft tissue changes are a result of orthodontic tooth movements or poor oral hygiene. Therefore, this study aimed to mitigate the confounding nature of oral hygiene by taking measurements early on in treatment, when patients are motivated and oral hygiene is not as poor, as well as enforcing strict oral hygiene protocols.

Most patients have at least some teeth that are initially misaligned. Alignment is typically the first stage of treatment and its necessary to bring misaligned teeth into the arch, control the anterior posterior position of incisors as well as begin to develop the form of the arches posteriorly and anteriorly. During alignment, teeth are expected to derotate as well as procline or retrocline by tipping facially or lingually. Therefore, rotational and tipping movements are the two tooth movements of interest in this study.

By looking at changes in soft tissue as well as degrees of rotation and proclination of teeth as a result of low orthodontic forces, this study can help clarify the specific periodontal soft tissue changes that begin to happen at the beginning of treatment, when low levels of orthodontic force are employed. If any association between amount of rotation, proclination, and periodontal parameters are found, the orthodontic provider will be able to use this knowledge to anticipate changes in periodontal parameters and give patients a clearer understanding of the changes that they will see not only in their teeth, but also their soft tissue. Specifically, papilla dimensions, which have not been studied extensively, contribute greatly to esthetics and lack of papilla fill is often a primary concern of patients and restoring dentists. If we are able to understand the dimensional changes of papilla that result from light orthodontic force, orthodontists can relay this information to the restorative dentist. If future esthetic restorations are planned, this is incredibly valuable information as the restoring dentist can request interproximal reduction to be done prior to final restoration placement or plan to minimize the appearance of black triangles with the design of the final restoration. Soft tissue parameters greatly affect the esthetic outcome as well as long-term stability of dental restorations. Thus, having this knowledge has the potential to bolster communication between the orthodontist and general dentist, ultimately leading to better patient care.

1.2 Preliminary Studies

The influence of orthodontic tooth movement on periodontium has been investigated. In an early study, Edwards (1968) reported that the fibrous elements of the periodontium adapt to tooth movement in various ways, including a progressive osteogenic activity, the stretching of the wavy collagen fibers and reorientation of their directional and the existence of a type of intermediate plexus that allows an elongation of fiber bundles by “slippage” of the fibers over one another and a subsequent reorientation of the fibers in the new position. This study highlighted the interaction between the periodontium and the orthodontic tooth movement, and further confirmed a displacement of the gingiva in the direction of tooth movement.

Several studies have analyzed the change of KTW during the orthodontic tooth movement. However, the conclusions from these studies are inconsistent. In a recent study, Wang et al. (2019) found that an increase in positive torque was more likely to cause a reduction in the KTW, while no significant correlation was detected between the intrusion and retraction of the teeth and the change in KTW. On the other hand, Coatoam et al. (1981) reported a significant decrease of KTW over the maxillary and mandibular lateral incisors, but a significant increase over the maxillary cuspids, and central incisors. A significant decrease in KTW was also found in the mandibular central incisors and cuspids. The discrepancy of the study results may result from the different force and torque applied during the orthodontic tooth movement and the different approaches used for cephalometric measurements.

The multifactorial etiology of black triangles has been documented in the literature. These etiologic factors include aging of the patient, gingival biotype, interproximal space between teeth, interproximal contact and the crestal bone, tooth morphology, distance between roots, and diverging roots (Athar and Jayadev 2020). At this point, the literature has well documented the etiological factors that lead to loss of papilla, however, there is little research done on the dimensional changes, in terms of height and width, of the papilla that occur as a result of orthodontics. Kandasamy et al. (2007) studied interdental papilla height changes following alignment of anterior teeth and found that papilla height significantly increased after palatal movement of labially placed or crowded teeth and following intrusion of one incisor relative to the adjacent incisor. This study also found that papilla height decreased following closure of a diastema. Furthermore, Jeong et al. (2016) studied both papilla height and papilla base width after orthodontic closer of a diastema between maxillary central incisors. They found that on average papilla height decreased significantly by 0.80 mm and width significantly increased after orthodontic closure of the diastema. Thus, both studies concurred that following closure of a diastema, papilla height decreased. Further studies on the influence of orthodontic movement on the papilla heights and papilla width are needed to further corroborate these findings.

In terms of tissue phenotype, Olsson and Lindhe (1993) analyzed the characteristics of maxillary central incisors in a cohort of 113 subjects and showed that long-narrow teeth presented more buccal marginal tissue recession than those with a short-wide tooth form. In addition, a native thick tissue phenotype has been associated with more favorable clinical outcomes following corrective periodontal procedures, such as root coverage (Hwang and Wang,

2006) and periodontal regeneration. However, the relationship between the orthodontic tooth movements and the changes of tissue phenotypes have not yet been investigated.

Whether orthodontic tooth movements may result in mid-facial gingival recessions is a controversial topic. Wennstrom et al. (1987) reported that orthodontic therapy involving bodily movement of incisors and premolars might result in recession of the gingival margin and loss of connective tissue attachment. However, the incidence of recessions could be minimized if the movement is within the envelope of alveolar process with adequate soft tissue volume and plaque control.

2. Central Hypothesis

We hypothesized that orthodontic incisor inclination and rotation of teeth in the esthetic zone would lead to a:

1) Decrease KTW

2) Increase midfacial recession

3) Change in tissue phenotype

4) Change interdental papilla dimensions (increase width, decrease height)

5) Change in alveolar bone width

The null hypothesis is orthodontic proclination, rotation and changes in the alveolar bone width would have no effect on soft tissue periodontal parameters.

3. Specific Aims

The first aim of the study is to describe changes in the periodontal soft tissue parameters that occur during the first 6 months of orthodontic treatment. The second aim is to identify potential associations between orthodontic tooth movement and changes in the periodontal hard and soft tissue.

4. Materials and Methods

4.1 IRB Approval

Ethical approval for this study was obtained from the Human Research Protection Program of the Institutional Review Board (IRB) at the University of California, San Francisco.

4.2 Study Design

This study is a prospective cohort study. Quantitative research methodology was employed to understand the effect of orthodontic alignment on KTW, the interdental papilla height, width and fill, the soft tissue phenotype, and mid-facial recession.

4.3 Study Population

The subjects were patients from the postgraduate orthodontic clinic at the University of California, San Francisco (UCSF) beginning orthodontic treatment in 2022 with full fixed appliances or removable clear aligners. Inclusion criteria are: 1) patients with permanent dentition 11-30 years old at the start of treatment 2) Patients with misaligned, rotated teeth, defined by the American Board of Orthodontics (ABO) model grading system and 3) Patients with a non-extraction orthodontic treatment plan. Exclusion criteria are patients who have: 1) craniofacial anomalies, 2) previous orthodontic treatment or who are currently in treatment, 3) ongoing active periodontal disease, 4) preexisting clinical attachment loss and/or recession, 5) patients whose malocclusion does not allow for use of a continuous archwire, 6) congenitally missing or impacted teeth in the esthetic zone.

4.4 Clinical Protocol

Patients interested in receiving orthodontic treatment in the UCSF postgraduate orthodontic clinic were seen for the standard initial consultation, beginning records and final consultation appointments. The initial consultation was consisted of an intraoral and extraoral exam to give the patient an estimate of what their treatment would entail, treatment length and treatment fee. At this time, the study investigators were notified if the patient was recommended a non-extraction treatment plan. During the beginning records appointment a cone beam computed tomography (CBCT) scan, iTero digital scan of the dentition, and intraoral and extraoral facial photographs were acquired. Inclusion and exclusion criteria were checked by evaluating the records. At the final orthodontic consult appointment, patients were informed of the final treatment plan and were informed of the study. The treatment consent along with the study consent form were signed if patients wish to participate. Patients were treated with full fixed appliances with Ormco .022 MBT bracket prescription or Invisalign removable clear aligners.

Variables measured for this study were degree of tooth rotation, degree of central incisor proclination, KTW, the interdental papilla height, width and papilla fill, the soft tissue phenotype, mid-facial recession and plaque index. These variables were measured at two time points, T0 and T2. T0 measurements were taken prior to the initiation of orthodontic treatment and T2 is approximately 6 months after orthodontic treatment initiation. Two periodontal providers (GHL, TT) were calibrated to take periodontal probing measurements. Two orthodontic data collectors (AJ, JO) were calibrated to measure alveolar housing and rotation. One orthodontic data collector (AJ) traced all cephalometric radiographs. The intra- and inter-examiner agreement for the two periodontal examiners (TT and GHL) was > 90% within 1 mm by repeating clinical measurements two times using 12 representative teeth. The intra- and inter-examiner agreement for the two orthodontic examiners (AJ and JO) was > 90% within 5 degrees for rotation measurement and within 0.5 mm for alveolar bone housing measurement by repeating CBCT measurements two times using 12 representative teeth.

4.5 Cone Beam Computed Tomography Protocol

The CBCT scans were acquired for standard orthodontic care. Thus, the patients were not exposed to additional sources of radiation that they would not normally receive during standard orthodontic treatment at UCSF. CBCT images were obtained on the Carestream 9600 machine with the following dimensions: 16x17 cm, 300 µm field of view, 120kV, 5.0 mA, 24.0 second exposure time, and 0.125 voxel resolution. All CBCTs were oriented in the coronal, axial and sagittal planes by one examiner (AJ). Dolphin Imaging was used to generate a lateral cephalogram and to measure alveolar bone thickness from the captured CBCT.

4.6 Oral Hygiene Protocol

All patient's received thorough oral hygiene instructions from their respective provider on the day of bonding. Proper brushing (modified Bass) and flossing techniques with braces and Invisalign were explained and demonstrated to every patient. Participants were instructed to brushing at least twice a day and floss at least once a day. All patients received an oral hygiene kit which includes a toothbrush and orthodontic floss threaders.

4.7 Variables & Measurements

Rotation: Dental rotation were measured on iTero digital casts using Dolphin Imaging software. Rotation was assessed by measuring the angle between a constructed vertical line drawn between the central incisors in the maxillary and mandibular arches and the extended line of the incisal edges of each tooth (Fig 1) (Kim et al., 2018 and Al-Jasser et al., 2020).

Incisor Proclination: Lateral cephalograms was constructed from the CBCT data. The lateral cephalogram was traced using Dolphin Imaging software. The angle between the long axis of the upper incisors to the palatal plane (U1-PP) and long access of the lower incisors to the mandibular plane (L1-MP) was measured using Bjork analysis (Fig 2).

Alveolar Housing: The buccal lingual widths of the alveolar housing was measured on Dolphin Imaging software. Each tooth in the maxilla and mandible was measured at three levels apical to the cementoenamel junction (CEJ). Measurements were taken at every 3 mm along the long axis of the tooth: crestal, midroot, and apical levels, S1, S2, and S3, respectively (Fig 3) (Chaimongkol et al., 2018).

KTW: The width of keratinized tissue was measured as the distance from the gingival margin to the mucogingival junction following the long axis of the teeth. A UNC probe was used and the probe was centered mesio-distally on the tooth (Fig 4).

Interdental papilla fill: Classification of papillary height was determined based on Nordland and Tarnow's classification system. Papilla fill was classified as normal, Class I, Class II, or Class III. Normal is defined as the interdental papilla filling the embrasure space to the apical extent of the interdental contact point. Class I is defined as the tip of the interdental papilla lying between the interdental contact point and the most coronal extent of the interproximal CEJ. Class II is defined as the tip of the interdental papilla lying at or apical to the interproximal CEJ but coronal to the apical extent of the facial CEJ. Class III is defined as the tip of the interdental papilla lying level with or apical to the facial CEJ (Fig 5).

Interdental papilla width and height: Papilla height and width was assessed using a UNC probe at the mesial and the distal aspect of the studies teeth. The papilla height is defined as the distance from the top of the papilla to a line connecting the mid-facial soft tissue margin of the two adjacent teeth. Papilla width is defined as the distance between the two midfacial soft tissue margins (Fig 6) (Olsson et al.,1993).

Gingival phenotype: The gingival phenotype was recorded as "thick" or "thin" based on the probe transparency when a UNC probe placed in the buccal gingival sulcus (De Rouck et al.,2009). If the transparency of the periodontal probe through the gingival margin was visible, the tissue phenotype was recorded as "thin". If not, the gingival phenotype was recorded as "thick" (Fig 7).

Mid-facial recession: The amount of mid-facial recession was measured from the CEJ to the lowest point of the facial gingival margin. If the gingival margin was over the CEJ, the recession was recorded as a minus number; if the gingival margin was below the CEJ, the recession was recorded as a positive number. The measurement was performed with a UNC probe.

Plaque index: Presence or absence of plaque was recorded at times T0, T1, and T2. If plaque is present on any surface of the tooth, that tooth received a score of 1. If plaque was not present on any surface of the tooth, that tooth received a score of 0 (Ainamo & Bay, 1975).

4.7 Statistical Analysis

Descriptive statistics were calculated to examine trends in the data. Data were summarized using medians and interquartile ranges because the data were not normally distributed. Differences between T2-T0 were calculated. The average of the differences across all teeth were calculated for each patient. Non-parametric Spearman's correlation tests were used to show associations at a patient level between: Rotation and periodontal variables, U1-PP and periodontal variables at the U1s, and IMPA and periodontal variables at the L1s.

Results

5.1 Participant Demographics

A total of 21 patients were recruited to participate in the study. Four patients were excluded as two participants had a change in treatment plan no longer allowing them to fit the inclusion criteria and 2 participants were unable to adhere to the follow-up timeline. A total of 16 patients were included in the study analysis, with 4 males and 12 females. The mean age was 15.6 years at the start of treatment and the participant's ages ranged from 13-25 years. The initial malocclusions ranged from class I to class II end on molar and canine. On average, T2 was taken 25.3 (SD 3.5) weeks after T0.

5.2 Orthodontic Variables: Rotation and Incisor inclination

The median change in rotation from T0 to T2 was -0.7° (IQR 12.5°). 1.6% of sites did not exhibit any rotation. 45.3% of sites rotated in a counterclockwise rotation and 53.1% of sites rotated in a clockwise direction. On average the teeth with the most to least amount of rotation is as follows: LR3(9.6°), LL3 (9.5°), UL3 (8.8°), LL1(8.6°), LR1 (8.4°), UR3(7.2°), UL2 (7.2°), LL2 (7.0°), UR2 (6.9°), LR2 (6.8°), UL1 (6.1°), UR1 (5.7°).

The median value of U1-PP at T0 was 113.6° (IQR 11.8°). The median value of U1-PP at T2 was 109.4°(IQR 7.7°). The median change of U1-PP from T2-T0 was -2.0° (IQR 4.2°). The median value of IMPA at T0 was 95.3° (IQR 9.9°). The median value of IMPA at T2 was 94.0° (IQR 11.7°). The median change in IMPA from T2-T0 was 0.75° (IQR 7.0°). From T0-T2, incisor inclinations were within the range of normal and were not excessively retroclined or proclined during treatment.

5.3 Periodontal Variables

Hard tissue: Alveolar housing

The median change in alveolar housing at the crestal, S1, level was. 0.0 mm (IQR 0.9 mm). 48.9% of sites had a decrease in S1. The magnitude of decrease ranged from 0.1-1.5 mm. U3s and U1s were the tooth types with the greatest percentage (23.4%) of sites with a decrease in S1. L1s were the were the tooth type with the smallest percentage (8.5%) of sites to have a decrease in S1 (Fig pie chart?). 45.8% of sites had an increase in S1. The magnitude of increase in S1 ranged from 0.1-1.0 mm. L1s were the tooth type that had the largest percentage (26.1%) of sites that saw an increase in S1, while U1s were the tooth type with the smallest percentage (9.1%) of sites with an increase in S1. 5.2% of sites had no change in S1.

The median change in alveolar housing at the midroot, S2, level was -0.1 mm (IQR 0.9 mm). 52.1% of sites had a decrease in S2. The magnitude of decrease ranged from 0.1-2.9 mm. U1s were the tooth type with the greatest percentage (21.0%) of sites with a decrease in S2, while U2s were the tooth type with the smallest percentage (13.0%) of sites a decrease in S2. There was a 43.8% of sites with an increase in S2. The magnitude of increase ranged from 0.1 to 1.9 mm. L2s were the tooth type with the greatest percentage (21.4%) of sites with an increase in S2, while U1s were the tooth type with the smallest percentage (10.7%) of sites with an increase. 4.1% of sites had no change in S2.

The median change in alveolar housing at the apical level was -0.2 mm (IQR 0.8mm). 61.5% of sites had a decrease in S3. The magnitude of decrease ranged from 0.1-4.3 mm. L3s were the tooth type with the greatest percentage (22.9%) of sites with a decrease in S3, while U3s were the tooth type with the smallest percentage (13.6%) of sites a decrease in S3. There was a 34.9% of sites with an increase in S3. The magnitude of increase ranged from 0.1 to 1.9

mm. U3s were the tooth type with the greatest percentage (20.9%) of sites with an increase in S3, while U1s and L3s were the tooth types with the smallest percentage (13.4%) of sites with an increase. 4.1% of sites had no change in S3.

Soft tissue: Gingival phenotype, midfacial recession, keratinized tissue width, papilla fill, papilla width, papilla height

65.2% of sites showed no change in gingival phenotype. 73.2% of sites were characterized as thick gingival phenotype at T0. At T2, 68.1% of sites were characterized as thick. 20.83% of sites changed from thick to thin phenotype. The U3s were the tooth type with the greatest percentage (30.0%) of sites converting from thick to thin, while the L1s were the tooth type with the smallest percentage (7.5%) of sites that changed from thick to thin. 13.5% of sites changed from thin to thick phenotype. The L1s were the tooth type that that had the greatest percentage (46.2%) of sites that changed from thin to thick, while the U1s had the smallest percentage (3.8%) of sites that changed from thin to thick phenotype.

The median change in midfacial recession was 0.0 mm (IQR 1 mm). 41.2% of sites had a decrease in recession. The magnitude of decrease ranged from 1-3 mm of midfacial recession with 77.2% of sites exhibiting a 1 mm magnitude of decrease. The L1s were the tooth type that exhibited the greatest percentage (24.1%) of sites with a decrease in midfacial recession, while the U2s and U3s were the tooth types with the smallest percentage (12.7%) of sites with a decrease in recession. 12.0% of sites had an increase in recession. The magnitude of increase ranged from 1-5 mm with 52.2% sites showing a 1 mm magnitude of increase. The U1s were the tooth type that had the greatest percentage (26.1%) of sites with an increase in recession, while the L2s were the tooth type with the smallest percentage (8.7%) of sites with an increase in recession. Overall, 46.9% of sites had no change in recession.

The median change in KTW was 0.00 mm (IQR 1.0 mm). 24.0% of sites had a decrease in KTW. The magnitude of decrease in KTW was 1-3 mm, with 80.4% of sites showing a 1 mm decrease in KTW. L1s were the tooth type with the greatest percentage (21.7%) of sites with an increase in KTW, while U2s were the tooth type with the smallest percentage (6.5%) of sites with a decrease in KTW. 39.1% of sites had an increase in KTW. The magnitude if increase ranged from 1-3 mm with 68.0% of the sites exhibiting a 1 mm increase. U2s were the tooth type with the largest percentage (21.3%) of sites with an increase in KTW, while U1s were the tooth type with the smallest percentage (12.0%) of sites with an increase in KTW. Overall, 37.0% of sites had no change in KTW.

The median change in papilla fill was 0.0, (IQR = 25.0). 27.8% of sites had a decrease in papilla fill. 4.5%of sites increased in papilla fill. 67.9% sites did not have a change in papilla fill. At T2, 70.1% of sites were fully filled and 29.9% were partially filled.

The median change in papilla width was 0.0 mm (IQR 1.0 mm). 16.1% of sites had a decrease in papilla width. The magnitude of decrease ranged from 1-3 mm decrease with 77.8% of sites exhibiting a 1 mm decrease. The L3/4 embrasure sites exhibited the greatest percentage (22.9%) of sites with a decrease in papilla width, while the L1/1 embrasure site exhibited the smallest percentage (2.9%) of sites with decrease in papilla width. 48.7% of sites had an increase in papilla width. The magnitude of increase ranged from 1 mm to 3 mm increase in papilla width, with 64.8% of sites exhibiting a 1 mm increase. The U3/4s embrasure sites had the largest percentage (20.4%) of sites with an increase in papilla width while the L1/1 embrasure site had the smallest percentage (7.4%) of sites with an increase in papilla width. 35.6% of sites had no change in papilla width.

The median change in papilla height was 1.0 mm (IQR 1.0 mm). 15.2% of sites had a decrease in papilla height. The magnitude of decrease ranged from 1-3 mm decrease with 76.5% of sites exhibiting a 1 mm decrease. The L3/4s embrasure sites exhibited the greatest percentage (26.5%) of sites with a decrease in papilla height, while the U1/1 embrasure sites exhibited the smallest percentage (5.9%) of sites with decrease in papilla height. 52.23% of sites had an increase in papilla height. The magnitude of increase ranged from 1 mm to 4 mm increase in papilla height, with 65.8% of sites exhibiting a 1 mm increase. The U1/2s and U3/4s embrasure sites had the largest percentage (16.2%) of sites with an increase in papilla height while the L1/1 embrasure site had the smallest percentage (6.8%) of sites with an increase in papilla height. 32.59% of sites had no change in papilla height.

Plaque Percentage

9 patients had increase in plaque percentage, Ranging from 16.7%-75.0% increase. Of the patients with an increase in plaque percentage, 6 patients had full fixed appliances and 3 had Invisalign. 4 patients had a decrease in their plaque percentage, Ranging from 33.3%-100.0% decrease. Of the patients with a decrease in plaque percentage, 1 patient had full fixed appliances and 3 had Invisalign. 3 patients had no change in their plaque percentage. Of the patients with no change, 1patient had full fixed appliances and 2 had Invisalign. 1 patient had 0% plaque at both T0 and T2. Thus, 93.8% of patients had plaque on their teeth at any one time during the study.

5.4 Spearman's Correlations

Spearman's correlations analyses were conducted to examine any correlations that exist between the variables studied. A significant negative correlation exists between the average change in rotation and the average change in alveolar housing width at S1 from T2-T0 (ρ= -0.53, P= 0.034). There are no other significant correlations between the average change in rotation and the other variables studied. A significant negative correlation exists between the average change in alveolar housing width at S1 and the average change in KTW from T2-T0 (ρ= -0.51, P= 0.042). There are no other significant correlations between the average change in alveolar housing width at S1 and the other variables.

There are several significant correlations that exists between the average change in inclination at the U1s and the periodontal variables. A significant negative correlation exists between the average change in inclination at the U1s and the average change in midfacial recession from T2-T0 (ρ= -0.60, P= 0.014). Significant positive correlations exist between the average change in inclination at the U1s and papilla width and papilla height (ρ= 0.64, P= 0.0069; ρ =0.64, P= 0.0073). A significant negative correlation exists between the average change in inclination at the U1s and the average change in alveolar housing width at S1 (ρ=-0.50, P= 0.048).

Discussion

During the first 6 months of orthodontic treatment, we observed minimal changes in the dentition and periodontium across all variables. These minimal changes are likely due to the mild malocclusion at initial presentation. Degree of rotation and inclination showed changes of varying magnitudes during the study period confirming that initial tooth alignment was occurring with both fixed and Invisalign appliances. Overall, there was the presence of plaque in all patients throughout the duration of treatment. Thus, the presence of plaque induced inflammation may have confounded the periodontal soft tissue measurements.

An increase in orthodontic rotation is significantly correlated with a decrease in alveolar housing width at the level of S1. As the tooth moves, bony remodeling may lead to dimensional changes in the alveolar housing. The amount of quantified rotation on average was minimal yet most teeth did experience rotational movement with an even number rotating clockwise and counterclockwise. There have been no clinical studies studying the effect of rotation on the alveolar housing. A finite element study by Pacurar et al. (2019) investigated the effect of pure rotation using coupling mechanics; however, the investigators found no effect on the alveolar bone.

An increase in alveolar housing width was significantly correlated with a decrease in KTW. As the alveolar housing width at S1 increased there was a decrease in KTW. Coatoam et al. (1981) reported that positional changes of teeth within the bone may lead to changes in KTW. Specifically, a more lingually displaced tooth had thicker KTW. KTW may vary throughout orthodontic tooth movement as the teeth are translating through bone. Bouri et al. (2008) reported that an increase in KTW around implant sites is associated with lower mean alveolar bone loss. This finding contradicts our findings as it states that implant sites with less alveolar bone loss have greater KTW. However, the findings from Bouri et al. are not directly comparable as they were specifically examining implant sites, while we were investigating the effect of orthodontic tooth movement on the alveolar housing. The present study is the first to study to evaluate the effect of changes in the alveolar bone on the KTW.

An increase in U1-PP was significantly correlated with a decrease in midfacial recession at the U1s. Joss-Vassalli et al. (2010) found that there is significantly more gingival recession on the labial side of orthodontically proclined teeth, which is in contrast with our findings. One reason our findings may be contradictory is because the teeth being studied did not exceed normal values of inclination and were not excessively proclined or retroclined. Furthermore, movement of the incisors out of the osseous envelope of the alveolar process via incisor proclination has been found to be associated with higher frequency for developing gingival recession (Wennstrom et al. 1987). Due to the minimal movement of the teeth in this study, teeth were not moved out of the osseous envelope and thus did not cause increased levels of midfacial recession. A systematic review by Flores-Mir (2011) concluded that before orthodontic movement, a combination of poor oral hygiene, thin gingival biotype in addition to proclination of the incisors will likely produce some degree of gingival recession. Thus, the occurrence of midfacial recession is multifactorial and may not be significantly influenced with a slight degree of proclination.

An increase in U1-PP was significantly correlated with a decrease in the alveolar housing width at the level of S1. Thus, as the teeth proclined, the width of the bone decreased. Chaimongkol et al. (2017) found that when maxillary incisors were advanced labially via light-force tipping and bodily movement the alveolar bone thickness was maintained in both the treated and the untreated group. Thongudomporn et al. (2014) found the palatal and total alveolar bone thickness at the midroot and apical levels decreased when maxillary incisors were tipped labial in class III patients. In this study, the magnitude of increase of the alveolar housing width at the level of S1 was very minimal, which could explain the discrepancy between our results and the other studys' results. It is interesting to note that Thongudomporn et al. (2014) found changes in the midroot and apical levels while, we observed changes in the coronal levels of the alveolar housing. It is possible that there is remodeling throughout the entire length of the root, but due to the minimal orthodontic tooth movement in this study we were not able to appreciate those changes.

An increase in U1-PP was significantly correlated with an increase in papilla width and height. This study is the first to investigate the relationship between inclination of incisors and papilla width and height. Kandasamy et al. (2007) found that papilla height between anterior teeth lengthen following palatal movement of labially displaced or imbricated teeth. Papilla dimensions are affected by interproximal alveolar height and contact point location, age, tooth shape, proximal contact length, and gingival thickness. Inflammation of the gingival tissue due to poor oral hygiene with orthodontic appliances likely contributed to these positive correlations.

No significant correlations were found for IMPA, alveolar housing width at S2 and S3, gingival phenotype and papilla fill. These variables are understudied and there is little literature investigating thee areas. Furthermore, the minimal amount of tooth movement observed may not have been enough to lead to changes in the periodontal parameters. Plaque percentage confirmed that many of the patients had plaque present on the teeth, likely leading to inflammation that could have also masked potential changes in the soft tissues.

Limitations of this study include the small sample size, lack of control group, and the difficulty in controlling for confounding clinical variables in a large group practice. For instance, it was difficult to control for differing oral hygiene practices amongst the patients and differing clinical treatment modalities amongst the orthodontic residents treating the patients. In addition, we were unable to control for the slight variation in T2 recall due to factors out of our control such as patients being sick requiring them to reschedule their appointments.

Future directions of this study include investigating more alveolar housing parameters such as total bone volume and bone density changes to see if there are correlations between these bony parameters and the periodontal soft tissue. In addition, studies investigating the posterior dentition as well as patients with more severe malocclusions that require extractions can help us to further understand how periodontal soft tissue changes in response to orthodontic tooth movement. Future studies should aim for longer follow up in order to confirm or deny the permanence of soft tissue changes even after orthodontic tooth movement has ceased.

Conclusion

In the first 6 months of orthodontic treatment with Invisalign and full fixed appliances, orthodontic rotation is correlated with a decrease in alveolar housing width at the level of S1. Orthodontic rotation has minimal impact on soft tissue changes in the anterior dentition. Changes in upper incisor inclination are correlated with an increase in papilla width and height, decrease in midfacial recession and a decrease in alveolar housing width at the level of S1. Future prospective, randomized clinical studies that implement stricter hygiene controls during and after treatment should be conducted to further understand the relationship between orthodontic tooth movement and periodontium.

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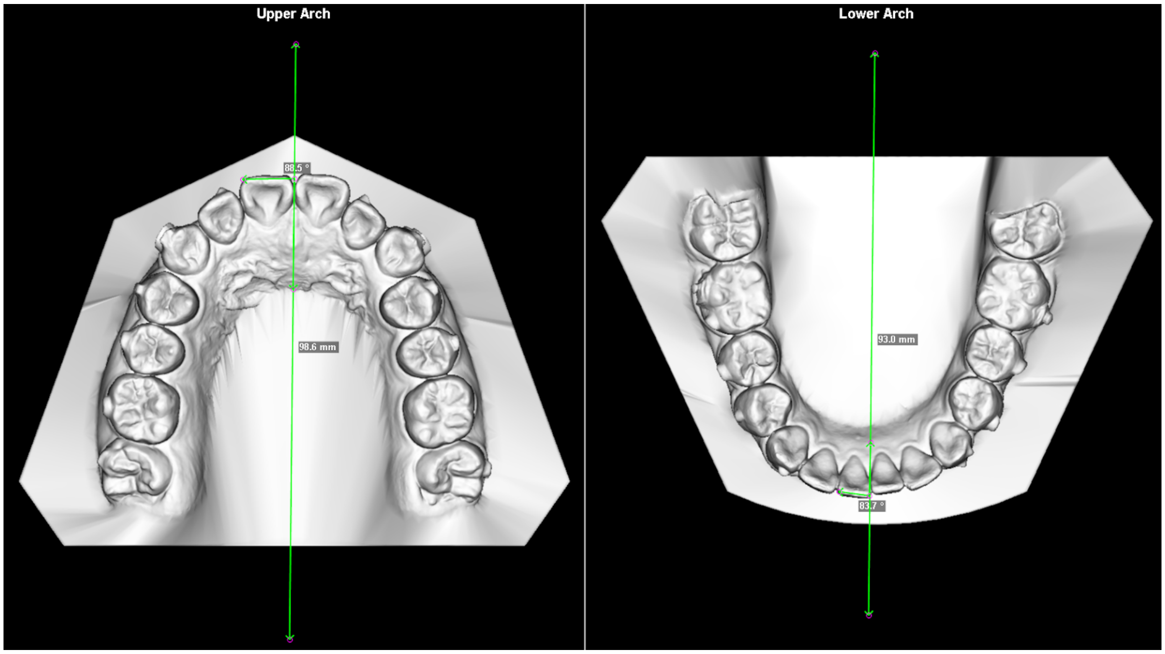
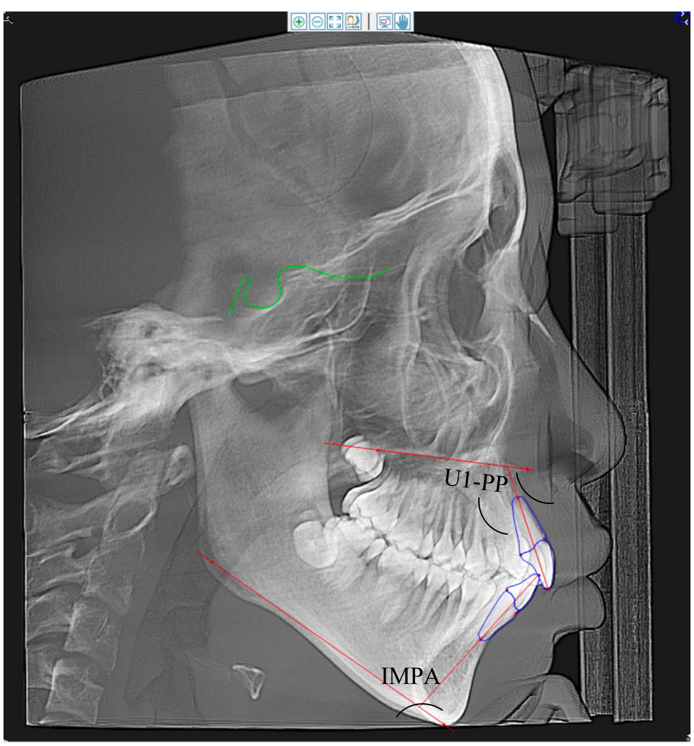
Figure 1



Rotation measurement protocol

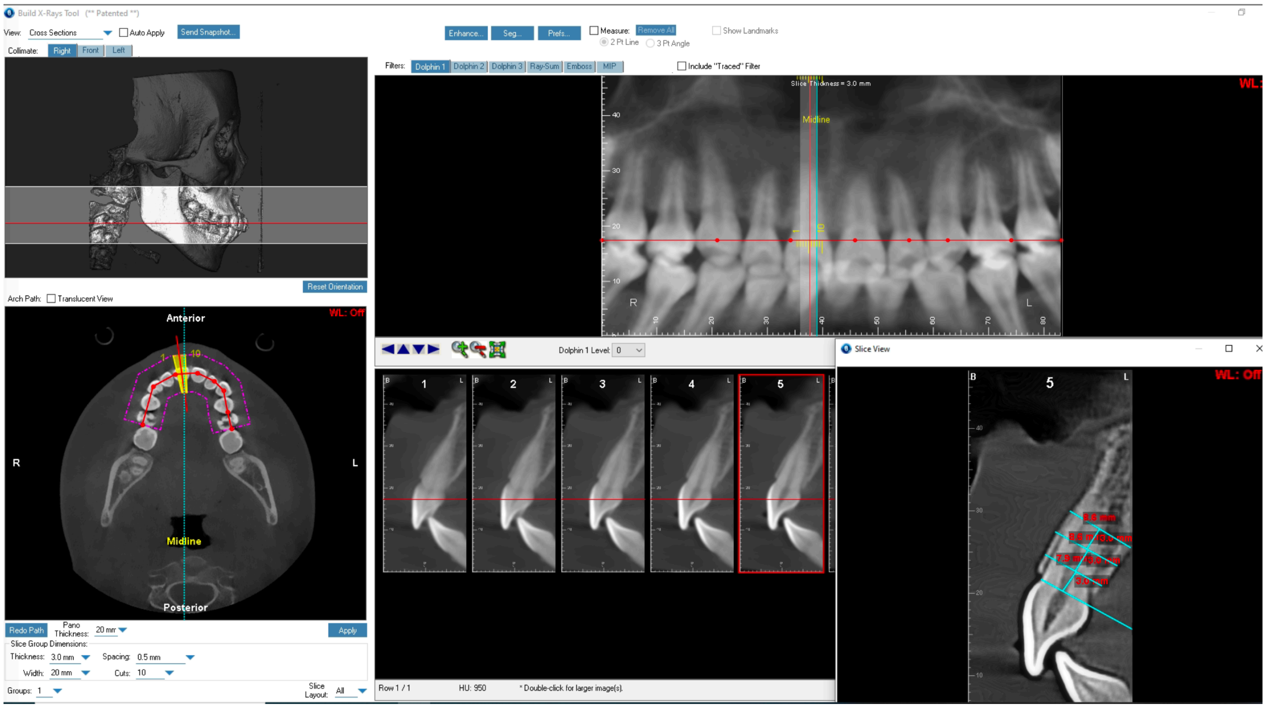
Figure 2



U1 - Palatal Plane	115.75	110.00	5.00
IMPA (L1-MP) (°)	97.02	95.00	7.00

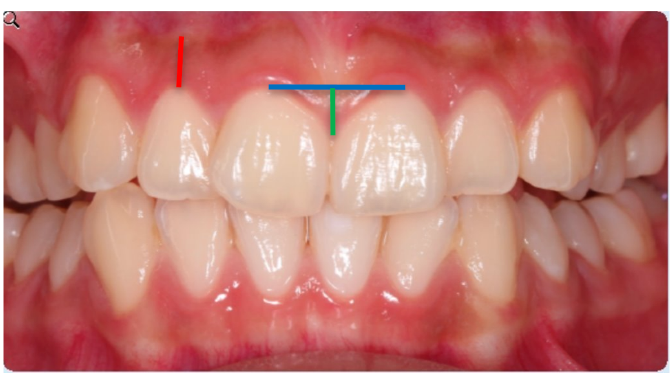
Incisor inclination measurement protocol

Figure 3



Alveolar housing width measurement protocol

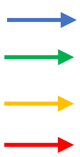
Figure 4



Keratinized Tissue Width
Papilla Width
Papilla height

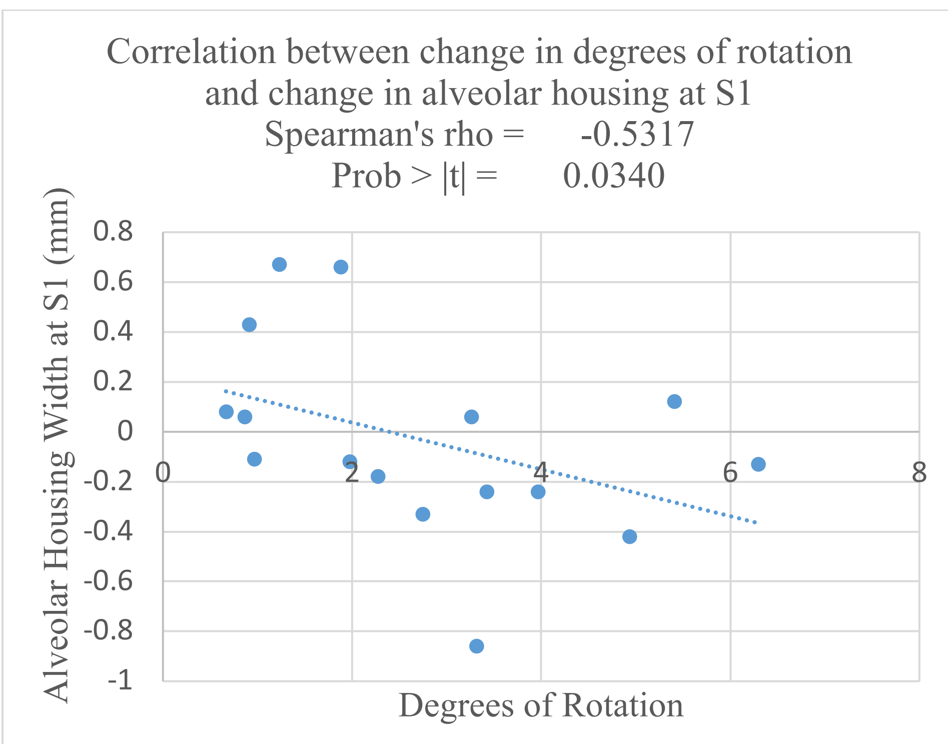
Soft tissue periodontal parameters

Figure 5



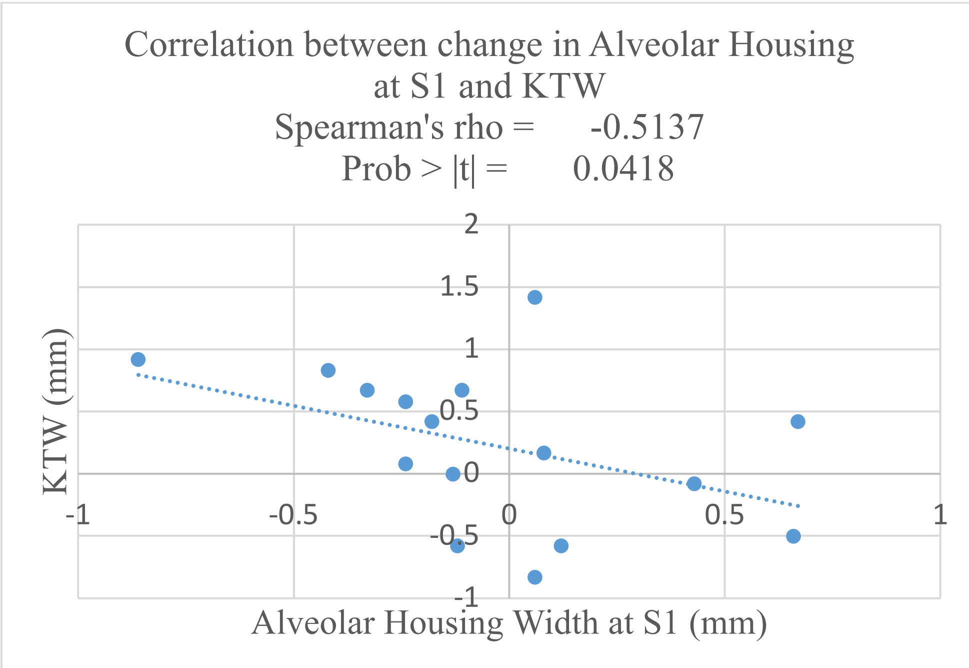
Papilla fill following Nordland and Tarnow’s (1998) classification system

Figure 6



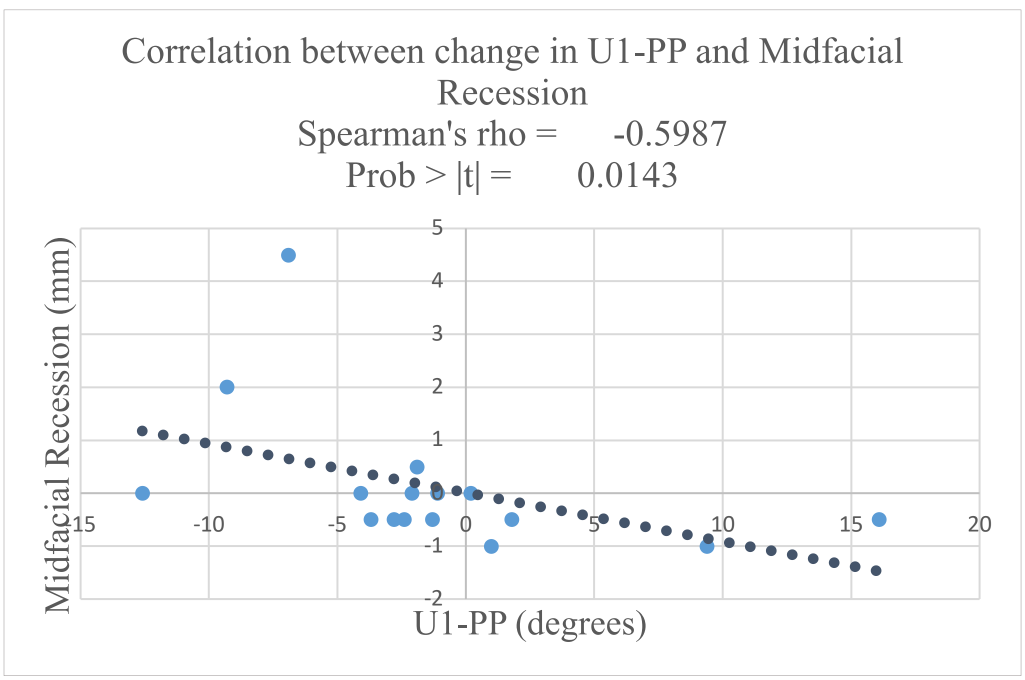
Correlation between change in degrees of rotation and change in alveolar housing at S1

Figure 7



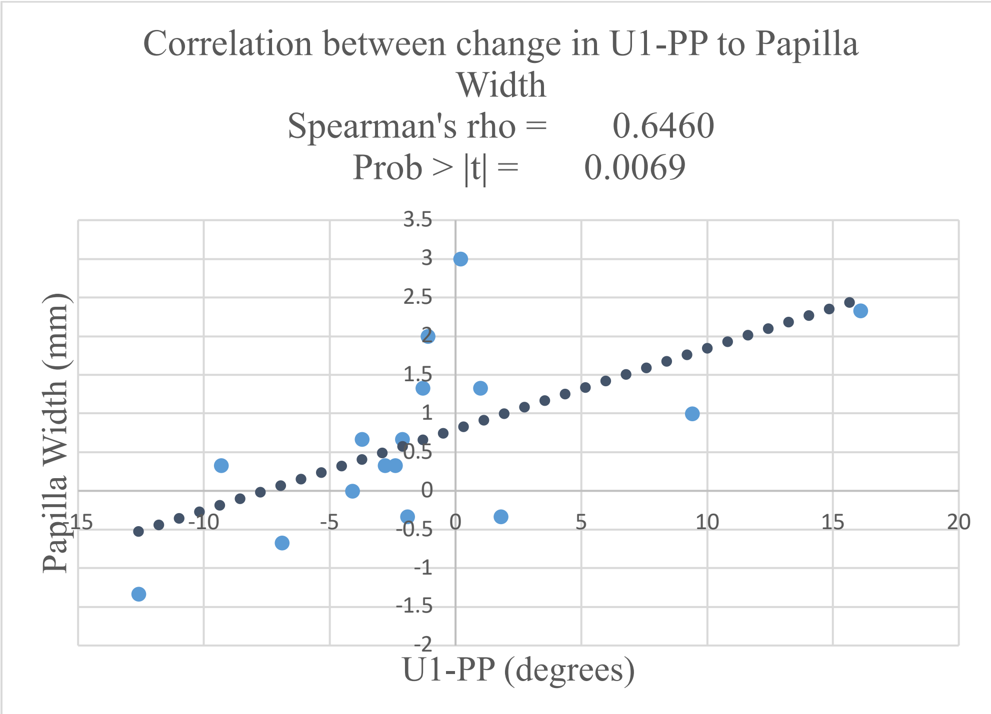
Correlation between change in alveolar housing at S1 and KTW

Figure 8



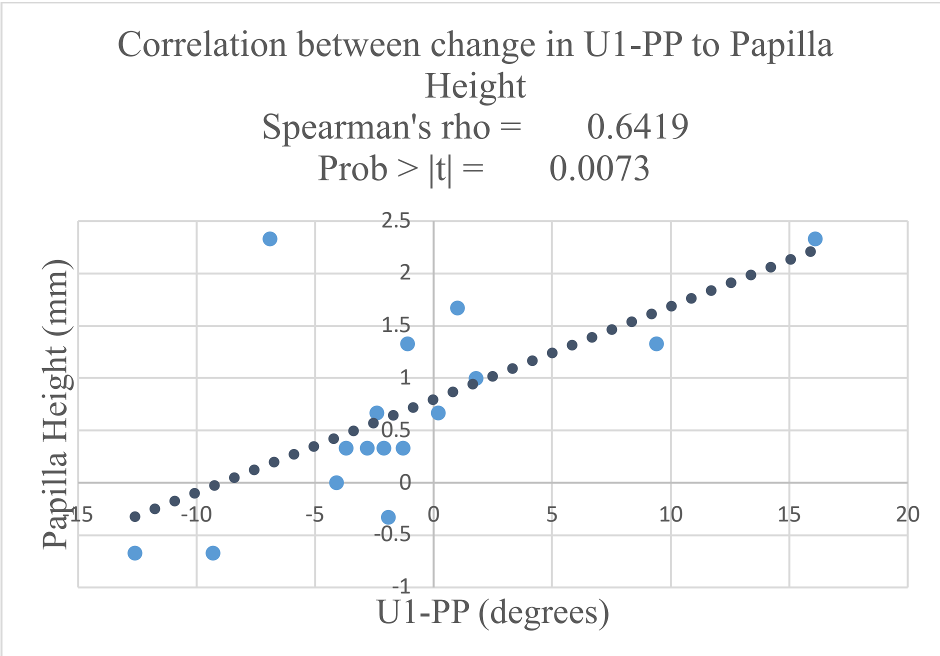
Correlation between change in U1-PP and midfacial recession

Figure 9



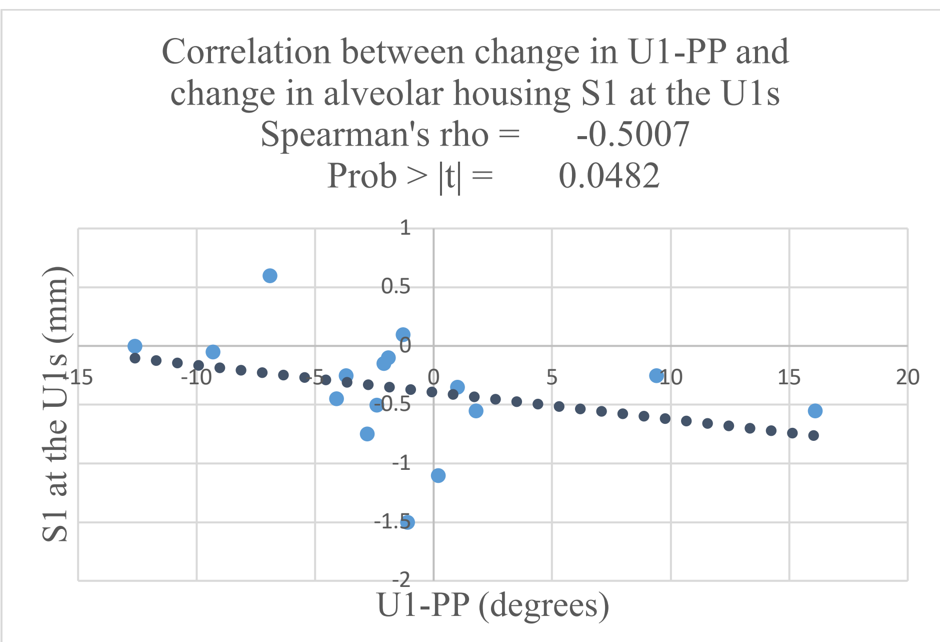
Correlation between change in U1-PP and papilla width

Figure 10



Correlation between change in U1-PP and papilla height

Figure 11



Correlation between change in U1-PP and change in alveolar housing at S1

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