POSTERIOR OCCLUSAL CONTACT CHANGES FOLLOWING TRADITIONAL BRACES AND INVISALIGN®: A RANDOMIZED CONTROLLED TRIAL

A Thesis

by

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ABSTRACT

Purpose

To compare treatment and posttreatment differences in areas of contact and near contact (ACNC) between traditional braces and Invisalign® in adults with Class I malocclusion using transilluminated bite registrations.

Materials and Methods

The sample consisted of 80 Class I patients, randomized into one of two treatment groups: traditional braces (40 patients) and Invisalign® (40 patients). The patients were treated by two standardized, ABO-certified orthodontists and were retained with upper wraparound Hawleys and bonded mandibular retainers (spanning lower canine to canine). Blu-Mousse® bite registrations and orthodontic study models were obtained at four timepoints: pre-treatment (T_1), debond (T_2), one-month retention (T_3), and six-months retention (T_4). Transillumination of the bite registrations allowed calculation of the areas of contact and near contact (ACNC, 0-350 microns) using a custom software, Halcon Contactos.

Results

ACNC decreased significantly during treatment (T_1-T_2, 68.8-72.8%), increased significantly during the first-month posttreatment (T_2-T_3, 14.4-19.6%), and further increased significantly between one- to six- months posttreatment (T_3-T_4, 11.9-16.6%). There were no statistically significant between-group differences at any of the timepoints. There also were no statistically significant between-group differences in the changes that occurred between timepoints. Trends were similar for areas of contact, areas of near contact, and total ACNC. Significant amounts of posttreatment settling were observed for both groups, with total ACNC values increasing 31.0% for traditional braces and 31.5% for Invisalign®. Total ACNC values obtained after six-months of posttreatment (T_4) settling did not attain pre-treatment (T_1) values. Traditional braces showed a 41.8% deficit and Invisalign showed a 37.3% deficit from pre-treatment values (T_1-T_4).

Conclusions

Areas of contact, near contact, and total ACNC decrease significantly during orthodontic treatment, and no significant differences were observed between traditional braces and Invisalign® for the decreases in ACNC. Statistically significant settling occurs posttreatment, with ACNC increasing approximately 31% during the first six months. Significantly more settling was seen at one-month posttreatment than the following five months posttreatment (14.4-19.6% increase after one month vs. 2.4-3.3% increase per month, respectively). Posttreatment ACNC values did not reach pre-treatment values, and a net deficit of approximately 40% was observed for both the traditional braces and Invisalign® groups. Neither treatment modality, when retained with wraparound Hawley retainers, results in a superior ACNC outcome.

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All patients included in this study were treated by two orthodontists, Katie C. Julien and Helder B. Jacob (previous faculty members of the Department of Orthodontics). Records were also collected by the treating orthodontists for each time point. The software used in this study was created and provided by Samuel I. Roldan of CES University, Department of Orthodontics in Medellín, Colombia.

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CHAPTER I

INTRODUCTION

A goal of orthodontic treatment is to provide patients with an optimal esthetic outcome and functionally stable bite. To function optimally, the literature has shown that the number of posterior occlusal contacts is critical. Bakke et al. showed that occlusal contacts are important in that they contribute to occlusal stability and are closely related to bite force.[1, 2] Increased areas of contact have also been shown to significantly impact and increase masticatory performance and efficiency.[3, 4] Following orthodontic treatment, the number of contacts has been shown to decrease from pre-treatment values.[5, 6] Sullivan et al. showed posttreatment contacts decreased to approximately 50% of their pre-treatment values following traditional braces.[5] Assessments using the American Board of Orthodontics Objective Grading System revealed that Invisalign® treatment resulted in fewer posterior occlusal contacts than traditional braces.[7-9]

Following orthodontic treatment, the teeth are seen to undergo posttreatment settling. The greatest rate of settling is typically observed during the first two months following treatment, with nonsignificant changes after six months.[10] Although settling leads to an increase in posterior contacts during the retention phase, it has also been shown that the number and locations may not improve to match pre-treatment values. [5, 6, 11]

The literature presents several methods of assessing posterior occlusion. A review of the available methods will be presented within the following literature review. More detailed assessments involve counting the numbers of contact[12, 13] and quantifying areas of contact and near contact (ACNC).[3, 4, 10, 14] The most reliable and objective means involves quantification of ACNC using transilluminated bite registrations. Transillumination enables visualization of perforated regions of the bite registration material and thus precise estimates of ACNC in square millimeters.[3, 4, 10, 14]

The purpose of this study is to compare treatment and posttreatment changes in posterior occlusion between Invisalign® and traditional braces using transilluminated bite registrations obtained at four timepoints (T_1: pre-treatment, T_2: appliance removal, T_3: one-month after appliance removal, and T_4: six-months after appliance removal) with the objective of identifying which treatment modality results in greater ACNC.

To date, there is no published literature assessing posterior ACNC in patients treated with Invisalign® or traditional braces. This lack of studies includes both the separate assessment of each treatment modality's effect on ACNC, as well as comparisons of posttreatment ACNC between the two treatments. Thus, this study is significant in that it will be the first to assess the differences in ACNC between Invisalign® and traditional braces using transillumination of PVS bite registrations taken at various time points during and after orthodontic treatment. The information provided will assist clinicians both in guiding treatment plans and in understanding posterior occlusal changes during the period following active orthodontics and into the retention phase.

CHAPTER II

BACKGROUND AND LITERATURE REVIEW

An Introduction to Posterior Occlusion

Occlusion can be divided into one of two aspects: anterior or posterior. The anterior occlusion, which involves the maxillary and mandibular central incisors, lateral incisors, and canines, should have light contact when the teeth are brought together. While anterior contact should be light in the intercuspal position, posterior occlusion – which involves the maxillary and mandibular premolars and molars – should bear heavier contacts along the axes of the dentition.[15] Anterior occlusion has been studied more extensively than posterior occlusion, yet the posterior occlusion is key for maintaining proper function over an individual's lifetime.

What exactly constitutes posterior occlusion, and what is its significance? Posterior occlusion pertains to the relationship between premolar and molar cusp tips and their opposing central fossae and marginal ridges. This relationship is of fundamental importance in that it serves as the foundation of many basic and higher functions of daily life. The posterior teeth not only establish and maintain the vertical dimension of occlusion, but they are also designed to withstand the heavier forces of mastication.[16] Importantly, the posterior teeth also enhance our ability to speak, assist in esthetics, and facilitate social interaction. While orthodontists seek to provide patients with visually appealing smiles, the significance of a functional bite that can serve patients throughout their lifetime should not be overlooked.

Methods of Classifying and Assessing Posterior Occlusion

The posterior dentition is most often evaluated using the maximum intercuspal position (MIP), as occlusal contacts in MIP have been found to be repeatable with minimal error.[17] Once the intercuspal position is recorded, posterior occlusion can then be assessed in terms of Angle Classification, by various aspects of the American Board of Orthodontics Objective Grading System (ABO OGS), as well as through quantifying absolute contacts and near contacts (ACNC).

The most fundamental assessment of posterior occlusion ought to begin with a review of Angle's Classification. In 1899, The Dental Cosmos published Edward H. Angle's "Classification of Malocclusion," which devised a classification system of the posterior dentition in relation to the positions of the maxillary and mandibular first permanent molars.[18] A Class I relationship involves the mesio-buccal cusp of the maxillary first molars aligned with the buccal groove of the mandibular first molars. A Class II relationship denotes the maxillary first molar is positioned more anteriorly than the mandibular first molar landmark, while a Class III relationship signifies the opposite. The Angle Classification system does not evaluate posterior contacts, but it does provide information regarding the relative positions of the maxillary and mandibular posterior dentition.[18, 19]

The American Board of Orthodontics has established a grading system to reliably evaluate treatment case success. Their Objective Grading System (ABO OGS) has undergone multiple revisions, and now includes several parameters used to evaluate the posterior dentition based on alignment, marginal ridges, buccolingual inclination, occlusal relationship, occlusal contacts, interproximal contacts, and root angulation.[20] To date, several studies have used this scoring system to evaluate the posterior occlusion following treatment.[9, 21-25] However, the ABO OGS is not as reliable as methods using occlusal bite registrations because it is dependent upon visual inspection of handheld models to determine the presence of occlusal contacts. As such, while the ABO OGS is a validated means in assessing posttreatment outcomes, it is perhaps not the most accurate, nor objective, way to evaluate posterior occlusal contacts in finished cases.

Articulating paper is perhaps the crudest method of assessing posterior contacts. It identifies areas of contact between the opposing teeth by directly marking on the occlusal surface. While it is simple to identify these marks, the surface topography of the dentition as well as the thickness of the articulating paper may result in differing bite records.[26] As such, articulating paper should only be used in situations that do not require more accurate assessment of posterior occlusal contacts.

Bite registrations made of impression materials have proven to be very reliable for evaluating the occlusion.[13, 17] Razdolsky et al. demonstrated this by evaluating consecutive polyether bite registrations for accuracy and reproducibility. A paired t-test found no significant difference in mean contact number recorded between the two consecutive bite registrations ($p<0.05$).[17] Blu-Mousse® is also a well-documented material and has been used in several studies to record occlusal contacts.[3, 4, 10, 14] Regisil® PB™, a vinyl polysiloxane, has been shown to be a reliable, reproducible method of capturing occlusal registrations in maximum intercuspation, as shown by Sauget et al.[13] In this study, contacts and near contacts were measured on consecutive bite registrations using a caliper, with near contacts defined as 0.20 mm or less. The standard measurement error from repeated thickness measurements of the same bite registrations was 0.014 mm, and comparison of measurements between paired bite registrations taken on the same day had an error of 0.018 mm. The variation found in these repeated registration measurements was not statistically significant and accepted as reliable. The literature also cites that there is perhaps more variation between patients than there is within a patient when comparing multiple consecutive bite registrations.[27] While several studies have counted the number of perforations in bite registrations and determined these to be the measure of absolute contact,[12, 13] other studies have more thoroughly evaluated the occlusal table by determining the actual areas of absolute contact and near contact in square millimeters, which is arguably a more precise assessment of posterior occlusal contacts.[3, 4, 10, 14] Actual contact areas are simply identified by perforations in occlusal registrations, however they may not be the most reflective of occlusal function. Near contacts increase the area of contact during function because of tooth movement in the periodontal ligament, which allows for the near contact to then become reflective of absolute contact under function.[1] As such, it is probable that measuring areas of contact and near contact (ACNC) is the most comprehensive method of evaluating the functional, posterior occlusion. Likewise, it is more objective and quantifiable than merely counting the number of perceived contacts. Previous studies have used 50 microns as the threshold for contact, with 0-50 microns serving as an area of contact and up to 250 or 350 microns as areas of near contact.[3, 4] These studies used transillumination to assess posterior occlusal contacts with reliable and significant results.[3, 4, 10, 14] Transillumination of bite registrations involves placing the bite registrations on a light source to view the gradations of light visible through the varying regions of material thickness. The gradation of light can then be converted from color to a grayscale, which enables quantification of light transmitted through the material and subsequently determines how thick the material is. Isolating the occlusal table with a computer imaging software application significantly enhances this process and allows for quantifying contact area in square millimeters. The computer software first calculates the grayscale and corresponding number of pixels in a given region. This pixel count is then converted to a measurable thickness by use of a step-wedge calibration tool.[3, 4, 10, 14]

In addition to transillumination, technological advances now enable clinicians to obtain and assess occlusal bite registrations through alternative approaches. Two examples include computerized T-scans and photo occlusion. The T-scan method involves a sensor that evaluates force and timing of occlusal contacts when the teeth are brought together in maximum intercuspation. The sensor then sends this information to a computer, allowing for visualization of the force and timing of the contacts displayed in a topographic color scheme. While some studies show that the T-scan method is reliable,[27] others have found that the T-scan lacks adequate sensitivity and results in a lower measured number of contacts than actually present.[28] As another alternative to the traditional bite registration assessment, the photo occlusion method uses a bite wafer and polariscope to visualize occlusal contacts. Gazit et al. found that this method was not adequately reproducible, but they did note that it was superior to articulating paper in recording occlusal contacts.[29]

After considering the available methods of assessing posterior occlusal contacts, the technique to be used in our study will involve a software application programmed to trace the occlusal table of Blu-Mousse® bite registrations. These isolated regions will then be quantified using a step-wedge to assess ACNC in square millimeters.

Normal Changes Observed in Posterior Occlusion

As previously discussed, posterior occlusion is fundamental to the function and stability of the dentition. Two studies found that early posterior tooth loss can negatively impact the development of the maxilla and mandible in Wistar rats.[30, 31] Therefore, it appears that a full dentition from early on is critical for supporting healthy oral development and function over the lifetime of an individual.

Much like the other systems of our body, the posterior dentition adapts with growth changes over time. The natural aging process encourages the dentition to maintain stability by adapting and compensating for growth of the craniofacial complex during our lifetime. To begin, the eruption of the posterior dentition does not occur at random, but rather is guided by a cusp-to-fossa scaffold that ensures adequate intercuspation when the teeth are brought together. This phenomenon has been described by Van der Linden in terms of the cusps funneling into the opposing fossae during eruption.[32] He claimed that opposing posterior teeth rarely erupt into the precise position and orientation required for proper intercuspation. Instead, the teeth are guided into an optimal intercuspal position by the cone-funnel mechanism, which begins when the first deciduous molars begin to contact one other. In most instances, the large palatal cusp of the maxillary first deciduous molar arrives with its cone-shaped cusp within the fossa of the mandibular first deciduous molar. The fossa will function as a funnel by which both the teeth are directed toward one other, thus assuming proper position and intercuspation. After the first deciduous molars have reached occlusion at approximately 16 months of age, the anteroposterior relationship of the dentition is confirmed each time the teeth are brought together. This serves as the first vertical support of the dentition and allows for interlocking of the maxillary and mandibular posterior teeth. Once these teeth wear down, the second deciduous molars assume the role of intercuspation and maintenance of the occlusion. Subsequently the first permanent molars perform the task, and during significant adolescent jaw growth, the permanent premolars and second permanent molars assume the role of guiding the cusp-fossa eruption.[32] Having this guide, therefore, appears to be critical in allowing the teeth to erupt into their proper position.

A study by Ostyn et al. assessing eruption in macaca monkeys found that intercuspation was critical for proper anteroposterior and vertical development of the orofacial complex.[33]

Grinding of the cusps of the molars and canines in the experimental group of monkeys resulted in a deviated anteroposterior relationship between the jaws and a significant inhibition of the vertical growth of the maxilla. They also noted that without proper intercuspation, a more prognathic mandible, Class III growth pattern, and mesiocclusion were produced.[33] A similar study by Ostyn et al. also involved reducing molar and canine cusps in macaca monkeys.[34] When the experimental outcomes were compared with untreated controls, a widening of the maxillary arch was found in the experimental cusp-reduced monkeys while palatally inclined maxillary molars were found in controls. This transverse compensation of the dentition suggests that the mandibular molars may restrict the maxillary molars from expanding.[34] These studies both illustrate the importance of cusp-to-fossa guidance in the development of the dentition and corroborate Van der Liden's original cone-funnel mechanism.

If such forces are at play in guiding the eruption potential of the dentition, it stands to reason that there are also adaptive changes seen in the posterior dentition during the natural aging process. For instance, wear of the enamel cusps ensues during an individual's lifetime due to such factors as parafunctional habits, bruxism, and dietary food intake. With wear of the dentition, a compensatory eruption of the teeth can be expected to allow for maintenance of occlusal contact and the vertical dimension of occlusion.[35] The molars continue to erupt approximately 0.07 mm per year to compensate for attrition and maintain the vertical dimension. With this finding comes an associated increase in lower anterior facial height with increasing age.[35, 36] Similarly, the interproximal surfaces tend to change over time, as demonstrated by a mesial migration of the teeth in both treated and untreated individuals due to the orientation of mesially-directed forces on the posterior dentition.[37, 38] At this time, there is limited data concerning age-related changes in areas of contact and near contact. However, based on the assumption that attrition results in increased occlusal wear and a flatter occlusal table, it may be assumed that the absolute areas of contact and near contact increase with age.

Ideal Number, Location, and Symmetry of Posterior Occlusal Contacts

The literature varies when attempts are made to define a set number or location for optimal posterior occlusal contacts. Ricketts recommended that an ideal occlusion has approximately 21 contacts per side, excluding third molars.[39] This notion is founded on his analysis of an occlusogram study of 200 consecutively observed cases in retention. When only the posterior teeth are included, the number of contacts is reduced from 21 to approximately 16 posterior occlusal contacts per side. In a study of untreated adult males with Class I normal occlusion, Korioth et al. assessed perforations in bite registrations to determine number, location, and symmetry of posterior occlusal contacts.[12] The perforations were counted based on visualization against a lighted background. This study found that upper and lower first and second molars appeared to have the most contacts, with 7-9 absolute contacts on the right molars versus 6-8 absolute contacts on the left molars in nearly half of the subjects. The other half ranged from 1-3 contacts to 13-15 contacts per side. This difference suggests that there is substantial variation in untreated Class I normal occlusions ($p<0.001$). Their findings also contend that having Rickett's recommended 16 posterior contacts per side may not be necessary for a fully functioning dentition. In normal occlusions, therefore, it is not uncommon to find varying numbers, locations, and symmetry of contacts from one side to the other.[12]

Posterior Occlusion and Masticatory Performance

Posterior occlusal contact area, especially near contact area, has been shown to be among the most important factors determining masticatory performance.[3, 10, 40-42] Yurkstas found that occlusal contact area, though only constituting a fraction of the total occlusal surface area, probably represents the most important fraction involved in mastication because of the high correlation between the two.[40] Intercuspation of the posterior dentition determines possible bite force, which affects the number of occlusal contacts, which in turn determines masticatory performance. If a malocclusion is present, all of these parameters may be negatively affected. Subjects with normal occlusion have been shown to break down food more efficiently than subjects with malocclusion,[43, 44] which further supports the importance of posterior occlusal contact area. An experiment by Toro et al. illustrated that among malocclusion subtypes, occlusal contact area and masticatory efficiency (as measured by mixing ability index) were highest in Class I malocclusion, followed by Class II and Class III malocclusion groups.[43] English et al. tested the assumption that malocclusion negatively affects masticatory performance.[44] In this study, 185 untreated individuals with various occlusions were evaluated for differences in CutterSil® particle size as a measure of masticatory performance. Subjects with normal occlusion had significantly smaller particle sizes than subjects with malocclusion. Compared with the normal occlusion group, the median particle sizes for the Class I, II, and III malocclusion groups were approximately 9%, 15%, and 34% larger, respectively. These findings suggest that malocclusion negatively affects the ability to break down food.[44] A study by Lepley et al. assessed the masticatory efficiency of Class I subjects by evaluating sizes of CutterSil® samples as well as recording Blu-Mousse® bite registrations to measure contact areas.[4] They found that ACNC, measured in 50 micron intervals, was negatively correlated with average particle size of the CutterSil® samples. This supports the relationship between enhanced masticatory performance and greater breakdown of food in subjects with higher ACNC. Similarly, Helkimo et al. found that masticatory performance was positively correlated with the number of occlusal contacts, with the number of absolute contacts having more importance than the number of teeth in contact.[45]

Posterior Occlusion and Stability

Most studies have evaluated changes of the mandibular anterior dentition following orthodontic treatment, since these are the most noticeable changes that might occur. Difficulty arises when attempts are made to distinguish between normal age-related changes and changes related to posttreatment relapse, as these changes occur in both untreated and treated individuals over time. The most frequent finding is that malalignment increases and arch dimensions decrease over time.[46-50] Based on this, it can be assumed that malalignment affects both the anterior and the posterior dentitions. Additionally, idealized intercuspation and optimal occlusal contacts of the posterior dentition may be essential for stable orthodontic results.[51, 52] Owens et al. revealed that subjects with normal occlusion demonstrate significantly more contacts than subjects with Class I, II, or III malocclusion, and therefore also have larger measures of ACNC. This study found that subjects with Class III malocclusion had the smallest areas of near contact (<350 microns).[3] Deng et al. showed that the location of posterior contacts is one of the main factors responsible for stabilization of the mandible.[52] Another longitudinal study followed untreated subjects for approximately 30 years. The Class I subjects had greater measures of ACNC and maintained their occlusal relationship, whereas the Class II and Class III subjects were seen to worsen in their malocclusion over time.[53] These findings support that greater areas of contact and near contact are critical for long-term stability and function of the dentition.

Posterior Occlusion and Bite Force

In evaluating force load and maximal bite forces, the occlusal surface of the molars constitutes the highest achievable bite force in the dentition. A study by Bakke revealed that unilateral maximum posterior bite forces can range from 300 to 600 Newtons in subjects with healthy dentitions; the anterior dentition can achieve only 40% of the force produced by the molars.[1] Therefore, it is important to have well-distributed contacts throughout the posterior dentition to enhance force delivery during mastication and provide stability during occlusal contact. When bite forces are intentionally increased, the absolute number of occlusal contacts may also increase, though this can be difficult to control when conducted on individuals due to variable circumstances. However, studies have reported significant results when subjects are provided with consistent, detailed instructions during bite registration collection.[3, 4, 10, 13, 14, 17, 27] While the number of posterior teeth has been shown to be important, arguably more important is the number of occlusal contacts in determining bite force and function. Bakke showed that when bite force increases from 30% to 100%, the occlusal contact area increases two-fold.[1] This study also found that occlusal contacts were more closely correlated with bite force than several other contributing variables, such as age, sex, height, and jaw angle. In adult patients, as much as 10-20% of the variation in bite force can be accounted for by the number of occlusal contacts.[2] Another study corroborating the importance of occlusal contacts in bite force showed that light bite forces (20% of maximum) yielded fewer contacts overall than heavier forces (50% of maximum) in both young adults and adults.[54] Ikebe et al. also revealed that reductions in bite force can inhibit masticatory performance, which they attributed to micromotion of the teeth under occlusal load and compressibility of the periodontal ligament.[42]

Based on the foregoing literature, an important dilemma arises. If an ideal occlusion and optimal orthognathic function are so heavily dependent upon posterior contacts, then clinicians should be interested in knowing which treatment procedures result in the largest areas of contact and near contact. The following will provide an overview of the available literature regarding treatment and posttreatment effects on the posterior dentition, with an emphasis on measures of ACNC.

Orthodontic Treatment Options and Clear Aligner Case Selection

Many options are available when considering occlusal correction. Traditional orthodontics has evolved from metal bands cemented around each tooth to small metal or ceramic brackets bonded to the teeth. Today's society is seemingly more aware of esthetic display and focused on appearance. As such, it is not surprising that the desires for straight teeth and esthetic orthodontic treatment outcomes have expanded and now include the use of clear aligner orthodontic therapy. Treatment of rotations without the use of braces was first discussed as early as 1946 by Kesling,[55] and today's treatment using clear aligners has grown from his ideas. Align Technology® modernized this modality by introducing Invisalign® in 1997, which is now used as a possible treatment option for many patients. In 2008, Invisalign® underwent refinements and changes that now allow for improved treatment results. Such auxiliaries include the addition of Precision Cuts, Precision Bite Ramps, and Smart Force Attachments[56] to better control tooth movements. As of February 2020, Align Technology® claims to have treated over eight million patients using Invisalign®.[57]

Despite this growing trend and its use, there are few published studies that focus on the long-term effects of aligner treatment. Papadimitriou et al. published a systematic review in 2018 outlining the clinical effectiveness of Invisalign® treatment.[58] After searching the literature, they included three randomized clinical trials, eight prospective studies, and eleven retrospective studies. While the studies consistently showed that Invisalign® is a viable alternative to conventional orthodontic treatment in the correction of mild-to-moderate malocclusions, they also importantly noted specific clinical limitations of aligner therapy. They found that

Invisalign® aligners can predictably level, tip and derotate most teeth, excluding canines and premolars. However, important limitations include arch expansion through bodily movement, closure of extraction spaces, correction of occlusal contacts, and overcoming large anteroposterior and vertical discrepancies.[58] Careful case selection, therefore, is imperative when considering clear aligner therapy, as much of the success or failure in its use is based on clinical judgement and experience in case selection. Many of the studies included in this systematic review lack proper methodology and have a moderate-to-high risk of bias. This lack of quality evidence presents a dilemma for clinicians to effectively guide patients in educated treatment decisions.

Traditional Braces Effects on Posterior Occlusion

In particular, and of significant importance to orthodontists, is the effect of orthodontic treatment on posterior occlusion. It is important to note that orthodontic treatment, both using aligner therapy and traditional braces, results in a relative decrease in the number of occlusal contacts.[5-7, 21, 58] Haydar et al. illustrated this in an RCT investigating occlusal contacts following orthodontic treatment. This study included three groups: fixed appliances retained with a Hawley, fixed appliances retained with a positioner, and untreated controls. The total mean number of contacts at the end of active treatment for both of the orthodontically treated groups was significantly less than that of the normal occlusion group (Hawley: $p<0.001$, positioner: $p<0.003$).[6] Another study by Sullivan et al. investigated the short-term and long-term effects of fixed orthodontic appliances on occlusal contacts.[5] When compared with untreated controls, their findings revealed that orthodontic treatment with fixed appliances diminished the number of occlusal contacts. The short-term measurements were obtained from adolescents who were one month into treatment, while the long-term measurements were taken on mature subjects approximately 81 months into retention. Importantly, they noted that orthodontic treatment may lead to an appreciable permanent reduction in occlusal contacts which is not always compensated by a prolonged period of posttreatment settling.[5]

With respect to aligner treatment, most studies contend that certain types of tooth movement, such as posterior extrusion, are difficult to achieve using aligners.[58, 59] Additionally, the thickness of the aligners over the occlusal surfaces of the teeth might interfere with settling of the occlusion.[21] Most studies that assessed the decrease in occlusal contacts following Invisalign® treatment utilized the ABO OGS method, which is perhaps less objective as it relies on visual inspection of posterior contacts based on handheld models. Therefore, this is not as precise a means of evaluating the number or area of contact, nor measuring the relative changes in each over time. Likewise, there is currently no published literature that has evaluated ACNC in aligner treatment. While the aforementioned studies validate the notion that orthodontic treatment decreases occlusal contacts, the question of which treatment modality presents an optimal posttreatment ACNC is still at hand.

Invisalign® Effects on Posterior Occlusion

Several studies have focused on subjects treated with only Invisalign®, but these lack a comparable group of subjects treated with traditional braces. Vincent et al. conducted a study comparing pretreatment and immediate posttreatment Invisalign® OGS scores in 65 patients.[8] Although the OGS revealed significant improvements in anterior tooth alignment following Invisalign® treatment, there was a negative change in posterior occlusal contacts, thus confirming that aligner treatment had an adverse effect on posterior intercuspation. Kassas et al. also assessed posttreatment outcomes in patients treated with Invisalign®.[9] In their study, 31 patients were evaluated using the ABO Model Grading System. While they did find that tooth alignment significantly improved, they conversely showed that Invisalign® treatment had no statistically significant effect on posterior occlusal contacts, marginal ridges, nor occlusal relationships. In fact, the occlusal contacts category showed a numerically higher average score posttreatment, reflecting a decrease in the number of posterior occlusal contacts. This article is limited because it fails to mention when the retrospectively-collected final posttreatment records were obtained. This could inadvertently impact the amount of settling that occurred after the end of treatment and thus misconstrue the number of occlusal contacts. Another study by Vlaskalic and Boyd found that Invisalign® aligners resulted in a decreased number of posterior occlusal contacts as well as a posterior open bite in some of their subjects, which has been cited as a common side effect of aligners due to different materials and thicknesses.[7]

Invisalign® Versus Traditional Braces Outcomes

As previously mentioned, few studies have compared Invisalign® to traditional braces treatment, and those that do are not conclusive as to which is superior. Importantly, there are not any studies directly comparing treatment effects on posterior occlusion, as measured with ACNC. At best, the literature includes indirect assessments using the ABO Objective Grading System or Peer Assessment Rating System to score occlusal contacts.

According to Djeu et al., who retrospectively studied posttreatment outcome assessments in 48 patients treated with Invisalign® vs. 48 patients treated with traditional braces, the Invisalign® group consistently scored higher than the braces group for both occlusal contacts and occlusal relationships.[21] Their posttreatment records showed that Invisalign® was able to close spaces, correct anterior rotations, and correct marginal ridge heights. However, it was not able to correct large discrepancies in occlusal contacts.[21] A detailed description of their methods and data collection procedures was provided, noting that the posttreatment final records were obtained immediately after debond. Importantly, if time is minimized between appliance removal and collection of final records, then less settling of the dentition will occur. This provides a more reliable outcome assessment as it captures the occlusal relationship due to treatment before settling can begin to alter or improve occlusal contacts.

Another article by Gu et al. indirectly assessed occlusal contacts by using the Peer Assessment Rating system to grade pretreatment and posttreatment casts between patients treated with either Invisalign® or traditional braces.[56] They showed that while the duration of Invisalign® treatment was an average of six months shorter, there was no statistically significant difference in mean weighted posttreatment PAR scores (p=0.4573). In fact, none of the eight components of the posttreatment PAR scores revealed significant differences between the two treatment groups. Both groups had more than a 30% reduction in PAR scores, indicating case improvement. The PAR scoring system defines "great improvement" as a reduction of at least 22 points. Interestingly, following logistic regression and after controlling for age, the odds of achieving great improvement in the Invisalign® group were 0.329 times the odds of achieving great improvement in the traditional braces group (p=0.0150). This finding indicates that Invisalign® may not be as effective as fixed appliances in achieving great improvement in malocclusion correction.[56]

While these studies provide indirect assessments, there are no studies that provide a direct assessment of the differences in posterior occlusal contacts based on areas of contact and near contact. However, it is reasonable to assume that Invisalign® will result in a greater decrease in ACNC from pretreatment to immediate posttreatment when compared to traditional braces. Due to the aligners' occlusal coverage during treatment, the opposing teeth are prevented from contacting and ACNC is thereby decreased.[13, 14, 23, 60]

Regardless of treatment modality, improvements in occlusal relationship after orthodontic treatment are best maintained with appropriate long-term retention. The importance of occlusal contacts has been previously discussed, and the particular type of retention chosen can impact the number of ACNC. As such, a discussion of retention protocols is warranted and will briefly highlight the significance of retention with respect to posterior occlusal contacts.

Retention Protocols and Settling Observed in Posterior Occlusion

Following orthodontic treatment, retention in the form of removable or fixed retainers is essential to maintain the position of the teeth. Removable retention can vary in design and appliance fabrication. Perhaps the most traditional are Hawley retainers, which generally have an anterior labial bow, whereas wraparound Hawley retainers include wire extensions around the buccal aspect of the posterior teeth.[10, 14] Vacuum-formed thermoplastic retainers, such as Essix retainers, are designed to contact all surfaces and include occlusal coverage. This makes Essix retainers different from the traditional removable Hawley retainers, which do not include occlusal coverage.[13] Positioners are elastic appliances that allow the dentition to adapt to predetermined positions, with small (0.25-0.50 mm) amounts of movements possible.[55, 61] A study by Dincer et al. found that the use of tooth positioners was effective in improving the occlusal finish, notably by means of first-order alignment and tipping of the teeth into an improved intercuspal position.[11]

Fixed retainers are steel wires bent to approximate the lingual of the maxillary and mandibular anterior teeth. Since they are bonded directly to the teeth, fixed retainers offer the advantage of a permanent form of retention.[62] Fixed retainers are also beneficial in that they lack occlusal coverage, which enables the posterior teeth to settle via relative movements in the vertical dimension, thereby increasing posterior occlusal contacts.[62]

While guidelines vary, removable appliances are generally worn full-time for a specified period, after which only nighttime wear is recommended. The literature contains many recommendations regarding duration of retention, though none are agreed upon nor guarantee lifelong stability if retention protocols are abandoned.[47, 48, 63] A systematic review on retention procedures found that the best type of retainer remains controversial and inconclusive, as there is insufficient evidence to determine which type of retainer best maintains tooth position and prevents relapse after orthodontic treatment.[63] Efforts to determine pretreatment predictors, such as potential dental or cephalometric attributes, and to identify associations with posttreatment crowding, relapse, or arch form changes have proven to be unsuccessful.[48, 49, 64] It is difficult, then, to differentiate changes due to relapse from those due to natural aging. Retention should be flexible enough to allow posterior occlusal adaptation to achieve improved intercuspation, but also be sufficiently rigid to prevent relapse and sequelae of the natural aging process.

Although changes in posterior occlusion should be anticipated during the retention phase of orthodontic treatment, our understanding of the pattern of changes that take place remains limited. The literature cites three primary reasons for posttreatment changes: physiologic changes due to aging,[37, 38] relapse to pretreatment positions,[65, 66] and settling of the dentition to improve intercuspal stability.[32] While physiologic changes due to age and relapse indicate a worsening of occlusal conditions, settling is the continual adaptation of teeth to achieve a more stable interocclusal relationship. Van der Linden’s cone-funnel mechanism, as previously discussed, characterizes the biological action of settling.[32]

Likewise, settling can be seen as a posttreatment phenomenon that typically occurs in two phases. The first phase of settling occurs immediately after appliance removal as the teeth begin to move as independent units, rather than as a single unit bound together by orthodontic appliances. This tends to be rapid as the teeth displace to achieve stability with the opposing dentition. The second phase is much slower and is a process that occurs over the lifetime of an individual. As tooth wear and attrition occur over time, both compensatory vertical eruption and mesial migration of the dentition may be seen to maintain occlusal contact.[37, 38]

Most studies show that settling of the dentition occurs after treatment, allowing for improved occlusion and an associated increase in number of occlusal contacts as time progresses. In terms of duration, there is no agreement as to how long the process lasts. Based on natural physiologic changes that take place with age, the teeth will continue to settle and adapt to changes that occur. Razdolsky et al. determined that settling occurs during the initial three months of retention.[17] Bauer et al. showed that the greatest rate of settling occurred during the first two months of retention and that there were no significant settling changes after six months.[10]

Gazit et al., who utilized a photo-occlusion method for quantification, found a 56% increase in contacts one year following orthodontic treatment.[29] Razdolsky et al. assessed 40 patients for changes in occlusal contacts in maximum intercuspation following orthodontic treatment.[17] While this study did not evaluate short-term changes, the long-term changes seen after treatment were significant. The total number of teeth in contact, as well as the total number of actual and near contacts, increased significantly ($p<0.001$) over an average of 21 months following the active phase of orthodontic treatment.

Another study by Hoybjerg et al. used the ABO CRE scoring system to evaluate patients at appliance removal and one year posttreatment.[23] They compared three groups of subjects retained with upper and lower Hawleys, upper Hawley with lower bonded, or upper Essix with lower bonded retainers. Though the exact numbers of contacts were not provided, they demonstrated that all three groups significantly improved in the ABO CRE occlusal contact scores. The upper Hawley/lower bonded group showed the greatest improvement in occlusal contacts ($p<0.0001$), the upper and lower Hawley group demonstrated the second greatest improvement ($p=0.0245$), and the upper Essix/lower bonded group showed the least improvement ($p=0.0013$).

Horton et al. evaluated short-term changes in ACNC in 50 patients using Blu-Mousse® bite registrations following orthodontic treatment.[14] Patients were randomly assigned into one of two retention groups: perfector/spring aligner or Hawley retainer. Occlusal bite registrations were obtained at debond and approximately two months later. They found that ACNC increased significantly and similarly for both the perfector/spring aligner and Hawley retainer groups, with no significant differences in the increases of ACNC between the two groups. A follow-up study was conducted by Bauer et al. to investigate posttreatment occlusal changes in the same patients.[10] Those initially retained with the perfector/spring aligner were given Hawley retainers two months after retainer delivery. Based on the 40 patients in this study, ACNC increased significantly in both groups during the first six months of retention. While the greatest increases in ACNC occurred during the first two months, further increases occurred between two and six months in both groups. The ACNC of the Hawley and perfector/Hawley groups increased by 129% and 105%, respectively. These studies reflect that Hawley retainers allow for a significant increase in posterior settling following orthodontic treatment.

In a study by Haydar et al., Hawley retainers, tooth positioners, and untreated normal occlusion groups were compared to evaluate changes in the number and location of occlusal contacts.[6] Significant differences between the treated and control samples were identified at appliance removal and three months posttreatment, with untreated controls having more contacts at both time points. There were no significant differences between the Hawley and perfector groups at appliance removal. Similar results were obtained at three months posttreatment, with both the Hawley and perfector groups having fewer contacts than the control group, and no statistically significant difference between the two treated groups. Interestingly, the increases in posterior contacts from appliance removal to three months posttreatment were not statistically significant in either of the treated groups. While slight changes and increases in posterior contacts may occur due to settling, Haydar et al. concluded that finished orthodontic cases should provide an occlusion that is as ideal as possible, as only minimal changes were observed during the retention phase.[6] It is worth noting that this study involved both extraction and non-extraction cases in the treated groups. This may have inadvertently altered the ability to draw valid comparisons with respect to the control group. Additionally, the posttreatment changes were evaluated only three months following treatment. Based on the study by Bauer et al., it is plausible that further settling could have occurred in the Haydar et al. samples for up to six months posttreatment, at which time measured changes in posterior contacts could have shown significant improvements.[6, 10]

Dincer et al. studied posttreatment changes in patients treated with thermoplastic Essix retainers.[67] Patients were instructed to wear the Essix retainers full-time for the first six months following appliance removal, then at nighttime only for the next three months. They assessed occlusal registrations taken at the end of active treatment, nine months into retention, and 2.5 years into retention. They compared these findings with a control sample who had not undergone treatment. The expected increase in occlusal contacts due to physiologic settling was not observed at the nine-month retention evaluation in the Essix retainer group. They attributed this finding to the Essix's complete coverage of the occlusal table and inhibition of settling.

However, a significant increase in posterior occlusal contacts was found at the 2.5-year posttreatment evaluation. Since instruction to wear the Essix retainers full-time ended at nine months, settling was able to occur between the nine-month and 2.5-year evaluations. As such, the full-coverage Essix retainers could no longer impede physiologic posterior settling, and a subsequent significant increase in posterior occlusal contacts was observed.[67]

More recent data investigating retention protocols has corroborated the notion that occlusal coverage can inhibit maximum settling. Aslan et al. randomized 36 patients into either a full-coverage Essix group or a modified-coverage (lacking posterior occlusal coverage) Essix group.[60] Silicone bite registrations were taken at the beginning of the retention period (two hours after debond, T_1), end of full-time retainer wear (six months posttreatment, T_2), and end of nighttime retainer wear (nine months posttreatment, T_3). Assessments revealed that the total number of posterior contacts increased significantly at T_3 compared to T_1 and T_2 only for the modified Essix group ($p<0.017$). No significant increases in the total number of posterior contacts were found in the full-coverage Essix group.[60] These findings lend support to posterior settling typically occurring to a greater extent in retainers that do not have occlusal coverage.

According to Sauget et al., Essix retainers worn full-time for three months and night-time only thereafter showed no appreciable settling during the first three months following debond.[13] While mean increases in the number of posterior contacts were observed from debond (23.67) to three months thereafter (27.93), this change was not statistically significant.

A more recent controlled clinical trial by Varga et al. demonstrated that maximum voluntary bite force (MVBF) and number of occlusal contacts (NOC) increased posttreatment.[68] This study included 176 individuals randomized into one of four groups: 30 individuals with upper and lower Essix retainers, 30 individuals with upper and lower wrap-around Hawley retainers, 30 individuals with upper Essix and lower bonded retainers, and 86 untreated controls. They evaluated MVBF and NOC immediately after removal of fixed appliances, six weeks after appliance removal, and another four weeks later. The results showed increases in MVBF and NOC, but those retained with upper and lower Essix retainers demonstrated less of an increase than the other posttreatment groups. The increases in NOC occurred faster than the increases in MVBF; NOC increased to a greater extent and sooner with Hawley retainers and in male subjects than with Essix retainers and in female subjects. Thus, they concluded that settling of the occlusion depends heavily on the type of retainer, as settling took longer in female patients and in those with Essix retainers in both arches than the other retention groups.[68] Based on these studies, it can be concluded that occlusal coverage of the posterior teeth during the retention period may result in minimal to relatively no detectable amount of posterior settling.[13, 60, 68]

Posttreatment Assessments of Invisalign® Versus Traditional Braces

Just as there are no studies that directly assess differences between Invisalign® and traditional braces in posterior ACNC at the completion of treatment, there are also no studies that directly assess the inter-group posttreatment differences. The only literature found comparing Invisalign® and traditional braces into the retention phase was published by Kuncio et al.[22] In this retrospective cohort study, all patients were retained similarly with occlusal coverage, either in the form of the final aligner (Invisalign® group) or with full-coverage Essix retainers (traditional braces group). Based on the ABO OGS, they found that occlusal contacts, while improved, were not significantly different between the two groups. Importantly, they had limited sample sizes, with only 11 patients in each group. The fact that their findings were not significant lends supports to the need for further research pertaining to this topic. With such limited literature available, it is not possible to draw a definitive conclusion on the comparative results of posttreatment changes in ACNC between the two treatment modalities.

Conclusions and Introduction of Current Study

Thus, if there is a difference in treatment and/or posttreatment areas of contact and near contact, it is imperative that orthodontists are informed as to whether aligner therapy or traditional braces will provide a better result. In knowing this, orthodontists will be more equipped to guide and educate patients in their treatment options. The aim of the current study is to evaluate the changes in ACNC observed in a group of patients treated with Invisalign® vs. a group of patients treated with traditional braces. Measurements of ACNC will be obtained from Blu-Mousse® occlusal bite registrations collected for each patient at four time points: pre-treatment, appliance removal, one-month posttreatment, and six-months posttreatment. Bite registrations will then be photographed on top of a light source (Model L4S LED Light Pad, Huion Technology®, Shenzhen, China). Use of a step-wedge and digital software application will enable tracing of the photographed occlusal surfaces, and measures of ACNC will subsequently be calculated from the transilluminated bite registrations. Based on the foregoing literature, it is assumed that posterior occlusal settling will result in an increase in ACNC for both groups at each subsequent time point. However, due to the occlusal coverage present during the Invisalign® group's treatment, it is hypothesized that ACNC at appliance removal will be less for the Invisalign® group than the traditional braces group. Since both groups will be given Hawley retainers lacking occlusal coverage, the increases in ACNC posttreatment are anticipated to be larger for the Invisalign® group than for the traditional braces group. The hypothesis is thus that there will be a significant difference in ACNC between the two groups. The null hypothesis is that there will be no significant differences in ACNC between the two groups.

CHAPTER III

MATERIALS AND METHODS

Patient Sample

The study included a sample of 80 adult patients who were recruited by posted fliers and internet advertisement on the Texas A&M College of Dentistry website between March 2013 and December 2016. Of the 80 patients, 40 patients were randomly allocated to each of two treatment groups (Invisalign® and traditional braces) using Microsoft Excel (Microsoft, Redmond WA) random number generation. All patients were screened and treated by two orthodontists at the Texas A&M College of Dentistry Department of Orthodontics.

To be considered for the study, the patients must have met the following criteria:

- Class I molar and canine malocclusion
- Non-extraction treatment
- Mandibular crowding ≤ 4 mm
- Full dentition, with no missing teeth from second molar to second molar
- Complete set of orthodontic records

Patients were excluded from the study if they met any of the following criteria:

- Anterior or posterior crossbite
- Anterior or lateral open bite
- Maxillary overjet ≥ 3 mm
- Impacted teeth

This clinical trial was approved by Texas A&M College of Dentistry's Institutional Review Board (2012-21-BCD-FB), and informed consent was obtained from all patients.

To ensure a sufficient sample size, an a priori power analysis was performed using the descriptive statistics previously reported for Invisalign® treatment outcomes.[21, 22] In the present study, statistical significance was determined to include a 5% chance of making a Type I statistical error and a 10% chance of a Type II error (power of 90%). With an effect size of 0.8, 36 patients per group were required.

Sample Breakdown

The median pre-treatment age for the traditional braces group was 26.5 (IQR 24.0,40.0) with a median debond age of 27.3 (IQR 25.1,38.8). The Invisalign® group's median ages were 27.3 (IQR 24.4,33.1) and 28.2 (IQR 24.8,40.6) at the time of pre-treatment records and debond, respectively. There were no statistically significant between-group differences in age at T_1 ($p=0.76$), T_2 ($p=0.73$), T_3 ($p=0.89$), or T_4 ($p=0.72$). Treatment duration was 1.6 and 1.3 years for the traditional braces and Invisalign® groups, respectively. However, the 3.6 months difference was not statistically significant. The time elapsed between T_2-T_3 and T_3-T_4 also revealed no statistically significant differences between groups. There were no statistically significant sex differences in age at any of the treatment timepoints, and there were no significant sex differences in areas of contact and near contact.

Orthodontic Treatment

For the patients assigned to the traditional braces group, orthodontic treatment was completed using Alexander 0.018" bracket prescription (American Orthodontics©, Sheboygan WI). Patients began in NiTi and progressed to stainless steel arch wires, at the discretion of the treating orthodontists. For the patients assigned to be treated with clear aligners, initial scans were taken and sent to Invisalign® (Align Technology®, San Jose CA) for fabrication of the aligner series. Each patient's ClinCheck® was revised by the treating orthodontists prior to approval and submission. Each patient underwent two refinements at most, per the treating orthodontists' clinical judgement. Of the 36 patients in the Invisalign® group, 24 had two refinements, 9 had one refinement, 1 had no refinements, and 2 lacked sufficient documentation to determine the number of refinements. All patients were instructed to wear aligners for 22 hours per day, with each set of aligners to be worn for a full two weeks. The treating orthodontists included heavy posterior occlusal contacts for each ClinCheck® to ameliorate the possibility of posterior bite opening that may occur due to occlusal coverage of the plastic aligners. For both the traditional braces and Invisalign® groups, no extraoral appliances or additional anchorage appliances were used. Inter-arch elastics were prescribed and used as needed to detail the occlusion.

Following treatment, all patients were retained in a similar manner. A twisted 0.0175" stainless steel wire was adapted and cemented to the lingual aspect of the mandibular anterior teeth, from lower canine to canine. Impressions were taken to fabricate maxillary wraparound Hawley retainers with C-clasps distal to the second molars. Patient were instructed to wear the Hawley retainer nightly. No occlusal equilibration was performed on any patient during retention. Six patients received at least one Essix retainer, nine were given a mandibular extended gemini removable retainer, and three patient charts lacked documentation regarding the retention protocol. Patients had a different retention protocol due to bruxism, intolerance to the Hawley retainer, or preference for removable retainers. Twenty patients with a pretreatment diastema had retainers bonded on the palatal surfaces of the maxillary incisors to prevent relapse.

Data Collection

Data was collected at four time points, including pretreatment initial records (T_1), day of debond (T_2), one-month posttreatment (T_3), and six-months posttreatment (T_4). Study models and Blu-Mousse® (Safco Dental Supply, Buffalo Grove IL) bite registrations were included in the data collection. The Blu-Mousse® bite registrations were confirmed by placing them on top of the coinciding study models to ensure proper fit.

Attrition of patients over the course of the study occurred (Figure 1). Six patients did not start or complete treatment due to not wanting to participate in the assigned treatment group, moving to a different city, unwilling to allow IPR as a part of Invisalign® treatment plan, and temporomandibular joint pain.

Blu-Mousse® bite registrations were taken bilaterally and included four posterior teeth, first premolar to second molar. During collection, patients were instructed to bite firmly on their back teeth for approximately 30 seconds until the material was fully set. Right and left trimmed bite registrations were then approximated using an anterior 3-3 jig to simulate a full-arch registration (Figure 2A). This configuration was laid on top of an LED light pad (Model L4S LED Light Pad, Huion Technology®, Shenzhen, China), along with the time point, patient identifier, step-wedge, and millimeter ruler to ensure focus of the image. A cardboard box with a two-inch hole was then placed over the LED light pad to remove ambient light and standardize the distance from the bite registrations to the camera (Figure 2B). Photographs of each transilluminated bite registration were taken using an Apple iPhone 8® camera that was placed on top of the light box.

The images were individually evaluated for areas of contact and near contact (ACNC) using a custom program, Halcon Contactos Software (Centro de Innovación Roldán Salud, Medellín, Colombia), on a 2017 MacBook Pro® laptop computer (Apple® Inc., Cupertino CA). The software required two selection steps in order to estimate ACNC values. The first step utilized a selection tool to outline a specified area around the bite registration, step-wedge, and millimeter ruler guide. The second step used a “lasso” selection tool to isolate the occlusal surfaces of each of the eight posterior teeth (Figure 3A). The “lasso” selection tool allowed the posterior occlusal table to be traced electronically, cropping everything else out of the image (Figure 3B). Halcon Contactos Software then computed ACNC for the isolated posterior occlusal surfaces.

Bite Registration Calibration

A step-wedge of Blu-Mousse® material was used to calibrate each bite registration. Blu-Mousse® was applied to a glass surface and a steel ball with a 19.05 mm radius attached to an articulator was lowered to create identical step-wedges, with the material perforated in the center of the step-wedge. The material was allowed to fully set before raising the ball bearing and recovering the spherical step-wedge.

The Halcon Contactos Software used the step-wedge to estimate the ACNC. Using polar coordinates, thickness (y, in microns) of the Blu-Mousse® material could be calculated for given distances (x, in mm) from the center of the step-wedge (Figure 4). This relationship was used to calculate areas of contact (material thickness of 0-50 μm) and near contact (material thickness of 51-350 μm), which were combined to calculate total posterior ACNC for all patients at each of the four respected time points.

After calibration, one blinded investigator performed duplicate measurements on 15 randomly selected images to confirm intra-examiner reliability. The replicated bite registration tracings indicated no statistically significant systematic error. Random error analysis included intraclass correlations and method errors. The intraclass correlations for contacts (0.996, $p<0.05$) and near contacts (0.996, $p<0.05$) were high. The method errors for contacts (0.81 mm^2) and near contacts (1.94 mm^2) were both within the range of acceptability.

Statistical Methods

One blinded investigator recorded all of the ACNC on a Microsoft Excel spreadsheet. The data were transferred to SPSS Version 26.0 (IBM® Corp., Armonk NY) for statistical analyses. Twenty-three observations were removed from data analyses due to extreme values associated with breakage. Normality of the data were assessed using skewness and kurtosis statistics. Since the data were not normally distributed, medians and interquartile ranges (IQRs) were used. Wilcoxon Signed Ranks Tests and Mann-Whitney U-Tests were used to evaluate the within-group and inter-group differences, respectively.

The data were divided into two samples. The mixed-longitudinal sample evaluated all available timepoints and included 74 patients (38 traditional braces, 36 Invisalign®) who had, at a minimum, completed treatment (i.e., T_1 and T_2 bite registrations available for evaluation). The six patients that did not complete full treatment were not evaluated. The longitudinal sample included 35 patients (16 traditional braces, 19 Invisalign®) with data for all four timepoints.

Patient Privacy Protection

Patient records were de-identified at the time of collection to prevent any risk of HIPPA violation. In order to de-identify the patients' records, all names, addresses, and identifying text were removed. Patient photos were not utilized during assessment of the occlusal bite registrations. Patient models and bite registrations, taken as a part of clinical records and orthodontic treatment, were assigned a random number to serve as a reference ID. No identifying information was retained or linked to the patient throughout the course of the study. The bite registrations were physically stored in a locked, temperature-controlled location (Room 725A, Texas A&M College of Dentistry). Electronic data and the photographs of the bite registrations were stored on an encrypted computer with a secure, password protected login.

CHAPTER IV

RESULTS

There were no statistically significant between-group differences for total ACNC for individual timepoints (Figures 9A and 9B, Table 1), nor in the durations between timepoints (Figure 10, Table 2). The longitudinal sample demonstrated similar changes in total ACNC as those observed in the mixed-longitudinal sample (Figures 9B, 10).

The mixed-longitudinal sample showed that the areas of contact (i.e., ≤50 μm thick) decreased significantly during treatment (T_1-T_2), increased significantly during the first-month posttreatment (T_2-T_3), and further increased significantly between one- to six-months posttreatment (T_3-T_4, Figure 5A). There were no statistically significant between-group differences at any of the timepoints. There also were no statistically significant between-group differences in the changes that occurred between timepoints (Figure 6). The longitudinal sample displayed the same pattern of changes over time as the mixed-longitudinal sample, with no statistically significant between-group differences in areas of contact at any of the timepoints and no significant differences in the changes that occurred between timepoints (Figures 5B, 6).

Areas of near contact (i.e., 50-350 μm thick) of both the mixed-longitudinal and longitudinal samples mirrored those seen for the areas of contact (Figures 7A, 7B). There were no statistically significant between-group differences at any of the timepoints and there were no significant differences in the changes recorded between timepoints (Figure 8).

Total ACNC (≤350 μm thick) in the longitudinal sample decreased significantly (68.8-72.8%) during treatment, increased significantly (14.4-19.6%) during the first month posttreatment and continued to increase significantly (11.9-16.6%) during the last five months posttreatment (Figure 9B; Table 3). There were no significant between-group differences. Total ACNC for the traditional braces group decreased by 72.8% and decreased by 68.8% for the aligner group during treatment (T_1-T_2, Table 3). During the first month posttreatment, total ACNC increased by 14.4% and 19.6% for traditional braces and Invisalign®, respectively (T_2-T_3, Table 3). During the last five months posttreatment, total ACNC further increased significantly by 16.6% and 11.9% for traditional braces and Invisalign®, respectively (T_3-T_4, Table 3).

There were statistically significant differences between the changes in total ACNC of posttreatment settling that occurred during the first month (T_2-T_3) and the last five months (T_3-T_4). Significantly more settling occurred during the first month posttreatment than the following five months. Total ACNC increased approximately 4.3 ($p=0.023$) and 8.2 times more ($p=0.035$) for the longitudinal sample braces and Invisalign® patients, respectively.

Overall, significant amounts of posttreatment settling were observed for both groups, with total ACNC values increasing 31.0% in the longitudinal braces group and 31.5% in the longitudinal Invisalign® group (T_2-T_4, Table 3). Importantly, total ACNC values obtained after six-months of posttreatment settling (T_4) did not attain pre-treatment (T_1) values. The longitudinal traditional braces group showed a 41.8% deficit and the longitudinal Invisalign® group showed a 37.3% deficit from pre-treatment values (T_1-T_4, Table 3).

CHAPTER V

DISCUSSION

Occlusal contacts and near contacts of patients treated with traditional braces and Invisalign® aligners significantly worsen during active orthodontic treatment. The current study found that total ACNC decreased 72.8% for the traditional braces group and 68.8% for the Invisalign® group during orthodontic treatment. While ACNC were not evaluated, it has been previously reported that orthodontic treatment, whether traditional braces[5, 6] or aligners[8], results in a decrease in the number of occlusal contacts. Sullivan et al. reported that the number of posterior contacts significantly decreased by 48% after only one month of active orthodontic treatment and that the number of contacts did not significantly increase over the following 11 months of treatment.[5] Haydar et al. showed that traditionally treated groups only had 54-63% as many contacts after treatment as untreated controls.[6] Posterior occlusal contacts, measured as part of the ABO-OGS, increased 6.3 points during treatment, from an initial 4.0 points to posttreatment 10.3 points ($p<0.001$), reflecting a significant decrease in occlusal contacts during treatment.[8] Kassas and colleagues, who also used the ABO-OGS, found worsening of occlusal contacts during Invisalign® treatment, though the increase of 1.23 points for the occlusal contacts parameter was not statistically significant (pre-treatment 5.48, posttreatment 6.71, $p=0.125$).[9] This is in agreement with the study by Sullivan et al. who found an appreciable 47.9% decrease in posterior occlusal contacts one month after traditional braces, as well as a 46.4% decrease observed after 12 months of active treatment.[5] ACNC might be expected to decrease during orthodontic treatment due to teeth movements out of equilibrium. The pre-treatment equilibrium created by wear and function are changed with orthodontic treatment, which would also reflect a decrease in ACNC.

Treatment effects on posterior occlusion are similar for traditional braces and aligners. In the present study, ACNC decreased 72.8% and 68.8% for traditional braces and Invisalign® longitudinal samples, respectively. While ACNC have not been previously used, the ABO-OGS and PAR Index have been used to compare occlusal contacts. Gu et al. found no statistically significant difference in mean weighted posttreatment PAR scores (p=0.4573) between traditional braces and aligners at the end of treatment, including no differences in occlusal contacts.[56] In contrast, Djeu et al. showed that Invisalign® consistently scored higher (i.e., greater worsening) than braces for both occlusal contacts and occlusal relationships.[21] They suggested that Invisalign® results in less adequate occlusal contacts due to the difficulty in aligners' ability to extrude teeth unless significant undercuts are present in the material, as well as aligners' inhibition of settling attributable to plastic interposed between the teeth. Importantly, Djeu and colleague's study took place prior to the 2008 refinements and changes that now allow for improved Invisalign® treatment results. Auxiliaries such as Precision Cuts, Precision Bite Ramps, and Smart Force Attachments[56] enable more controlled tooth movements. This may explain why they found significant differences (poorer Invisalign® tooth control and extrusion mechanics) and the current study did not (more controlled tooth movement, similar to that achieved with braces).

Posttreatment settling was observed in both groups during the retention period. Between appliance removal and 6-months posttreatment, total ACNC increased 31%. These findings confirm the previous literature showing occlusal settling following appliance removal. Based on 50 cases treated by board-certified orthodontists, it has been suggested that the greatest improvements of occlusal contacts occur within the first four years posttreatment.[69] Nett and Huang, who used the ABO-OGS to score 100 cases ten years following treatment, found that occlusal contacts had significantly improved posttreatment (decrease of 2.5 points, $p<0.001$).[70] Van der Linden's cone-funnel phenomenon suggests that the dentition settles to regain an occlusal and masticatory harmony following appliance removal as the teeth are allowed to move and function as individual units.[32]

Greater settling of the occlusion occurs during the first month posttreatment than during the following five months. Total ACNC in the longitudinal sample increased 14.4-19.6% after one month, and only 2.4-3.3% per month over the following five months. Based on ACNC, Bauer et al. reported that the greatest rate of settling occurred during the first two months of retention and that there were no significant settling changes after six months.[10] Durbin and Sadowsky reported a 16.32% increase in the number of posterior contacts during the initial three months of retention.[71] These studies support the concept of Phase I settling, where the teeth move independently immediately after appliance removal instead of as a single unit bound together by arch wires or aligners. The posterior teeth rapidly displace to achieve stability and contact with the opposing dentition, thus resulting in an increased number of contacts and near contacts.[5]

Patients treated with traditional braces and aligners undergo similar amounts of posttreatment settling. In the present study, there were no significant between-group differences in the amount of posttreatment settling that occurred between traditional braces and Invisalign®. At this time, there is only one study assessing posttreatment posterior occlusion into the retention phase. Kuncio et al., who utilized the ABO-OGS, reported no statistically significant differences between braces and Invisalign® in the posterior occlusal contacts' increase three years after treatment. The Invisalign® group improved by 0.36 points, while the braces group improved by 1.91 points (p=0.6244). Similar amounts of settling could be partially due to the heavy posterior occlusal contacts that were built into the Invisalign® ClinCheck® Software. Since the two groups ended orthodontic treatment with similar (i.e., no significant difference) posterior ACNC, similar amounts of posttreatment settling should not be surprising. Likewise, the two groups followed a similar retention protocol, which surely played a role in ensuring similar amounts of posttreatment settling.

Despite posttreatment settling of the occlusion during the retention phase, posterior occlusal contacts do not attain pre-treatment values after six months of retention. Total ACNC showed a net loss of approximately 40% in the present study. This could be due to the short-term six-month retention period. As Whittaker previously reported, normal wear, attrition, and compensatory eruption of the dentition continue to occur over time, thus it is likely that the posterior dentition will continue to settle and increase its ACNC throughout an individual's lifetime.[35, 36] To this point, the addition of a more prolonged follow-up retention timepoint, such as five or ten years posttreatment, may lend insight to continued long-term settling and increases in total ACNC. The net deficit observed could also be attributed to the quality of finished orthodontic cases. An astute eye to detail during the last stage of orthodontic treatment could lend itself to enhanced occlusal contacts and a better finish. Orthodontists have to devote special attention to occlusal contacts because they are among the top four parameters related to improved treatment quality and case outcomes.[72] Perhaps more credence is imparted by Ballard, who measured mesiodistal tooth size dimensions and concluded that tooth size is highly variable.[73] Approximately 90% of the 500 cases he measured had a significant discrepancy between the right and left pairs of teeth, and 82% had a discrepancy greater than 0.5 mm. If such tooth-size disharmonies so commonly exist, it is unlikely that an ideal occlusal finish and intercuspation of the teeth can be obtained.

This study is not without its limitations. Most notably, patient compliance with the posttreatment retention protocol could have played a role in how occlusal contacts changed. Following treatment, most patients were retained with a twisted 0.0175” stainless steel wire bonded from lower canine to canine and upper wraparound Hawley retainer with C-clasps distal to the second molars. Patient were instructed to wear the Hawley retainer nightly. Additionally, it is also plausible that the Invisalign® patients may have continued using the last aligners in their refinement series as their final retainers, as these were not collected at the conclusion of treatment. Posttreatment retention compliance was not assessed, which prevented group comparisons from being made. In addition, some patients were lost to follow-up for retention visits at the one-month and six-month records appointments, which may have also impacted the results obtained. The longitudinal sample included only 35 patients (16 traditional braces, 19 Invisalign®) of the 80 enrolled patients. Additionally, the long duration that occurred between bite registration collections and the time of actual ACNC measurements resulted in breakage of bite registration materials.

Whether a patient desires a more esthetic approach to orthodontic correction, such that clear aligner therapy offers, or prefers to proceed with traditional treatment, there appear to be no significant differences in posttreatment or post-retention occlusal contact outcomes (i.e., posterior ACNC values). Astute clinicians should include heavy posterior occlusal contacts in the ClinCheck® Software revisions to ameliorate the effects of the aligners’ plastic interposed between the teeth. Doing so appears to diminish the effects that the interposed aligner thickness may have on posterior occlusal contacts. The clinical implications, therefore, suggest that there is no superior treatment modality in the correction of minor Class I malocclusions, at least so far as posterior ACNC is considered. Settling of the posterior dentition with subsequent increases in ACNC can be anticipated into the short-term retention phase, with similar posttreatment settling observed among the two groups. Likewise, use of retention that lacks occlusal coverage is also recommended to maximize posttreatment settling. Settling of the occlusion depends heavily on the type of retainer, and it can be concluded that occlusal coverage of the posterior teeth during the retention period may result in minimal to relatively no detectable amount of posterior settling.[13, 60, 68]

CHAPTER VI

CONCLUSIONS

- Areas of contact, near contact, and total ACNC decrease significantly (≈70%) during orthodontic treatment.
- There are no significant differences between traditional braces and Invisalign® in the decreases in the areas of contact, near contact, and total ACNC that occur during treatment.
- Statistically significant settling occurs posttreatment, with ACNC increasing approximately 31% during the first six months.
- Significantly more settling is seen one-month posttreatment than the following five months in both groups. Total ACNC in the longitudinal sample had increased 14.4-19.6% after one month, and only 2.4-3.3% per month over the following five months. Total ACNC increased approximately 4.3 (p=0.023) and 8.2 times more (p=0.035) for the braces and Invisalign® groups, respectively.
- Despite settling, posttreatment ACNC values did not reach the pre-treatment values, and a net deficit of approximately 40% was observed for both the traditional braces and Invisalign® groups.

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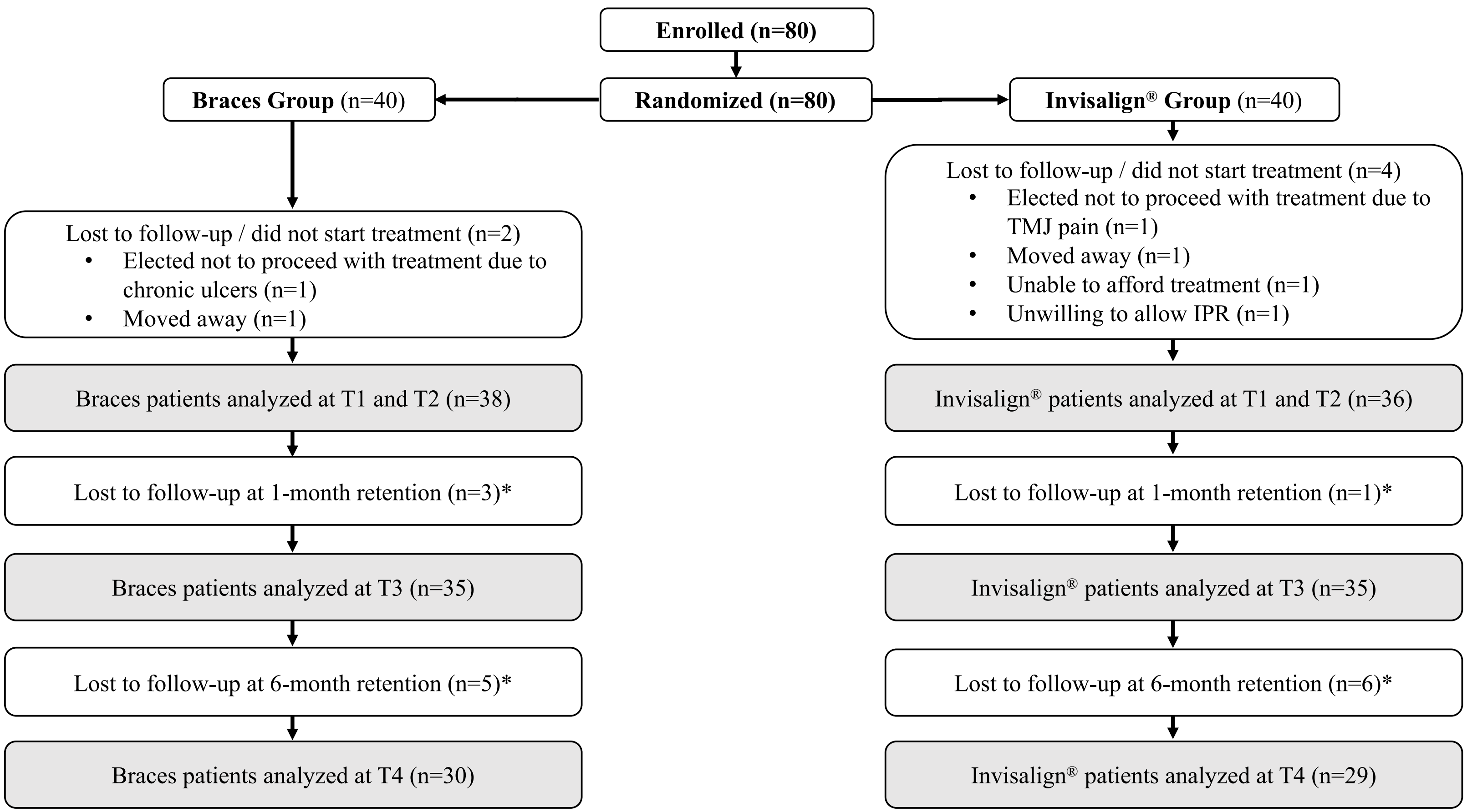
APPENDIX A

FIGURES

Figure 1: Patient flowchart depicting enrollment, randomization, attrition, and analyses



* Patients lost to follow-up at 1-month and 6-months due to failure to return for post-treatment records appointments

Figure 2: A) Data collection set-up on top of LED light pad. Bite registration (BR), step-wedge (SW), and ruler guide (MM)],

B) Cardboard box on LED light pad for photo standardization

Figure 3: A) Image of transilluminated bite registration, step-wedge, and ruler guide,

B) Software selection of occlusal table outlined with lasso tool

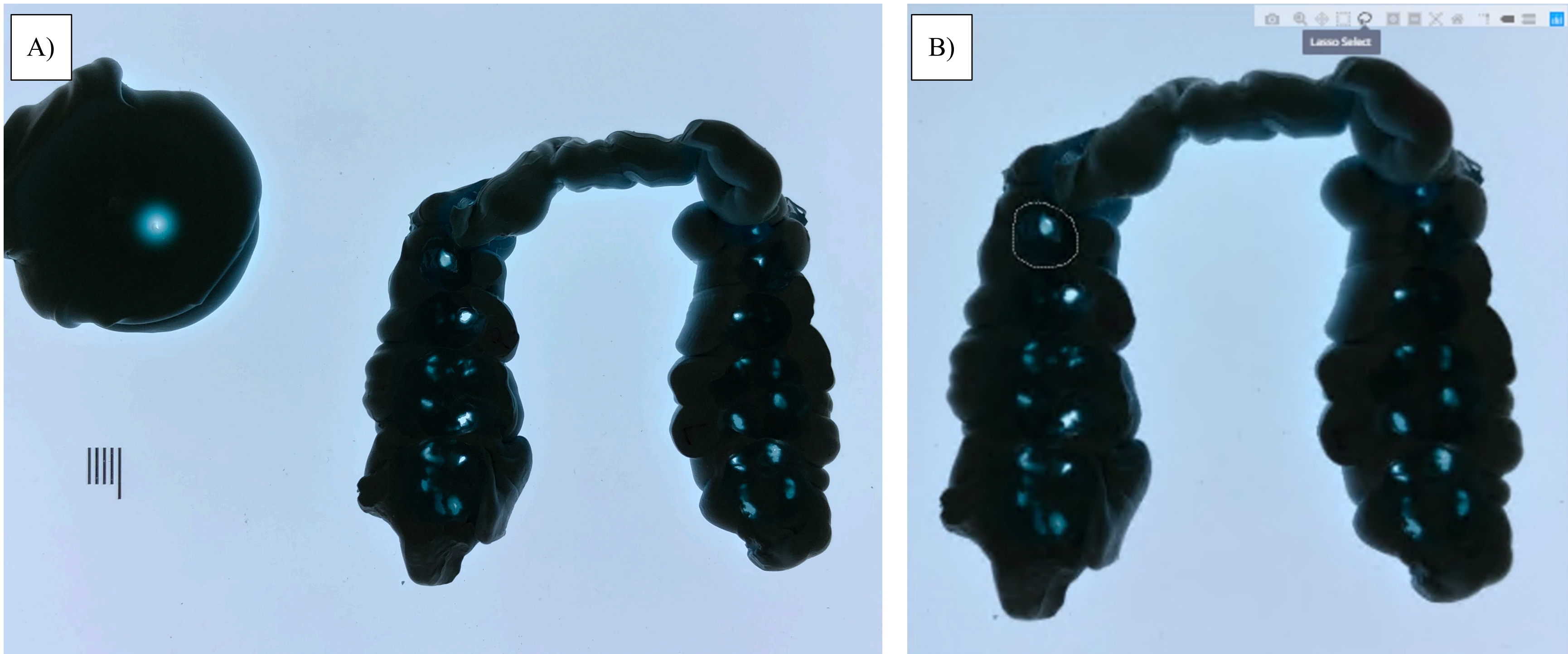


Figure 4: Depiction of sphere with Cartesian coordinates used to determine thickness of Blu-Mousse® based on distance of arc

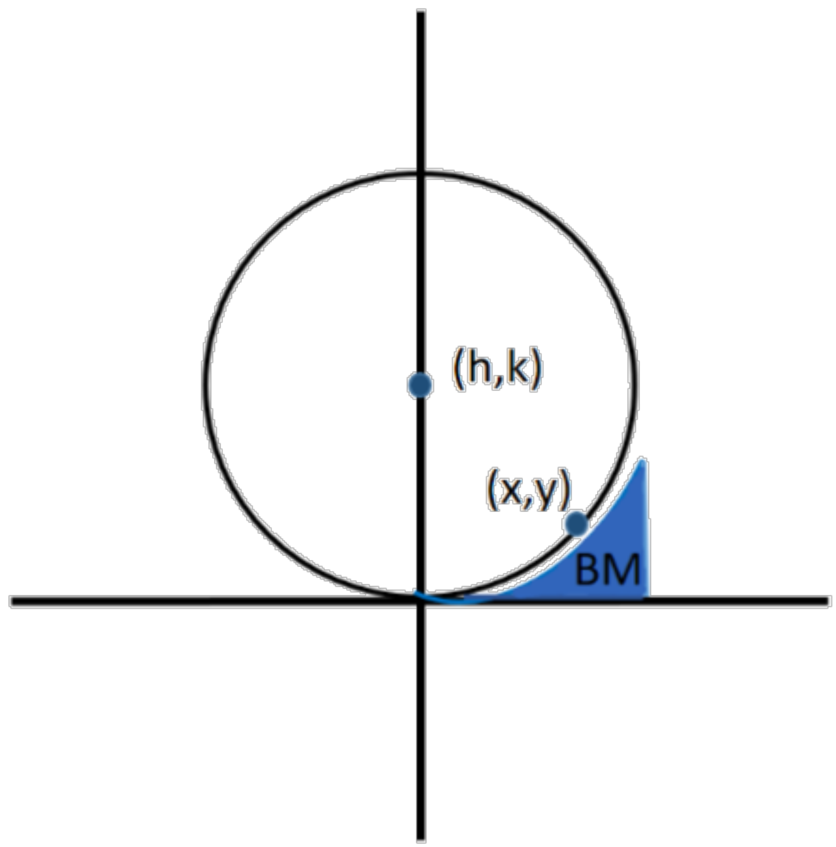


Figure 5: A) Median areas of contact observed T_1-T_4 in mixed-longitudinal sample

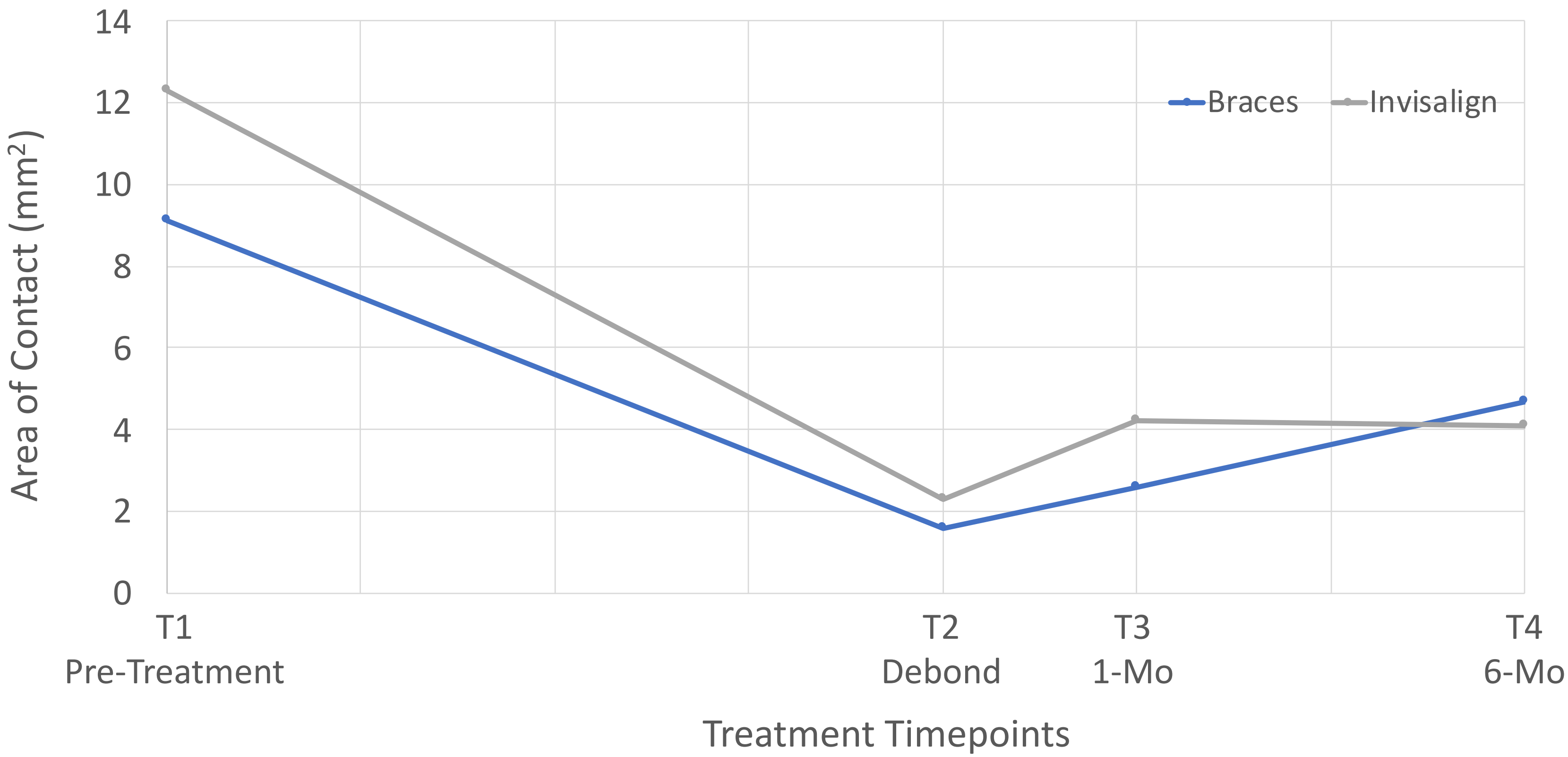


Figure 5: B) Median areas of contact observed T_1-T_4 in longitudinal sample

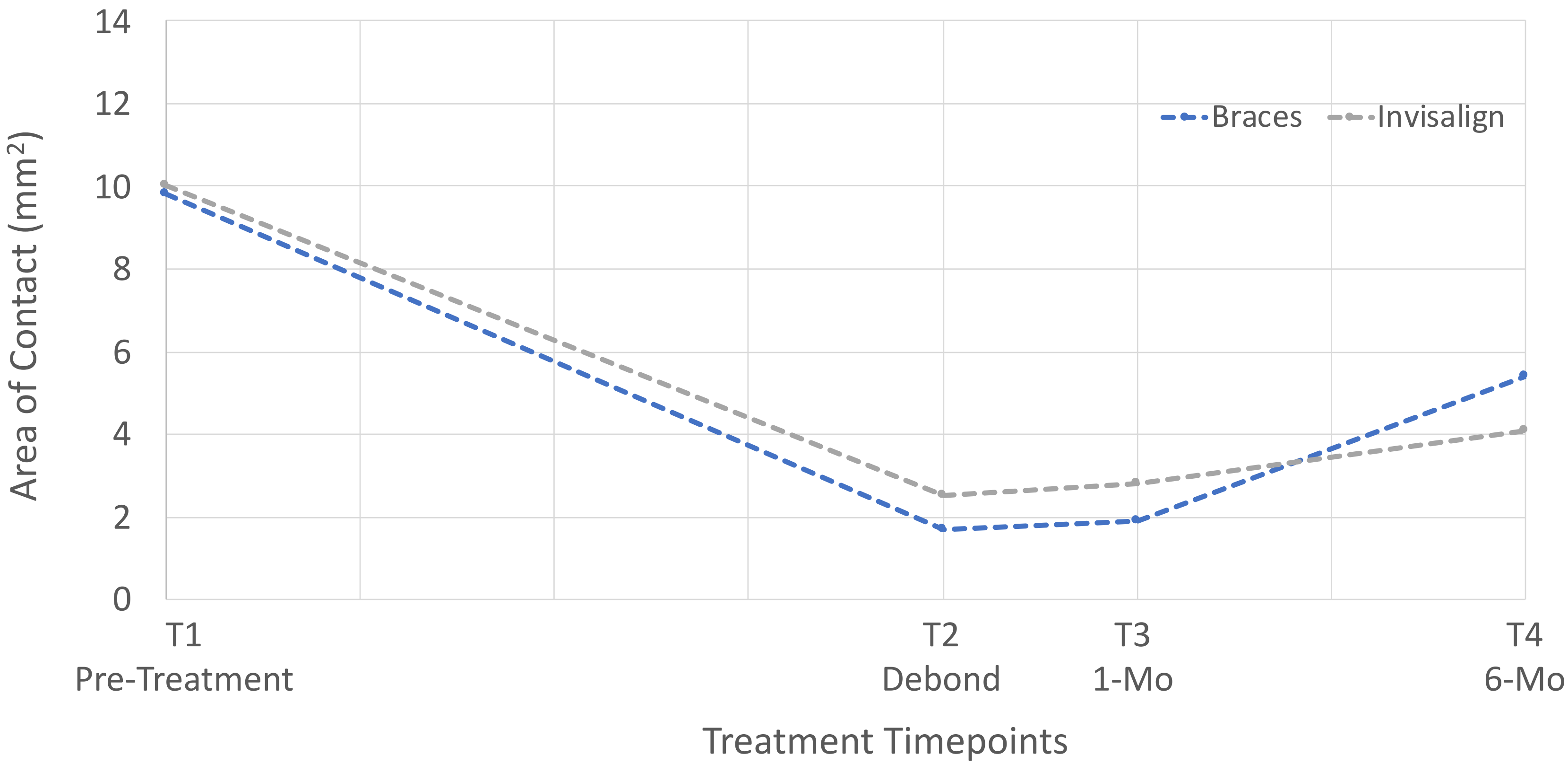


Figure 6: Median changes in areas of contact observed between T_1-T_2, T_2-T_3, and T_3-T_4 in mixed-longitudinal and longitudinal samples

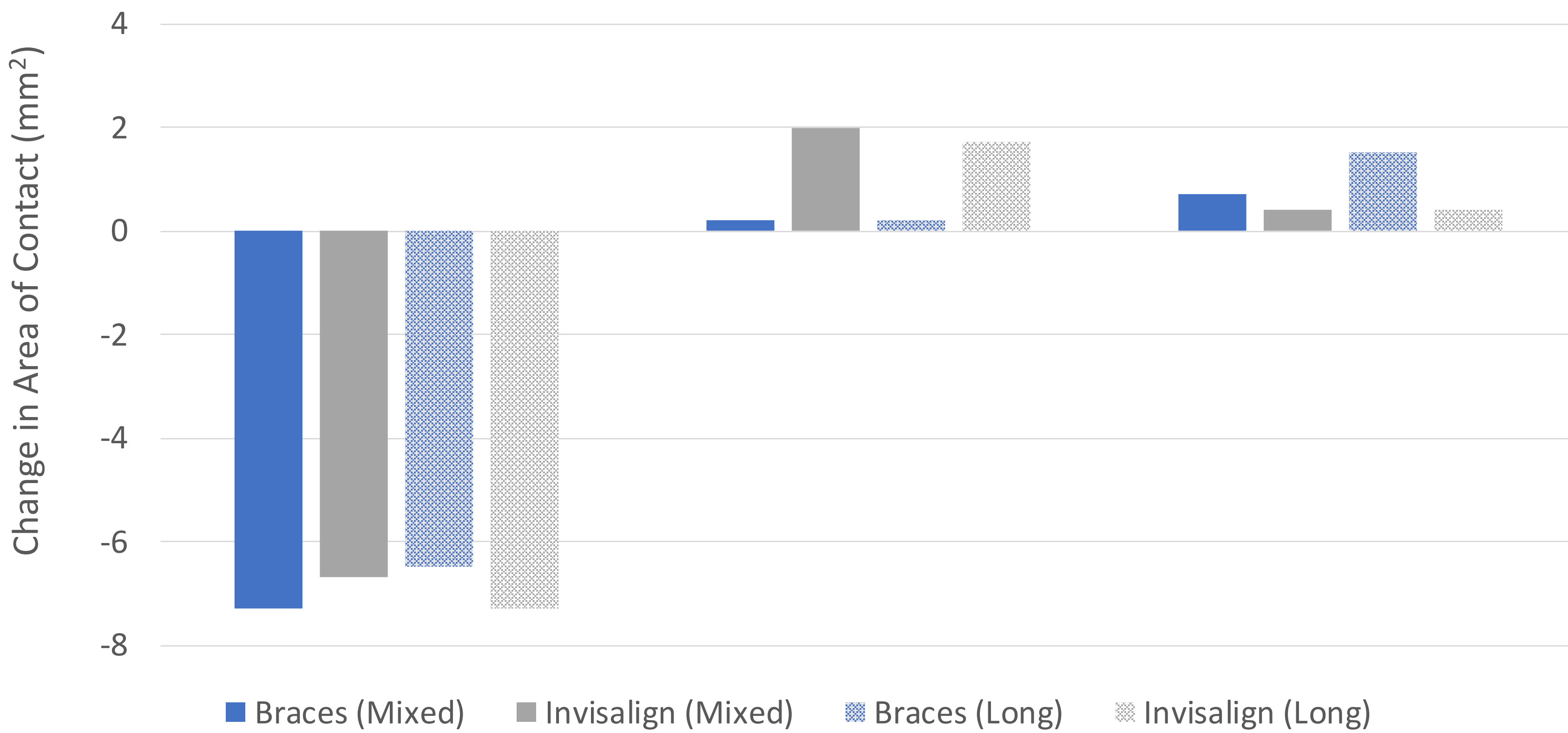


Figure 7: A) Median areas of near contact observed T_1-T_4 in mixed-longitudinal sample

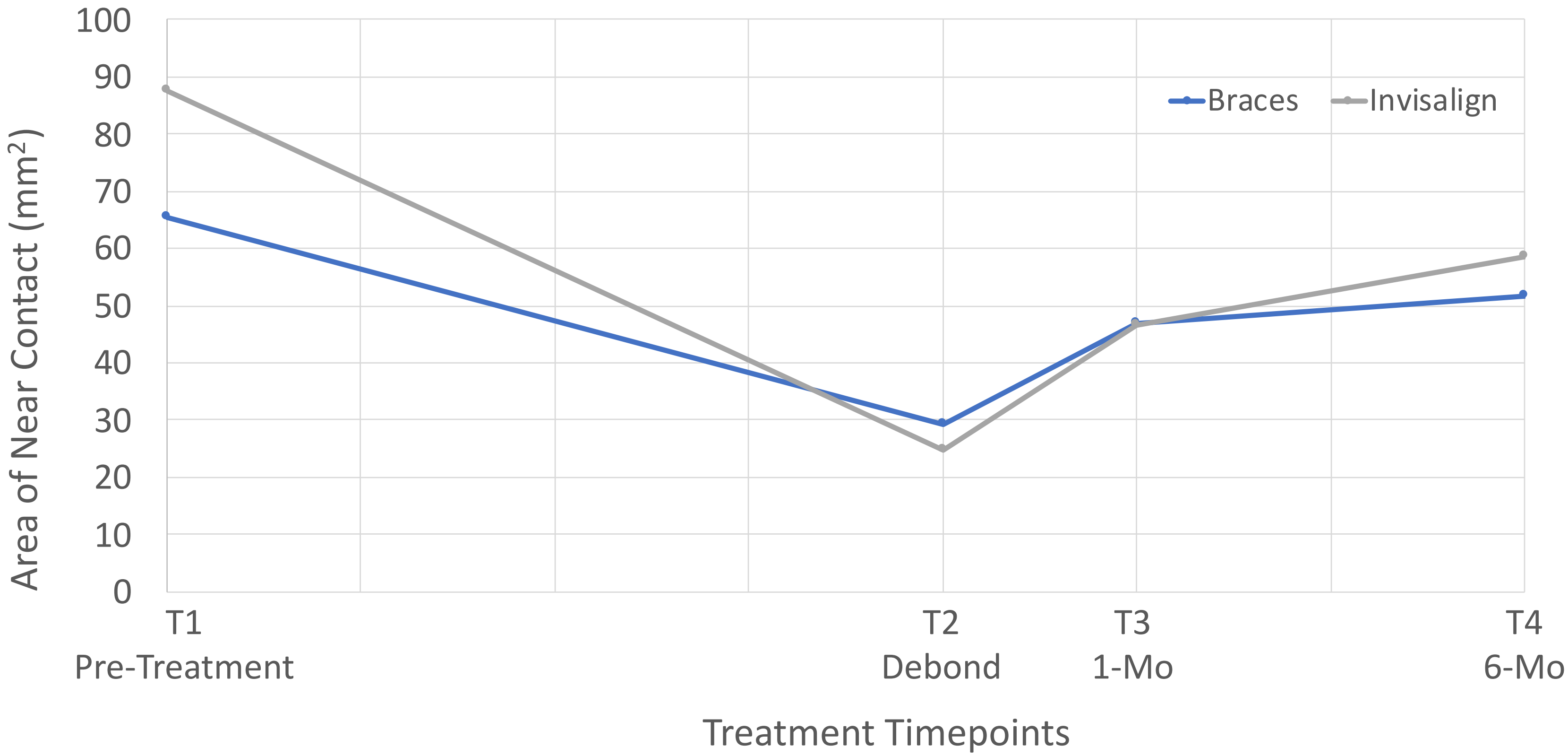


Figure 7: B) Median areas of near contact observed T_1-T_4 in longitudinal sample

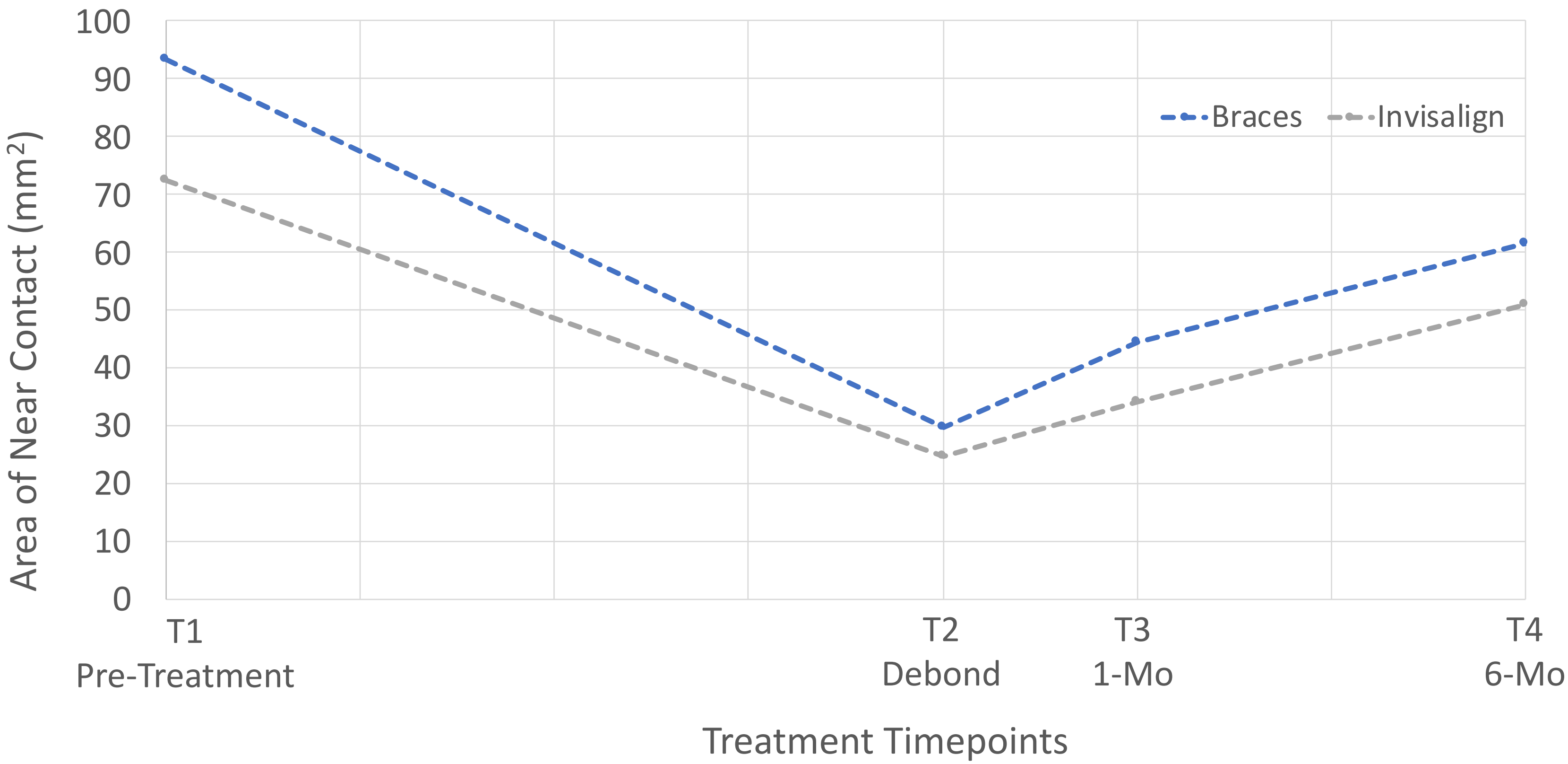


Figure 8: Median changes in areas of near contact observed between T_1-T_2, T_2-T_3, and T_3-T_4 in mixed-longitudinal and longitudinal samples

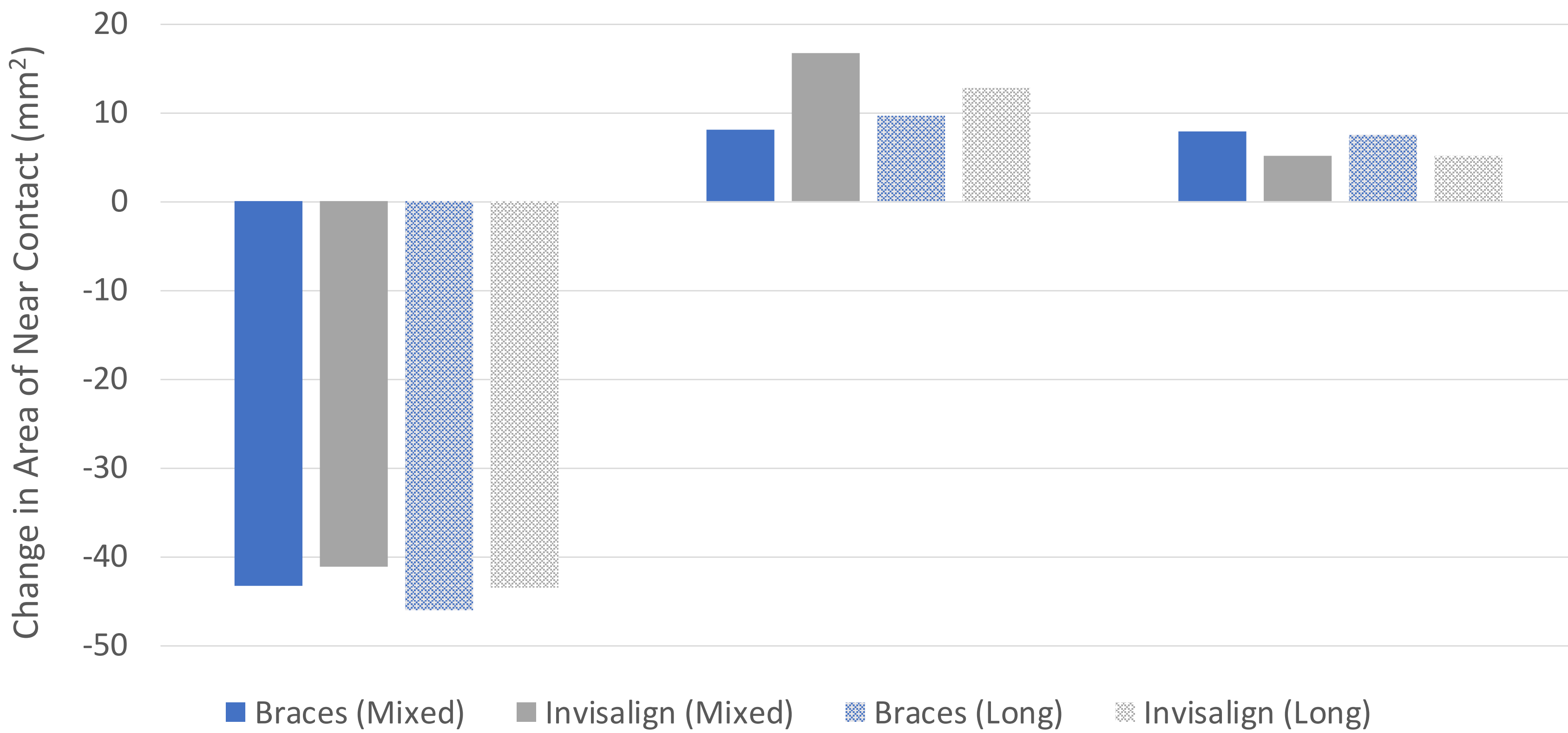


Figure 9: A) Median total ACNC observed T_1-T_4 in mixed-longitudinal sample

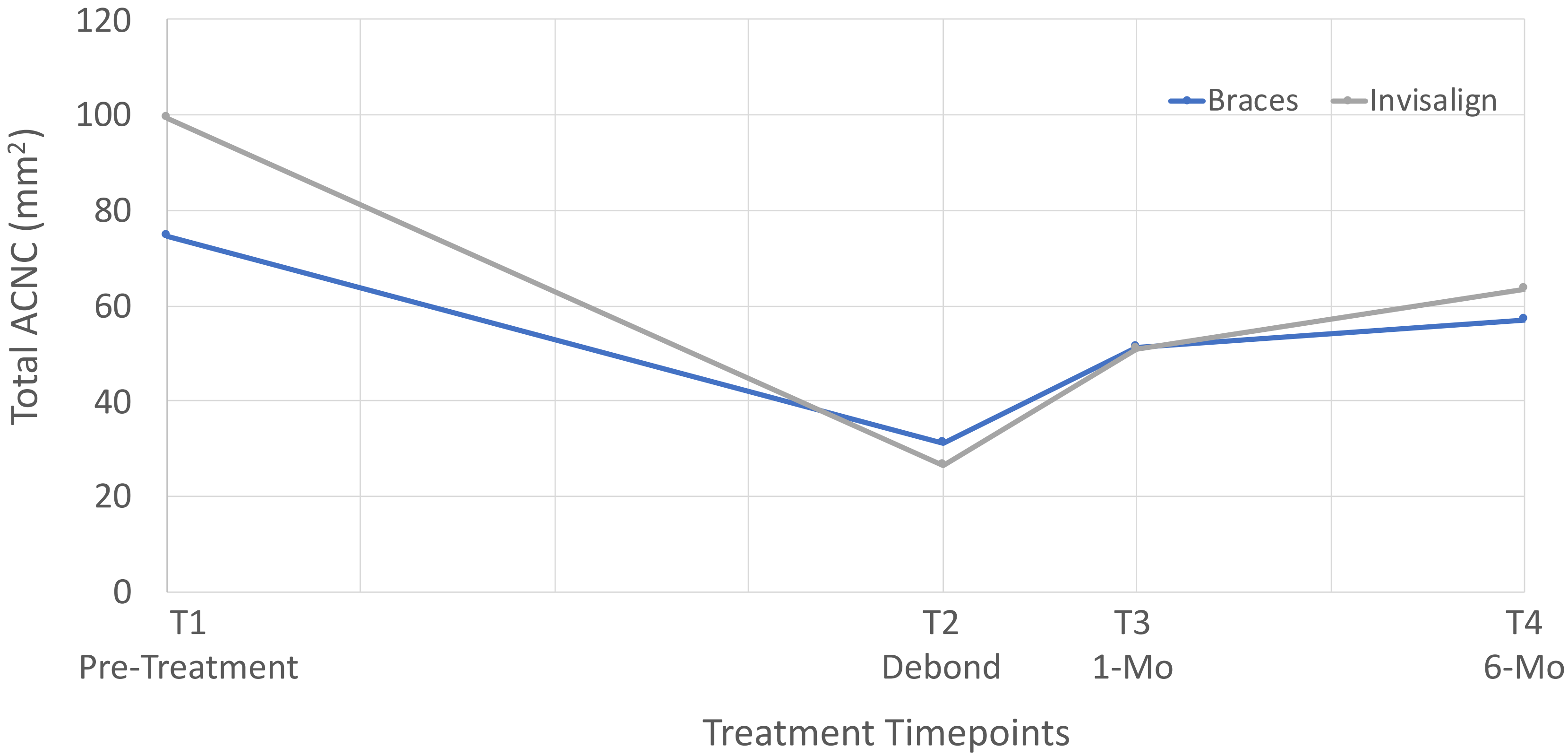


Figure 9: B) Median total ACNC observed T_1-T_4 in longitudinal sample

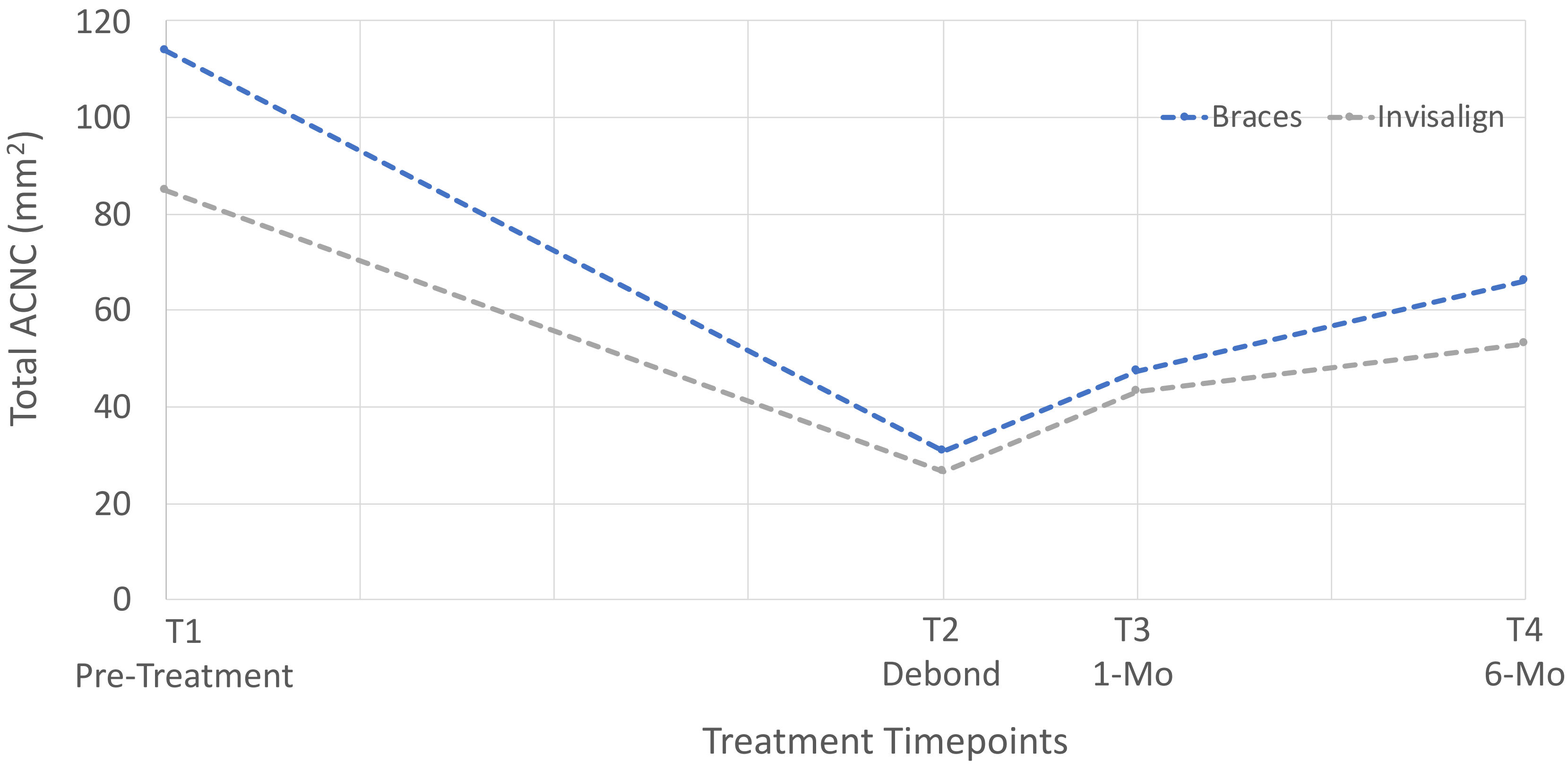
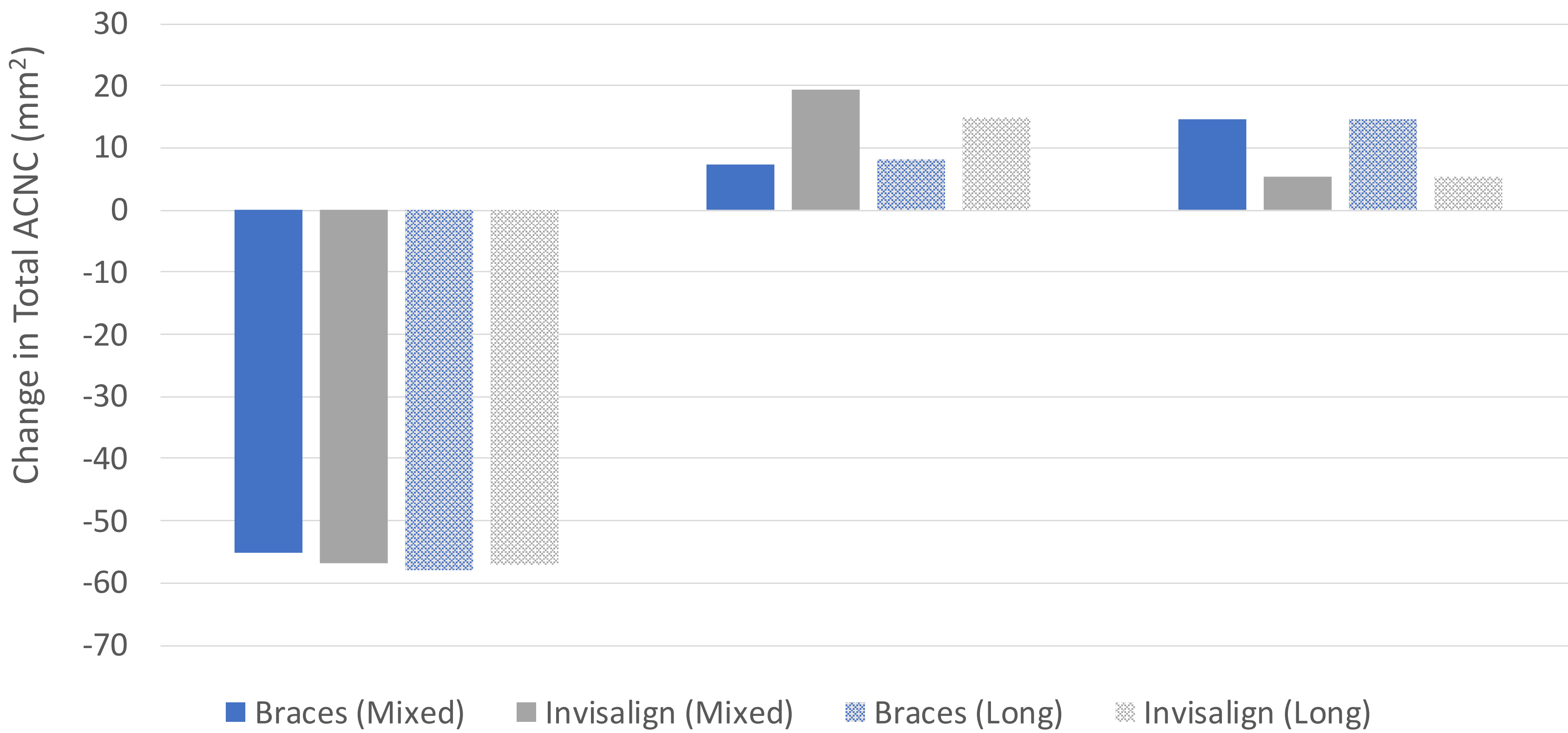


Figure 10: Median changes in areas of near contact observed between T_1-T_2, T_2-T_3, and T_3-T_4 in mixed-longitudinal and longitudinal samples



APPENDIX B

TABLES

Table 1: Median areas of contact, near contact, and total ACNC observed at each timepoint

		Mixed-Longitudinal					Longitudinal				
		Braces		Invisalign		Mann Whitney P-Value	Braces		Invisalign		Mann Whitney P-Value
		Median (50%)	IQR (25%, 75%)	Median (50%)	IQR (25%, 75%)		Median (50%)	IQR (25%, 75%)	Median (50%)	IQR (25%, 75%)	
Contacts ≤50 μm	**T1 (Pre-Tx)**	9.1	3.7, 17.3	12.3	6.0, 17.9	p=0.45	9.8	5.0, 17.7	10.0	5.7, 18.1	p=0.92
	T2 (Debond)	1.6	0.8, 3.8	2.3	0.7, 5.3	p=0.85	1.7	1.0, 3.0	2.5	0.7, 4.5	p=0.79
	T3 (1-Mo)	2.6	1.0, 5.4	4.2	1.8, 7.8	p=0.37	1.9	0.9, 3.5	2.8	0.9, 6.9	p=0.34
	T4 (6-Mo)	4.7	2.2, 9.2	4.1	1.9, 6.0	p=0.56	5.4	1.6, 11.3	4.1	2.1, 5.9	p=0.35
Near Contacts 50-350 μm	**T1 (Pre-Tx)**	65.3	46.2, 103.6	87.6	48.8, 119.5	p=0.36	93.4	51.4, 126.2	72.4	37.1, 115.7	p=0.41
	T2 (Debond)	29.4	20.5, 45.7	24.8	13.6, 52.4	p=0.62	29.7	23.7, 46.7	24.8	15.2, 44.0	p=0.29
	T3 (1-Mo)	47.0	36.9, 58.3	46.5	26.6, 79.6	p=0.89	44.5	33.9, 57.9	34.3	21.4, 61.0	p=0.41
	T4 (6-Mo)	51.7	31.9, 73.9	58.6	24.9, 98.1	p=0.93	61.4	31.2, 73.3	50.9	26.8, 74.0	p=0.51
Total ACNC ≤350 μm	**T1 (Pre-Tx)**	74.4	53.9, 121.4	99.4	62.3, 137.7	p=0.31	113.8	57.8, 147.6	84.7	47.1, 135.3	p=0.47
	T2 (Debond)	31.3	21.1, 47.6	26.4	14.4, 60.2	p=0.75	30.9	25.7, 48.9	26.4	16.3, 47.5	p=0.34
	T3 (1-Mo)	51.1	39.6, 64.5	51.0	29.3, 85.2	p=0.92	47.3	36.3, 62.0	43.0	22.1, 77.2	p=0.62
	T4 (6-Mo)	57.1	35.4, 84.0	63.5	26.3, 106.4	p=0.97	66.2	33.7, 82.9	53.1	29.0, 85.8	p=0.61

Table 2: Median changes in areas of contact, near contact, and total ACNC observed between timepoints

		Mixed-Longitudinal					Longitudinal				
		Braces		Invisalign		Mann Whitney P-Value	Braces		Invisalign		Mann Whitney P-Value
		Median (50%)	IQR (25%, 75%)	Median (50%)	IQR (25%, 75%)		Median (50%)	IQR (25%, 75%)	Median (50%)	IQR (25%, 75%)	
Contacts ≤50 μm	**ΔT1-T2**	-7.3*	-14.6, -2.3	-6.7*	-16.2, -1.4	p=0.72	-6.5*	-14.0, -2.7	-7.3*	-16.7, -2.9	p=0.92
	ΔT2-T3	0.2*	-0.6, 2.9	2.0*	-0.3, 3.5	p=0.21	0.2*	-0.6, 1.3	1.7*	-0.6, 2.8	p=0.21
	ΔT3-T4	0.7*	-0.4, 6.1	0.4*	-0.1, 1.6	p=0.39	1.5*	0.2, 7.8	0.4*	-0.1, 1.6	p=0.06
	ΔT1-T4	-2.9*	-11.7, 0.3	-4.7*	-15.8, -0.6	p=0.52	-3.1*	-11.5, -1.0	-4.7*	-14.3, -0.7	p=0.65
Near Contacts 50-350 μm	**ΔT1-T2**	-43.3*	-73.2, -23.1	-41.2*	-70.6, -12.4	p=0.75	-46.1*	-81.4, -24.8	-43.5*	-70.6, -7.0	p=0.55
	ΔT2-T3	8.0*	2.3, 16.4	16.7*	2.4, 29.9	p=0.19	9.7*	2.7, 22.9	12.8*	-0.7, 22.8	p=0.97
	ΔT3-T4	7.8*	-1.0, 23.5	5.2*	-1.0, 20.6	p=0.86	7.5*	0.6, 21.8	5.2*	0, 20.6	p=0.92
	ΔT1-T4	-12.3*	-52.4, 14.1	-0.8*	-48.1, 5.9	p=0.70	-15.1*	-74.9, 6.5	-0.8*	-51.0, 5.4	p=0.43
Total ACNC ≤350 μm	**ΔT1-T2**	-55.1*	-88.4, -26.1	-56.8*	-83.4, -18.7	p=0.70	-58.0*	-95.6, -27.5	-57.1*	-83.4, -15.7	p=0.53
	ΔT2-T3	7.4*	4.2, 18.5	19.5*	2.7, 33.3	p=0.11	8.3*	4.6, 22.2	15.0*	-0.7, 25.5	p=0.79
	ΔT3-T4	14.6*	-1.1, 27.9	5.3*	1.0, 22.2	p=0.75	14.6*	2.0, 28.0	5.3*	1.0, 22.2	p=0.49
	ΔT1-T4	-15.9*	-67.7, 4.2	-13.9*	-65.6, 5.5	p=0.80	-28.6*	-87.7, 4.4	-13.9*	-66.2, 2.6	p=0.51

*Wilcoxon Signed Ranks, p<0.001

Table 3: Percent changes observed in total ACNC between timepoints compared to T_1 values

		ΔT1-T2	ΔT2-T3	ΔT3-T4	ΔT1-T4	ΔT2-T4
Mixed-Longitudinal	**Braces**	-57.9%	+26.6%	+8.1%	-23.3%	+34.7%
	Invisalign	-73.4%	+24.7%	+12.6%	-36.1%	+37.3%
Longitudinal	**Braces**	-72.8%	+14.4%	+16.6%	-41.8%	+31.0%
	Invisalign	-68.8%	+19.6%	+11.9%	-37.3%	+31.5%