

Changes in Occlusal Contact Area Following Orthodontic Treatment: At Time of Debond and  
Into Retention

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**Abstract**

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**Introduction:** The purpose of this study was to evaluate changes in occlusal contact surface area from pre-treatment (T1), post-treatment (T2), and into retention (T3) using 3D models acquired when patients presented for retainer replacement. The influence of patient demographics, treatment characteristics, time since debond and retention types on occlusal contact changes were analyzed. **Methods:** Patients treated in the University of Washington Orthodontics clinic who obtained an intra-oral scan for the fabrication of new retainers were screened. Inclusion criteria were a history of orthodontic treatment of the permanent dentition with fixed appliances and without orthognathic surgery, the availability of good quality intra-oral scans prior to and after orthodontic treatment, and the absence of restorative treatment since debond. Occlusal contact surface area on the intra-oral scans was analyzed using 3D analysis software across a range of -1mm to 1mm of inter-occlusal distance between the maxillary and mandibular dentition. Three categories were differentiated: open (0.46 to 1 mm), near (0.21-0.45 mm), and tight (0-0.2 mm)

contacts. Surface areas were evaluated for the anterior, posterior, and total dentition at each of the three time points. Changes in occlusal contact surface area were assessed between the three time points (T1-T2, T2-T3 and T1-T3) with subgroup analyses based on age, malocclusion, extraction status, retainer type, and retention time. **Results:** 60 patients met the inclusion criteria (mean age 15.8 years, 57% female, 43% male, mean time since debond 20.3 months). From T1 to T2, tight and near contact surface area decreased, while open contact surface area increased in the anterior, posterior, and total dentition. From T2 to T3, tight and near contact surface area increased, while open contact surface area decreased in the anterior, posterior, and total dentition. The majority of occlusal contact changes during retention occurred within the first 24 to 36 months following appliance removal. From T1 to T3, there was no significant net change overall for tight, near, and open contacts in the anterior, posterior, and total dentition. Age, extraction status, and retainer type demonstrated limited influence on occlusal contact changes. Class II and III malocclusions exhibited greater increases in near contact surface area and greater decreases in open contact surface area compared with Class I malocclusions, primarily in the total dentition. **Conclusions:** Orthodontic treatment with fixed appliances temporarily disrupts close occlusal contacts, while retention allows for occlusal settling which increases the occlusal contact areas with a return toward pretreatment values obtained after 24 to 36 months following appliance removal.

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## I. INTRODUCTION

One of the aims of orthodontic treatment is the correction of a malocclusion. In orthodontics, malocclusion is defined as a misalignment or incorrect relationship between the teeth of the maxillary and mandibular dental arches when the teeth are in contact. A malocclusion can affect chewing, speech, and may contribute to abnormal tooth wear or jaw problems (1). It is estimated that over 20% of the global population present with dental malocclusions or discrepancies in the way the teeth are aligned within the dental arches, which can arise from discrepancies in tooth position, jaw relationships, skeletal patterns, or a combination of these factors (2).

Although patients often pursue orthodontic treatment for esthetic reasons, orthodontic providers consistently emphasize improvement in occlusion as one of the objectives of treatment. The American Association of Orthodontists (AAO) identifies occlusal improvement as a key rationale for orthodontic care, citing improved function, ease of cleaning, and reduced abnormal enamel wear as benefits of achieving a proper bite (3). Similarly, the American Board of Orthodontics (ABO) underscores the importance of occlusal contacts in achieving a stable and functional occlusion. The ABO grading system for finished orthodontic cases incorporates occlusal contacts as a critical measure of maximum intercuspation and interarch fit, reinforcing the clinical goal of increasing intercuspation between the maxillary and mandibular arches (4)(5).

The relationship between malocclusion, occlusal contacts, and masticatory function has been explored in the literature with mixed findings. Some studies report reduced chewing performance associated with fewer occlusal contacts (6,7), while others suggest that masticatory efficiency is more closely related to the number of occlusal pairs rather than the specific classification of malocclusion (8). These findings suggest that patients with malocclusions may experience decreased masticatory function due to a limited number of functional occlusal contacts.

Given that orthodontic treatment is intended to improve a malocclusion, it is often assumed that occlusal function will improve following treatment. Even though an important objective of orthodontic treatment is to establish ideal positional relationships among the teeth within and between the dental arches (9), evidence suggests that occlusal contact area may decrease immediately following appliance removal compared to pre-treatment values (10,11). Over time, occlusal contacts typically increase during the retention phase through a process known as settling (12). Settling occurs as teeth undergo vertical movement once orthodontic appliances are removed, allowing increased intercuspation when teeth are no longer restricted by continuous arch wires (13). Clinicians often rely on this settling phase to improve posterior occlusion, although the extent of necessary settling and the amount of settling which occurs varies among patients.

Retention modality may influence the degree and rate of occlusal settling. Multiple retention options exist, and there is no clear consensus regarding which method best promotes optimal occlusal outcomes. Previous studies evaluating occlusal contacts with a variety of retainer designs have produced conflicting results (13). Bonded retainers have been associated with more rapid settling, likely due to minimal restriction of vertical tooth movement, while full-time wear of removable retainers with full occlusal coverage may impede settling. Kara et al, reported a significant decrease in occlusal contact area after one year of retention in patients using clear plastic overlay retainers, whereas patients with Hawley or bonded retainers demonstrated increased occlusal contacts (14). Despite these findings, much of the existing literature lacks long-term retention data and consensus regarding retention-related effects on occlusion.

Extraction therapy in combination with orthodontics is another factor that may influence occlusal contact area. Premolar extractions are commonly prescribed in orthodontic treatment plans for patients with severe crowding or certain malocclusions, with approximately 34.4% of orthodontic

patients undergoing premolar extractions (15). While extractions reduce the total number of teeth available for occlusal contact, alignment and space closure may ultimately improve functional contacts in patients who present with significant pre-treatment crowding.

Age may also play a role in occlusal contact changes. Most orthodontic patients are adolescents, with approximately 75% under the age of 18, although the number of adults seeking orthodontic treatment continues to increase (16). Limited evidence exists regarding age-related differences in occlusal contact surface area. It may be hypothesized that occlusal contact area increases with age due to natural tooth wear over time; however, this relationship has not been well documented in the orthodontic literature which currently exists.

Advancements in digital technology have provided new opportunities to objectively evaluate occlusal contacts. Intraoral scanning is now a routine component of orthodontic records, offering accurate and reliable three-dimensional digital models as an alternative to traditional plaster casts (17). Bite registration obtained during scanning allows identification of occlusal contacts with high reliability (18). However, most commercially available scanning software provides only qualitative representations of occlusal contacts, such as heat maps, without automated methods for quantifying occlusal contact surface area. As a result, third-party software is often required to calculate occlusal contact areas, limiting the ability to assess occlusal changes over time through a quantitative measurement.

The purpose of this study is to measure the changes in occlusal contact surface area at specific time points using 3D imaging analysis by comparing changes to occlusal contacts before (T1), immediately after treatment (T2), and into retention (T3) following orthodontic treatment. Secondary objectives include evaluating the influence of patient age, gender, type of

malocclusion, extraction versus non-extraction treatment, retention type, and duration of retention on occlusal contact surface area.

## **2. MATERIALS AND METHODS**

### **2.1 Study Design**

This retrospective case-series compared changes in occlusal contact surface area between T1 (pre-treatment) to T2 (at time of debond) and T3 (into retention- various intervals). Institutional Review Board (IRB) approval was obtained from the University Human Subjects Division before initiating the study procedures on July 5<sup>th</sup>, 2024.

### **2.2 Participants, eligibility criteria, and data collection**

Subjects from the University of Washington Orthodontic clinic who received an intraoral scan to replace a retainer were screened. The clinic's database was searched for patients who had made a payment for a replacement retainer from July of 2022-June of 2025. These patients were then screened to determine whether they had intraoral scans at all three time points (pre-treatment, debond, retention scan for a new retainer). Only those who received fixed-appliance treatment were included. Excluded were patients who had missing scans from any of the three timepoints, patients in the mixed dentition, those with unerupted permanent teeth, patients who underwent orthognathic surgery in combination with orthodontic treatment, patients who had clear aligner treatment, and patients who received prosthetic replacement of missing teeth between the time of debond and retention.

The age, gender, treatment modality performed, time in treatment, time since debond at T3 scan, initial malocclusion, extraction type, final malocclusion, and type of retention were all collected for each patient.

## **2.3 Methods**

### **2.3.1 Intra-oral Scans**

All patients had an intra-oral scan taken using an iTero (Align Technology, Inc. Tempe, AZ) digital scanner at the University of Washington Orthodontic Clinic for all three time points (T1- pre-treatment, T2- day of debond, T3- retention scan). The arches were scanned while laying down and biting in maximum intercuspation. All scans were downloaded with maxilla and mandible oriented in occlusion from [www.mycadent.com](http://www.mycadent.com) as an open shell STL file for both the maxilla and mandible. The STL files were then imported into GeoMagic ControlX software for analysis (Hexagon Manufacturing Intelligence, North Kingstown, Rhode Island).

### **2.3.2 Preparing Models and Scan Measurements**

The STL files were imported into Geomagic Control X software for each of the three time points (T1, T2, T3). The upper arch was used as the reference model and was therefore selected and the color made gray for ease of visualizing the color map. The reference model was then auto segmented, unmerged as same primitive shapes, and mesh roughness checked smooth, which made the models appear as multiple different colors as the different vertices were all visible. The lower model was hidden from view, and the upper model was then trimmed in a horseshoe shape, so that there were minimal interferences and only the teeth were visualized. Gingiva were trimmed to leave about one millimeter margin surrounding the teeth. The occlusal surfaces of the upper teeth were highlighted using the paintbrush feature and made all one region. The mesh was then inverted. The upper and lower models were both selected and then added to a single analysis workspace (labeled “Result 1” within the software), without aligning,

as the models are already aligned in their STL formats. The upper model was selected within this workspace and moved to the reference model, as all measurements were made on the upper.

Three vertical distances between the upper and lower dentition were measured at each time point for the anterior teeth (canine to canine) and the posterior teeth (first premolar to second molar) and added together to get the total scan area (second molar to second molar). The distances selected were based on a study by Wilding, et al (19,20), and defined as follows: tight contact area between 0-0.2 mm, near contact between 0.21-0.45 mm, and open contact between 0.46-1 mm. Open contacts of greater than 1 mm were not included. Beginning with the smallest contact area (0-0.2 mm), the color map generated a green color where there was contact within that range. The paintbrush feature was used to encapsulate the green area, and the surface area was calculated and recorded in a spreadsheet using Microsoft Excel (Microsoft Excel, Microsoft Office 365, Redmond, Washington). This was repeated for near and open contact measurements. The surface areas for each of the three contact categories were expressed as a percentage of the total occlusal surface area with an inter-occlusal distance of 1 mm or less. Two dental students at the University of Washington assisted with data collection.

## **2.4 Measurement Error Analysis**

To ensure the accuracy and consistency of the contact measurements, an intra- and inter-examiner reliability assessment was conducted. For the inter-examiner reliability three examiners (AS, MP, and SR) each remeasured the same two randomly selected patients at all three time points (T1, T2, T3), and for the intra-examiner reliability each examiner remeasured two different randomly select patient at all three time points, 12 weeks after the first measurement.

To compare the three measurements for inter-examiner reliability the mean and standard deviation (SD) were computed for each examiner (AS, MP and SR), and the intraclass correlation coefficient (ICC) and 95% CI for the ICC (21) was computed to describe the (relative) reliability among the 3 examiners, and Dahlberg's error (22), and the minimum and maximum for the absolute value of the difference between the three examiner's measurements was computed to describe the (absolute) measurement error.

To compare the two measurements for intra-examiner reliability the mean and standard deviation (SD) were computed for each set of measurements. The mean (SD) of the differences and 95% confidence interval (CI) for the mean difference, the intraclass correlation coefficient (ICC) and 95% CI for the ICC (21) was computed to describe the (relative) reliability, and Dahlberg's error (22). The minimum and maximum for the absolute value of the difference between the two measurements was computed to describe the (absolute) measurement error.

#### **2.4.1 Power Calculations**

A sample size of 60 patients was calculated to have 97% power to demonstrate a change in contact equal to a modest effect size of 0.5 at a 0.05 significance level and 91% power at an adjusted significance level 0.017 for the three contact types (tight, near and open) based on a two-sided paired t-test. Based on the observed change in total contact from pre-treatment to retention, an effect size of 0.5 corresponds to a change of 2.6 to 5.3 percentage points. For the comparison of contact change by patient and treatment factors, the power was 81% to demonstrate a difference equal to an effect size of 0.75 at a 0.05 significance level based on a two-sample t-test and assuming an equal number of patients in two groups.

#### **2.5 Data Analysis**

For the analysis each contact type (tight, near and open), the surface area percentage was determined at pre-treatment (T1), post-treatment (T2) and retention (T3), and then the change calculated from pre-treatment to post-treatment (T2-T1), post-treatment to retention (T3-T2) and pre-treatment to retention (T3-T1). Tight, near and open contact was summarized by the mean and standard deviation at each time point. The change was summarized by the mean, standard deviation, and 95% confidence interval for the mean change, and paired t-tests were used to test for change over time.

The Holm's method was used to adjust the p-values for multiple testing for tight, near and open contact change between each pair of time points. Multivariable linear regression using robust standard errors for heteroscedasticity was used to compare if the change in tight, near and open contact varied by treatment or retention time, malocclusion classification (Class I vs Class II or III), age (growing versus non-growing), extractions (none versus any), and retainer type (Essix versus Hawley). Growing was defined as 18 years old or younger for females and 20 years old or younger for males. All analyses were performed with R software, Version 4.5.2 (The R Foundation for Statistical Computing) and a significance level 0.05 was used for statistical significance.

### **3. RESULTS**

#### **3.1 Sample Population Characteristics**

A total of 233 patients were screened for inclusion in this study. Of these, 173 patients were excluded primarily due to incomplete scanning records (missing scans at one or more time points, n = 110), receiving interdisciplinary care (e.g. missing teeth, implants, surgery, n = 31) or receiving treatment with clear aligners (n = 32). In the end, 60 patients were selected for this study and included in the final analysis, as they met all inclusion criteria.

### 3.2 Patient Demographics

The mean age of the study population was 15.8 years old, with a slightly higher percentage of females (56.7%) than males (43.4%). Mean treatment duration was 26.1 months, and mean retention time was 20.3 months. Detailed demographic characteristics are summarized in Table 1.

**Table 1.** *Demographics of patients*

<b>Characteristic</b>	<b>N = 60</b>
<b>Age, y</b>	
Mean (SD)	15.8 (6.7)
Median (IQR)	14.0 (12.0, 16.0)
Min to Max	10.0, 39.0
<b>Gender, n (%)</b>	
Female	34 (56.7%)
Male	26 (43.3%)
<b>Treatment time, months</b>	
Mean (SD)	26.1 (7.8)
Median (IQR)	23.3 (21.1, 30.2)
Min to Max	13.5, 46.1
<b>Retention time, months</b>	
Mean (SD)	20.3 (16.5)
Median (IQR)	12.9 (8.3, 35.5)
Min to Max	0.7, 58.3

### 3.3 Verification of Measurement Error and Technical Error

Overall, reliability testing demonstrated mostly excellent inter- and intra-examiner reliability across examiners and measurements. Intra-examiner reliability ICC values ranged from 0.84-1, except for anterior tight contact change (ICC = 0.72). The corresponding Dahlberg's errors were small (Appendix Table 1). For examiner AS, ICC values were excellent, with ICC values between 0.94-1 and small Dahlberg's errors (Appendix Table 2). Examiner MP

demonstrated good to excellent intra-examiner reliability with ICC values ranging from 0.61-0.96. An increased Dahlberg's error was observed for anterior contact and changes in total and posterior contact (Appendix Table 3). Examiner SR showed excellent intra-examiner reliability, with ICC values ranging from 0.92-1 and small Dahlberg's errors (Appendix Table 4).

### 3.4 Occlusal Contacts of Class I vs Class II and III at T1

According to this study, there was no statistically significant difference in the occlusal contact surface area of Class I malocclusions vs Class II and III malocclusions (Table 2).

**Table 2.** Comparison of Tight, Near, and Open Contact at T1 for Class I vs. Class II and III Malocclusions

Contact	Class I N = 28	Class II or III N = 32	Difference <sup>1</sup>	95% CI <sup>1</sup>	p-value <sup>1</sup>
<b>Tight, Mean (SD)</b>	11.5 (4.8)	12.7 (4.0)	-1.2	-3.6, 1.1	0.286
<b>Near, Mean (SD)</b>	26.3 (4.5)	26.4 (3.2)	-0.06	-2.1, 2.0	0.951
<b>Open, Mean (SD)</b>	62.2 (8.4)	60.9 (6.7)	1.3	-2.7, 5.3	0.513

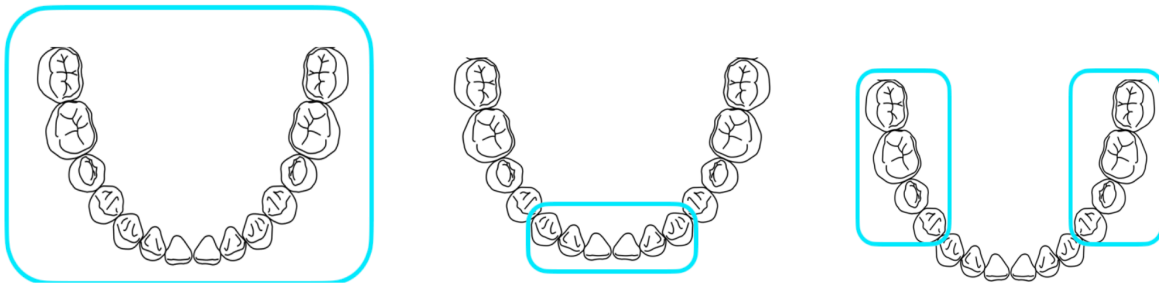
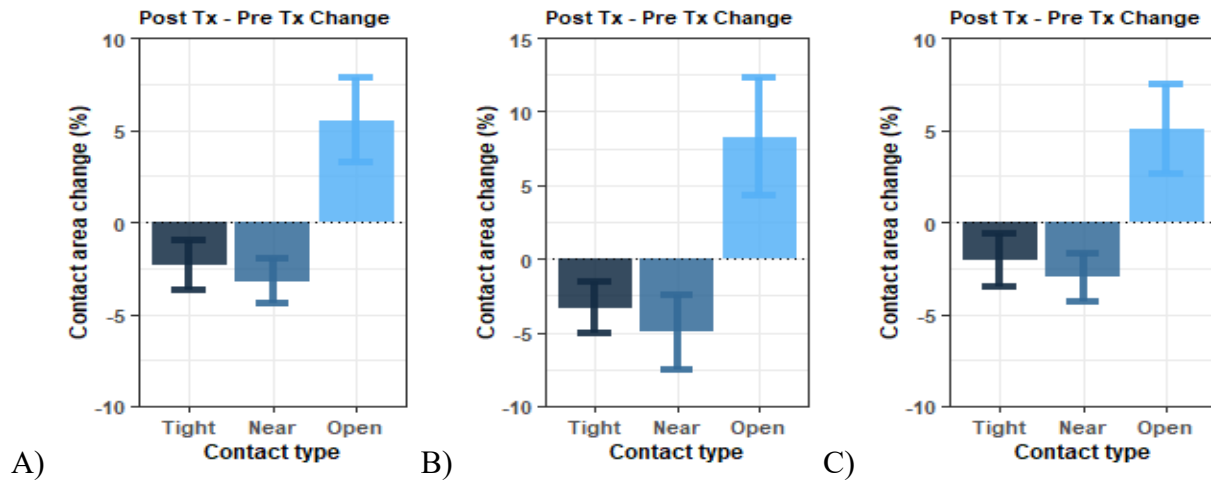
<sup>1</sup>Welch Two Sample t-test

Abbreviation: CI = Confidence Interval

### 3.5 Change in Occlusal Contact Area (%) from T1 (pre-treatment) to T2 (immediately following treatment) for Total, Anterior, and Posterior Dentition Following Orthodontic Treatment

Changes in tight, near, and open contact surface area between pre-treatment to immediately following debond are illustrated in Figure 1. Percent changes were evaluated for the total dentition (Figure 1A), anterior dentition (Figure 1B), and posterior dentition (Figure 1C). Bars above zero indicate an increase in contact area, whereas bars below zero indicate a decrease. Across all regions, tight and near contacts decreased from T1-T2, while open contacts

increased. Statistical comparisons between pre-treatment and post-treatment are summarized in Table 3. MANOVA demonstrated statistically significant changes for total, anterior, and posterior contacts.



**Figure 1.** Change in Occlusal Contact Area (%) from Pre- to Post-Treatment for total, anterior, and posterior dentition.

**Table 3.** Summary of Occlusal Contact Area from Pre-Treatment to Post-Treatment (T1 to T2). Statistical significance was indicated through MANOVA for all pre- to post-treatment changes for total, anterior, and posterior contacts.

Total:

<b>Contact</b>	<b>Pre Tx Mean (SD)</b>	<b>Post Tx Mean (SD)</b>	<b>Change Mean (SD)</b>	<b>95% CI</b>	<b>p-value</b>
					<0.001 <sup>1</sup>
<b>Tight</b>	12.2 (4.4)	9.8 (2.9)	-2.3 (5.2)	-3.7, -1.0	<0.001 <sup>2</sup>
<b>Near</b>	26.4 (3.8)	23.2 (3.8)	-3.2 (4.7)	-4.4, -2.0	<0.001 <sup>2</sup>
<b>Open</b>	61.5 (7.5)	67.0 (6.2)	5.5 (8.9)	3.2, 7.8	<0.001 <sup>2</sup>

Anterior:

<b>Contact</b>	<b>Pre Tx Mean (SD)</b>	<b>Post Tx Mean (SD)</b>	<b>Change Mean (SD)</b>	<b>95% CI</b>	<b>p-value</b>
					0.004 <sup>1</sup>
<b>Tight</b>	9.3 (5.8)	6.0 (3.2)	-3.3 (6.8)	-5.1, -1.5	<0.001 <sup>2</sup>
<b>Near</b>	23.9 (7.2)	18.9 (6.5)	-5.0 (10.0)	-7.6, -2.4	<0.001 <sup>2</sup>
<b>Open</b>	66.8 (11.8)	75.1 (9.0)	8.3 (15.5)	4.3, 12	<0.001 <sup>2</sup>

Posterior:

<b>Contact</b>	<b>Pre Tx Mean (SD)</b>	<b>Post Tx Mean (SD)</b>	<b>Change Mean (SD)</b>	<b>95% CI</b>	<b>p-value</b>
					0.002 <sup>1</sup>
<b>Tight</b>	12.4 (4.7)	10.4 (3.3)	-2.1 (5.5)	-3.5, -0.66	0.005 <sup>2</sup>
<b>Near</b>	26.6 (4.0)	23.6 (4.1)	-3.0 (5.0)	-4.3, -1.7	<0.001 <sup>2</sup>
<b>Open</b>	61.0 (8.0)	66.0 (6.9)	5.1 (9.5)	2.6, 7.5	<0.001 <sup>2</sup>

### 3.5.1 Influence of Age on Occlusal Contact Changes Following Orthodontic Treatment

Patients were categorized as growing (females aged 10-18 years, males aged 10-20 years) or non-growing (females >18 years, males > 20 years). No significant differences were observed between growing and non-growing patients for percent change in tight, near, or open contacts within the total, anterior, or posterior dentition (Appendix Figure 1A-C).

### 3.5.2 Influence of Extractions vs No Extractions on Occlusal Contact Changes Following Orthodontic Treatment

No significant differences in occlusal contact changes were identified between extraction and non-extraction treatment groups for total, anterior, or posterior dentition from T1-T2 (Appendix Figure 2 A-C).

### 3.5.3 Influence of Malocclusion on Occlusal Contact Changes Following Orthodontic

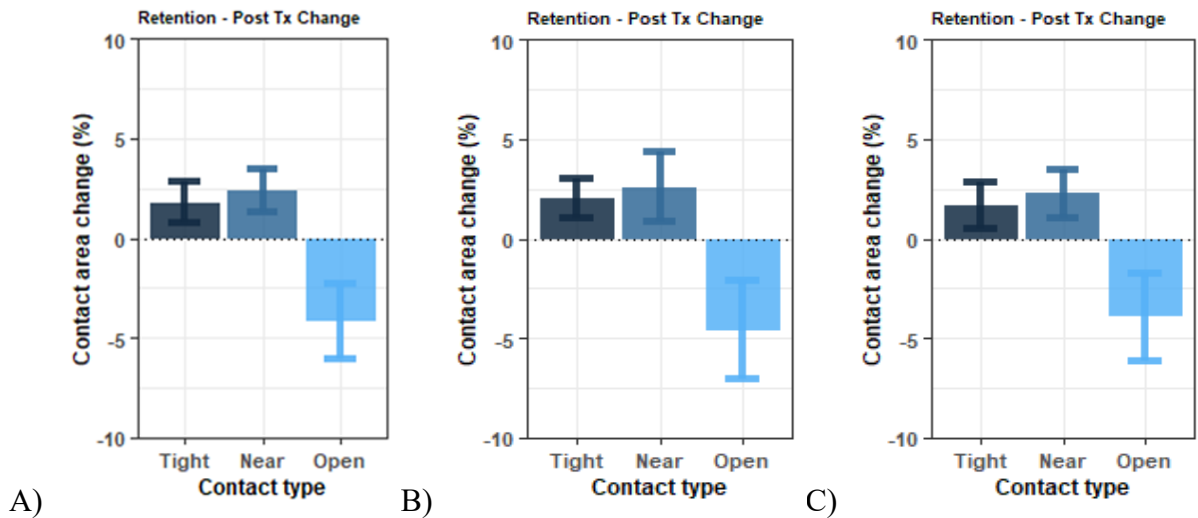
#### Treatment

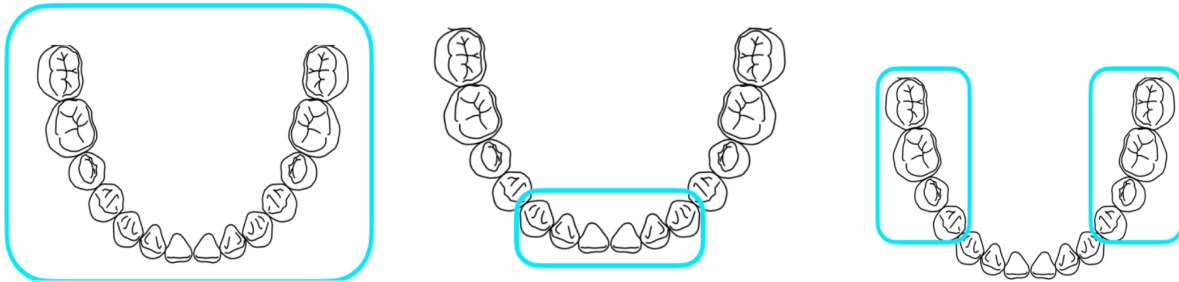
Occlusal contact changes from T1 to T2 did not differ significantly among patients with a Class I, Class II, or Class III malocclusion (Appendix Figure 3 A-C).

### 3.6 Change in Occlusal Contact Area (%) from T2 (immediately following treatment) to T3 (retention) for Total, Anterior, and Posterior Dentition into Retention After Orthodontic

#### Treatment

Changes in contact surface area from post-treatment into retention are shown in Figure 2. Percent changes were assessed for the total dentition (Figure 2A) anterior dentition (Figure 2B), and posterior dentition (Figure 2C). From T2 to T3, tight and near contacts increased, while open contacts decreased across all regions. Statistical comparisons are summarized in Table 4, with MANOVA indicating statistically significant changes for total, anterior, and posterior dentition.





**Figure 2.** Change in Occlusal Contact Area (%) from Post-Treatment into Retention for Total, Anterior, and Posterior Dentition.

**Table 4.** Summary of Occlusal Contact Area from Post-Treatment into Retention (T2 to T3). Statistical significance was indicated through MANOVA for all post-treatment to retention changes for total, anterior, and posterior contacts.

Total:

Contact	Post Tx Mean (SD)	Retention Mean (SD)	Change Mean (SD)	95% CI	p-value
					<0.001 <sup>1</sup>
<b>Tight</b>	9.8 (2.9)	11.6 (4.3)	1.8 (4.0)	0.76, 2.8	0.001 <sup>2</sup>
<b>Near</b>	23.2 (3.8)	25.5 (3.8)	2.4 (4.1)	1.3, 3.4	<0.001 <sup>2</sup>
<b>Open</b>	67.0 (6.2)	62.9 (7.6)	-4.2 (7.3)	-6.0, -2.3	<0.001 <sup>2</sup>

Anterior:

Contact	Post Tx Mean (SD)	Retention Mean (SD)	Change Mean (SD)	95% CI	p-value
					0.001 <sup>1</sup>
<b>Tight</b>	6.0 (3.2)	8.1 (3.9)	2.0 (3.8)	1.1, 3.0	<0.001 <sup>2</sup>
<b>Near</b>	18.9 (6.5)	21.5 (6.2)	2.6 (6.8)	0.82, 4.3	0.005 <sup>2</sup>
<b>Open</b>	75.1 (9.0)	70.5 (9.4)	-4.6 (9.6)	-7.1, -2.1	0.001 <sup>2</sup>

Posterior:

Contact	Post Tx Mean (SD)	Retention Mean (SD)	Change Mean (SD)	95% CI	p-value
					0.002 <sup>1</sup>
<b>Tight</b>	10.4 (3.3)	12.0 (4.9)	1.7 (4.6)	0.47, 2.8	0.007 <sup>2</sup>
<b>Near</b>	23.6 (4.1)	25.9 (4.7)	2.3 (4.8)	1.0, 3.5	0.002 <sup>2</sup>
<b>Open</b>	66.0 (6.9)	62.1 (9.0)	-3.9 (8.5)	-6.1, -1.7	0.002 <sup>2</sup>

### **3.6.1 Influence of Age on Occlusal Contact Changes into Retention Following Orthodontic Treatment**

No significant differences were observed between growing and non-growing patients for changes in tight, near, or open contacts from T2 to T3 within the total, anterior, or posterior dentition (Table 6; Appendix Figure 4A-C).

### **3.6.2 Influence of Extractions vs No Extractions on Occlusal Contact Changes into Retention Following Orthodontic Treatment**

Extraction versus non-extraction treatment did not significantly influence occlusal contact changes from T2 to T3 (Table 6; Appendix Figure 5 A-C)

### **3.6.3 Influence of Malocclusion on Occlusal Contact Changes into Retention Following Orthodontic Treatment**

Due to sample size considerations, Class I malocclusion was analyzed separately, while Class II and Class III malocclusions were grouped together. Overall, no major differences were observed between these groups for total, anterior, or posterior dentition (Appendix Figure 6 A-C).

For individual contact types, tight contact changes did not differ significantly by malocclusion classification across any region (Table 6A; Appendix Tables 5A and 6A). However, regression analysis revealed evidence of a greater increase in near contact in the total dentition from T2 to T3 among patients with Class II or III malocclusions compared with Class I (Table 5). This association strengthened after adjustment for post-treatment contact (Table 6) and remained evident when incorporating a quadratic term for retention time (Table 7).

Open contacts in the total dentition demonstrated a greater decrease from T2 to T3 in patients with a Class II or III malocclusion compared with Class I when a quadratic term for retention time was included (Table 7C). In the posterior dentition, a significantly greater decrease in open contacts was also observed for Class II or III malocclusions (Table 8), with slightly stronger evidence after adjustment for retention time (Appendix Table 6C). No significant differences in anterior open contact changes were observed based on malocclusion (Appendix Table 5C).

**Table 5.** *Regression Results for Near Contact Area in the Total Dentition*

Variable	Regression coefficient (β)	SE	95% CI	p-value
Retention time, months	-0.02	0.042	-0.10, 0.06	0.651
Growing				
Growing	—	—	—	
Not growing	-1.2	1.71	-4.6, 2.2	0.485
Initial malocclusion				
Class I	—	—	—	
Class II or III	2.4	1.20	0.02, 4.8	0.048
Extraction				
No extractions	—	—	—	
Extractions	0.50	1.10	-1.7, 2.7	0.655
Retainer type				
Essix	—	—	—	
Hawley	1.6	1.42	-1.2, 4.4	0.267

**Table 6.** *Regression Results for Near Contact Area in the Total Dentition Adjusted for Post-Treatment Contact (version 2)*

Variable	Regression coefficient (β)	SE	95% CI	p-value
Near contact, T2	0.44	0.157	0.13, 0.76	0.007
Treatment time, months	0.05	0.063	-0.08, 0.18	0.422
Growing				

Variable	Regression coefficient (β)	SE	95% CI	p-value
Growing	—	—	—	
Not growing	-0.89	1.21	-3.3, 1.5	0.467
Initial malocclusion				
Class I	—	—	—	
Class II or III	2.4	0.954	0.45, 4.3	0.016
Extraction				
No extractions	—	—	—	
Extractions	0.70	0.909	-1.1, 2.5	0.442
Retainer type				
Essix	—	—	—	
Hawley	0.86	1.18	-1.5, 3.2	0.467

**Table 7.** Regression Results for Total Dentition Tight, Near, and Open Contact Area with Quadratic for Retention Time.

A) Total Dentition Tight Contact

Variable	Regression coefficient (β)	SE	95% CI	p-value
Retention time, months	0.14	0.050	0.04, 0.24	0.007
Retention time, months	-0.01	0.002	-0.01, 0.00	0.006
Growing				
Growing	—	—	—	
Not growing	1.1	1.79	-2.5, 4.7	0.527
Initial malocclusion				
Class I	—	—	—	
Class II or III	1.5	1.05	-0.61, 3.6	0.160
Extraction				
No extractions	—	—	—	
Extractions	0.34	1.15	-2.0, 2.6	0.766
Retainer type				
Essix	—	—	—	
Hawley	0.45	1.47	-2.5, 3.4	0.761

B) Total Dentition Near Contact

Variable	Regression coefficient (β)	SE	95% CI	p-value
Retention time, months	0.03	0.055	-0.08, 0.14	0.634
Retention time, months	0.00	0.002	-0.01, 0.00	0.142
Growing				
Growing	—	—	—	
Not growing	-1.1	1.55	-4.2, 2.0	0.464
Initial malocclusion				
Class I	—	—	—	
Class II or III	2.7	1.20	0.30, 5.1	0.029
Extraction				
No extractions	—	—	—	
Extractions	0.17	1.11	-2.1, 2.4	0.880
Retainer type				
Essix	—	—	—	
Hawley	1.3	1.54	-1.8, 4.4	0.411

C) Total Dentition Open Contact

Variable	Regression coefficient (β)	SE	95% CI	p-value
Retention time, months	-0.16	0.096	-0.36, 0.03	0.093
Retention time, months	0.01	0.004	0.00, 0.02	0.022
Growing				
Growing	—	—	—	
Not growing	0.00	3.06	-6.1, 6.1	>0.999
Initial malocclusion				
Class I	—	—	—	
Class II or III	-4.2	2.05	-8.3, -0.10	0.045
Extraction				
No extractions	—	—	—	
Extractions	-0.51	2.06	-4.6, 3.6	0.805
Retainer type				
Essix	—	—	—	
Hawley	-1.7	2.76	-7.3, 3.8	0.535

**Table 8.** Regression Results for Posterior Dentition Open Contact Area with Adjustment for Post-Treatment Contact

Variable	Regression coefficient (β)	SE	95% CI	p-value
Open contact, T2	0.55	0.151	0.25, 0.86	<0.001
Treatment time, months	-0.04	0.122	-0.29, 0.20	0.728
Growing				
Growing	—	—	—	
Not growing	-1.4	3.25	-7.9, 5.1	0.667
Initial malocclusion				
Class I	—	—	—	
Class II or III	-5.0	2.24	-9.5, -0.54	0.029
Extraction				
No extractions	—	—	—	
Extractions	-2.4	2.24	-6.9, 2.1	0.287
Retainer type				
Essix	—	—	—	
Hawley	-2.2	2.75	-7.7, 3.3	0.428

### 3.6.4 Influence of Retainer Type on Occlusal Contact Changes into Retention Following Orthodontic Treatment

Retainer type did not significantly influence occlusal contact changes from T2 to T3 in the total, anterior, or posterior dentition (Table 6; Appendix Figure 7 A-C).

### 3.6.5 Influence of Retention Time on Occlusal Contact Changes into Retention Following Orthodontic Treatment

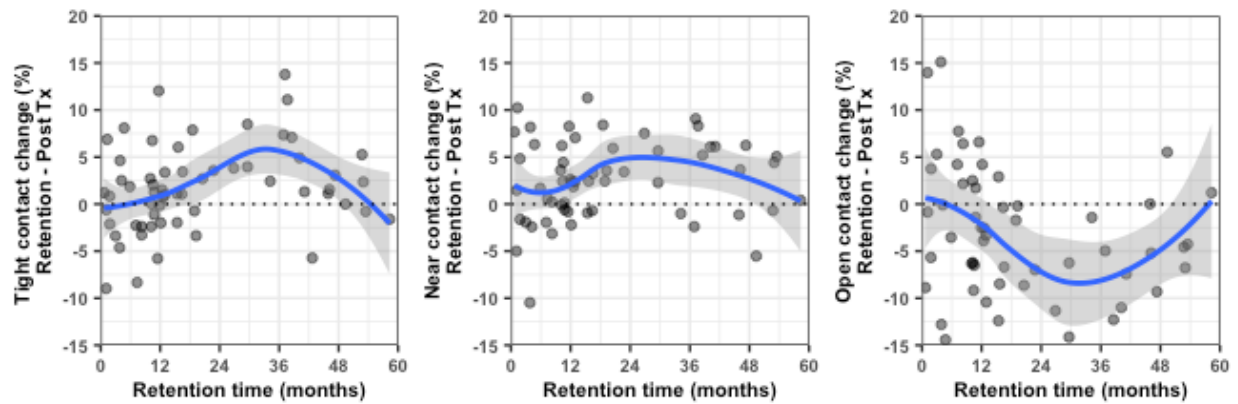
A quadratic association was observed between retention time and occlusal contact changes between T2 to T3. Tight and near contacts increased from 0 to approximately 36 months into retention, after which the rate of increase diminished from 36 to 60 months. Open contacts, however, decreased from 0 to 36 months, and with a slower rate from 36 to 60 months.

Regression results for the total dentition (Table 7) support this non-linear relationship and correspond with trends illustrated in Figure 3. Similar patterns were observed in the anterior and

posterior dentition (Appendix Tables 5 and 6). Appendix Table 8 shows the number of patients in each retention time frame.

In the anterior dentition, tight contacts increased and open contacts decreased from 0 to 36 months with a slowing of change beyond 36 months, while near contacts remained relatively stable until 48 months, followed by a decrease from 48 to 60 months (Appendix Figure 8). The posterior dentition demonstrated comparable quadratic trends for tight and open contacts (Appendix Figure 9).

**Figure 3.** *Change in Contact Area (%) from T2 (post-treatment) to T3 (into retention) for Total dentition Tight, Near, and Open Contacts based on Retention Time*

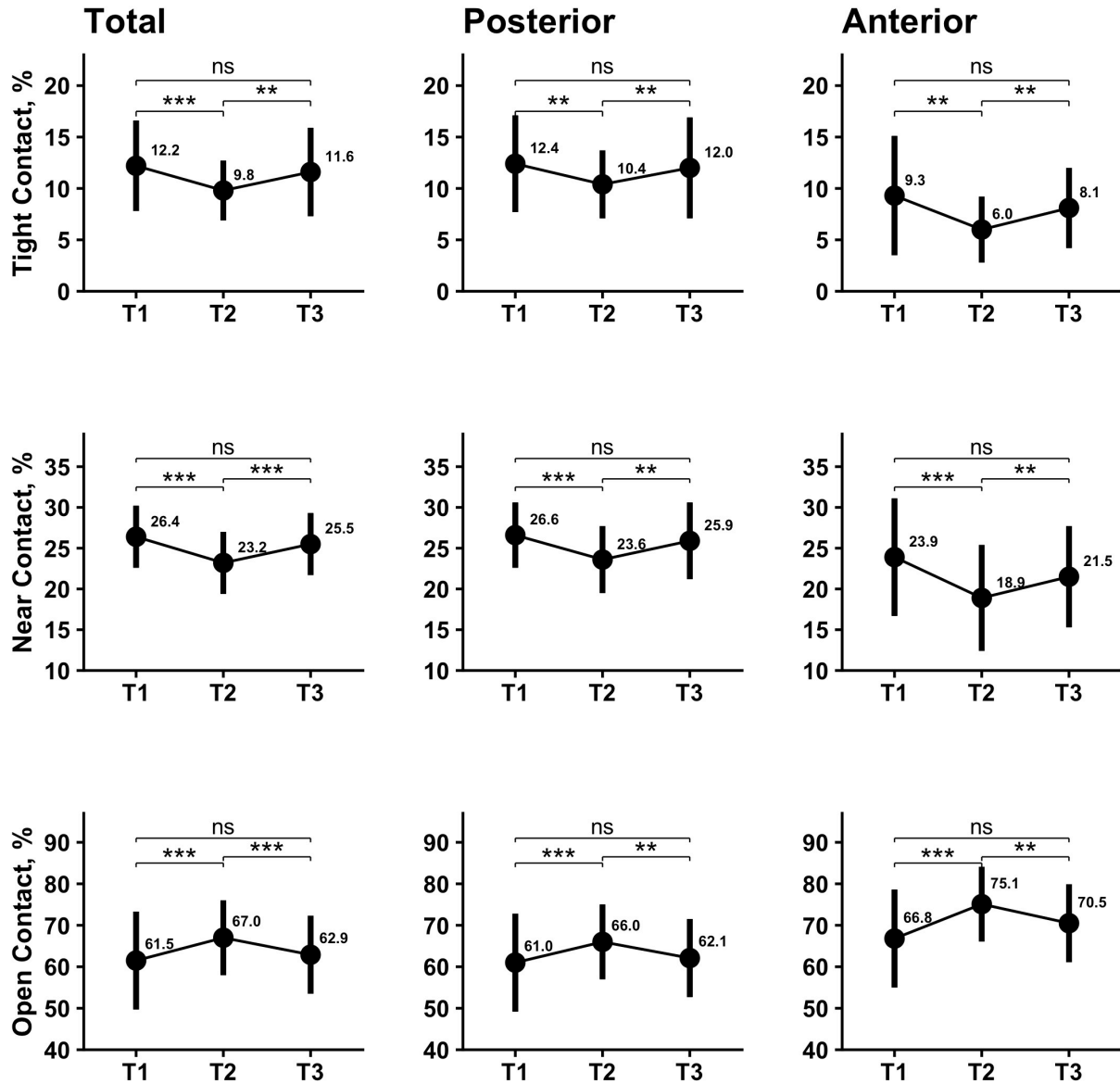


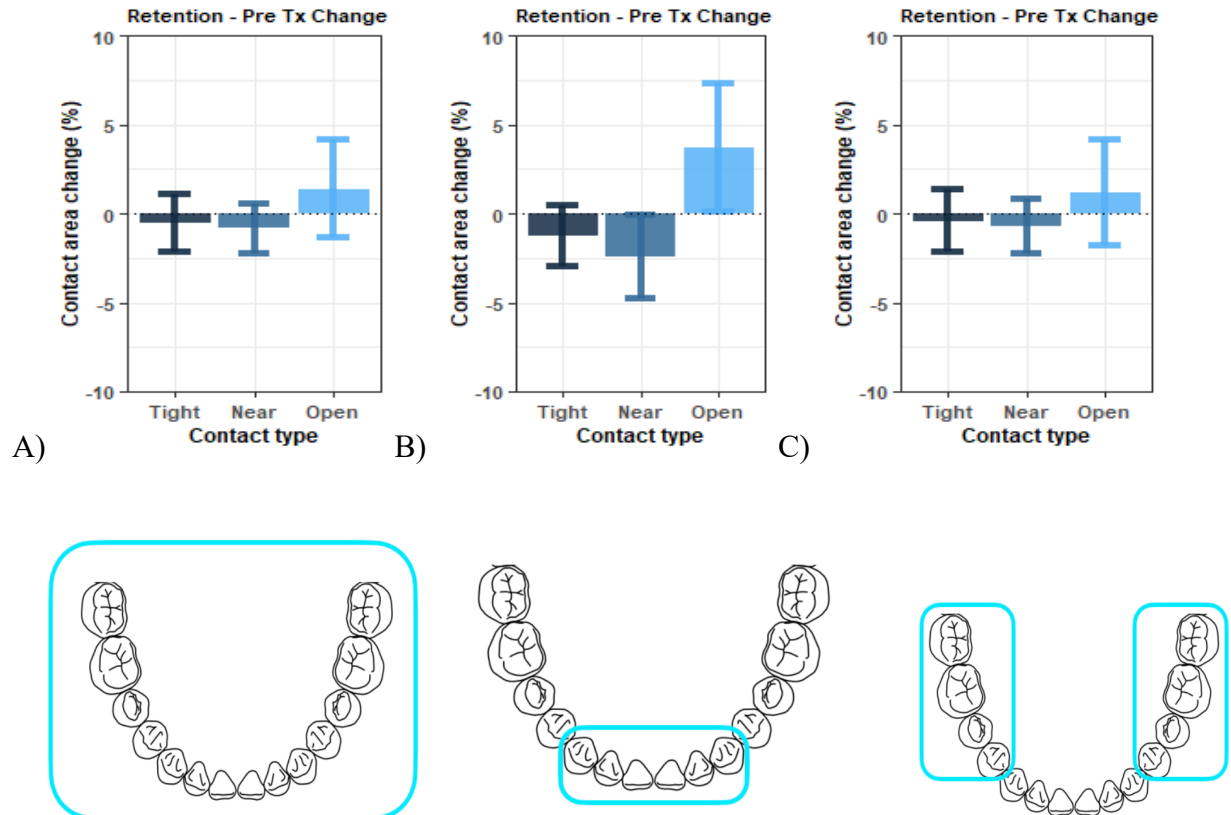
### **3.7 Change in Occlusal Contact Area (%) from T1 (pre-treatment) to T3 (retention) for Total, Anterior, and Posterior Dentition into Retention After Orthodontic Treatment**

Changes in contact surface area from pre-treatment to retention are shown in Figure 5 for the total dentition (Figure 5A), anterior dentition (Figure 5B), and posterior dentition (Figure 5C). From T1 to T3, tight and near contacts decreased following treatment and increased during retention, resulting in no statistically significant net change overall (Figure 4). Open contacts

showed the opposite pattern. Statistical analyses are summarized in Table 9, with MANOVA indicating no significant differences for total, anterior, or posterior dentition.

**Figure 4.** Mean percent of tight, near, and open contact area at T1, T2, and T3 for the total, posterior, and anterior dentition.





**Figure 5.** Change in Occlusal Contact Area (%) from Pre-Treatment to Retention for Total, Anterior, and Posterior Dentition.

**Table 9.** Summary of Occlusal Contact Area from Pre-Treatment into Retention (T1 to T3).

Based on MANOVA p-value testing, the values for total, anterior, and posterior contact were not significant.

Total:

Contact	Pre Tx Mean (SD)	Retention Mean (SD)	Change Mean (SD)	95% CI	p-value
					0.846 <sup>1</sup>
<b>Tight</b>	12.2 (4.4)	11.6 (4.3)	-0.5 (6.3)	-2.2, 1.1	0.657
<b>Near</b>	26.4 (3.8)	25.5 (3.8)	-0.8 (5.3)	-2.2, 0.52	0.657
<b>Open</b>	61.5 (7.5)	62.9 (7.6)	1.4 (10.6)	-1.4, 4.1	0.657

Anterior:

<b>Contact</b>	<b>Pre Tx</b> Mean (SD)	<b>Retention</b> Mean (SD)	<b>Change</b> Mean (SD)	<b>95% CI</b>	<b>p-value</b>
					0.189 <sup>1</sup>
<b>Tight</b>	9.3 (5.8)	8.1 (3.9)	-1.3 (6.6)	-3.0, 0.43	0.141 <sup>2</sup>
<b>Near</b>	23.9 (7.2)	21.5 (6.2)	-2.4 (9.2)	-4.8, -0.05	0.138 <sup>2</sup>
<b>Open</b>	66.8 (11.8)	70.5 (9.4)	3.7 (14.0)	0.06, 7.3	0.138 <sup>2</sup>

Posterior:

<b>Contact</b>	<b>Pre Tx</b> Mean (SD)	<b>Retention</b> Mean (SD)	<b>Change</b> Mean (SD)	<b>95% CI</b>	<b>p-value</b>
					0.971 <sup>1</sup>
<b>Tight</b>	12.4 (4.7)	12.0 (4.9)	-0.4 (6.8)	-2.2, 1.3	1.0 <sup>2</sup>
<b>Near</b>	26.6 (4.0)	25.9 (4.7)	-0.7 (5.9)	-2.3, 0.80	1.0 <sup>2</sup>
<b>Open</b>	61.0 (8.0)	62.1 (9.0)	1.2 (11.6)	-1.8, 4.1	1.0 <sup>2</sup>

### 3.7.1 Influence of Age on Occlusal Contact Changes from Pre-Treatment to Retention

Age did not significantly influence occlusal contact changes from pre-treatment to retention for the total, anterior, or posterior dentition (Appendix Figure 10 A-C).

### 3.7.2 Influence of Extractions vs. No Extractions on Occlusal Contact Changes from Pre-Treatment to Retention

Overall, extraction versus non-extraction treatment did not significantly affect occlusal contact changes from T1 to T3 (Appendix Figure 11 A-C). However, regression analysis suggested some evidence that extractions were associated with increased tight contacts in the posterior dentition (Table 10) and a greater decrease in posterior open contacts (Table 11).

**Table 10.** *Regression Results for Tight Contact Area in the Posterior Dentition*

Variable	Regression coefficient (β)	SE	95% CI	p-value
Treatment time, months	0.08	0.130	-0.18, 0.34	0.544
Retention time, months	0.19	0.057	0.07, 0.30	0.002
Growing				
Growing	—	—	—	
Not growing	-3.3	3.30	-9.9, 3.4	0.328
Initial malocclusion				
Class I	—	—	—	
Class II or III	-0.02	1.82	-3.7, 3.6	0.993
Extraction				
No extractions	—	—	—	
Extractions	3.5	1.91	-0.30, 7.4	0.070
Retainer type				
Essix	—	—	—	
Hawley	3.0	2.56	-2.1, 8.1	0.245

**Table 11.** *Regression Results for Open Contact Area in the Posterior Dentition*

Variable	Regression coefficient (β)	SE	95% CI	p-value
Treatment time, months	-0.13	0.211	-0.55, 0.29	0.545
Retention time, months	-0.24	0.090	-0.42, -0.06	0.011
Growing				
Growing	—	—	—	
Not growing	5.1	4.42	-3.8, 14	0.253
Initial malocclusion				
Class I	—	—	—	
Class II or III	-3.4	3.08	-9.6, 2.8	0.273
Extraction				
No extractions	—	—	—	
Extractions	-5.4	3.12	-12, 0.84	0.088
Retainer type				
Essix	—	—	—	
Hawley	-6.0	4.32	-15, 2.6	0.170

### 3.7.3 Influence of Malocclusion on Occlusal Contact Changes from Pre-Treatment to Retention

For the total dentition, malocclusion demonstrated a significant influence on changes in near contact when regression analysis included a quadratic term for retention time (Table 12). When the regression was adjusted for pre-treatment contact, patients with Class II or III malocclusions exhibited a significantly greater increase in near contact and a greater decrease in open contact from T1 to T3 compared with patients with a Class I malocclusion (Table 13).

No significant associations between malocclusion and changes in tight, near, or open contacts were observed in the anterior dentition. In contrast, analysis of the posterior dentition revealed a significant association between malocclusion and near contact changes, with patients presenting with Class II or III malocclusions demonstrating a greater increase in near contact compared with those with Class I malocclusion (Table 14).

**Table 12.** *Regression Results with Quadratic for Retention Time for Total Dentition Area*

A) Tight

Variable	Regression coefficient (β)	SE	95% CI	p-value
Treatment time, months	0.10	0.114	-0.13, 0.33	0.379
Retention time (linear), months	0.30	0.079	0.14, 0.46	<0.001
Retention time (quadratic), months	-0.01	0.003	-0.02, 0.00	0.008
Growing				
Growing	—	—	—	
Not growing	-2.9	2.98	-8.9, 3.0	0.328
Initial malocclusion				
Class I	—	—	—	
Class II or III	0.53	1.62	-2.7, 3.8	0.744
Extraction				
No extractions	—	—	—	
Extractions	2.0	1.59	-1.2, 5.2	0.211
Retainer type				
Essix	—	—	—	
Hawley	2.0	2.22	-2.5, 6.4	0.374

B) Near

<b>Variable</b>	<b>Regression coefficient (β)</b>	<b>SE</b>	<b>95% CI</b>	<b>p-value</b>
Treatment time, months	0.08	0.090	-0.10, 0.26	0.399
Retention time (linear), months	0.10	0.052	0.00, 0.21	0.051
Retention time (quadratic), months	0.00	0.003	-0.01, 0.00	0.232
Growing				
Growing	—	—	—	
Not growing	-2.2	1.73	-5.7, 1.2	0.203
Initial malocclusion				
Class I	—	—	—	
Class II or III	2.6	1.37	-0.17, 5.3	0.066
Extraction				
No extractions	—	—	—	
Extractions	1.1	1.45	-1.8, 4.0	0.439
Retainer type				
Essix	—	—	—	
Hawley	2.5	1.86	-1.2, 6.3	0.180

C) Open

<b>Variable</b>	<b>Regression coefficient (β)</b>	<b>SE</b>	<b>95% CI</b>	<b>p-value</b>
Treatment time, months	-0.18	0.188	-0.55, 0.20	0.349
Retention time (linear), months	-0.40	0.115	-0.63, -0.17	0.001
Retention time (quadratic), months	0.01	0.006	0.00, 0.03	0.026
Growing				
Growing	—	—	—	
Not growing	5.2	4.28	-3.4, 14	0.233
Initial malocclusion				
Class I	—	—	—	
Class II or III	-3.1	2.67	-8.5, 2.3	0.251
Extraction				
No extractions	—	—	—	
Extractions	-3.1	2.71	-8.6, 2.3	0.252

Variable	Regression coefficient (β)	SE	95% CI	p-value
Retainer type				
Essix	—	—	—	
Hawley	-4.5	3.90	-12, 3.3	0.251

**Table 13.** Regression Results for Open Contact Area with Adjustment for Pre-Treatment Contact for Total Dentition

A) Near

Variable	Regression coefficient (β)	SE	95% CI	p-value
Near contact, T1	0.06	0.149	-0.24, 0.36	0.700
Treatment time, months	-0.02	0.085	-0.19, 0.15	0.847
Retention time, months	0.03	0.035	-0.04, 0.10	0.394
Growing				
Growing	—	—	—	
Not growing	-0.57	1.12	-2.8, 1.7	0.610
Initial malocclusion				
Class I	—	—	—	
Class II or III	2.5	1.05	0.43, 4.7	0.019
Extraction				
No extractions	—	—	—	
Extractions	1.4	1.13	-0.84, 3.7	0.211
Retainer type				
Essix	—	—	—	
Hawley	-0.14	1.45	-3.0, 2.8	0.922

B) Open

Variable	Regression coefficient (β)	SE	95% CI	p-value
Open contact, T1	0.05	0.153	-0.26, 0.36	0.739
Treatment time, months	-0.01	0.159	-0.33, 0.30	0.929
Retention time, months	-0.12	0.072	-0.27, 0.02	0.088
Growing				
Growing	—	—	—	
Not growing	-0.56	2.50	-5.6, 4.4	0.822

Variable	Regression coefficient (β)	SE	95% CI	p-value
Initial malocclusion				
Class I	—	—	—	
Class II or III	-3.9	2.12	-8.2, 0.33	0.070
Extraction				
No extractions	—	—	—	
Extractions	-3.4	2.21	-7.9, 1.0	0.127
Retainer type				
Essix	—	—	—	
Hawley	-0.03	3.12	-6.3, 6.2	0.992

**Table 14.** Regression Results for Near Contact Area with Quadratic for Retention Time in the Posterior Dentition

Variable	Regression coefficient (β)	SE	95% CI	p-value
Treatment time, months	0.06	0.091	-0.12, 0.25	0.487
Retention time (linear), months	0.10	0.058	-0.01, 0.22	0.084
Retention time (quadratic), months	0.00	0.004	-0.01, 0.00	0.261
Growing				
Growing	—	—	—	
Not growing	-1.8	1.64	-5.1, 1.5	0.277
Initial malocclusion				
Class I	—	—	—	
Class II or III	3.7	1.57	0.56, 6.9	0.022
Extraction				
No extractions	—	—	—	
Extractions	1.5	1.60	-1.8, 4.7	0.367
Retainer type				
Essix	—	—	—	
Hawley	2.7	1.99	-1.3, 6.7	0.179

### 3.7.4 Influence of Retainer Type on Occlusal Contact Changes from Pre-Treatment to Retention

Retainer type did not significantly influence occlusal contact changes from pre-treatment to retention in the total, anterior, or posterior dentition (Appendix Figure 13 A-C).

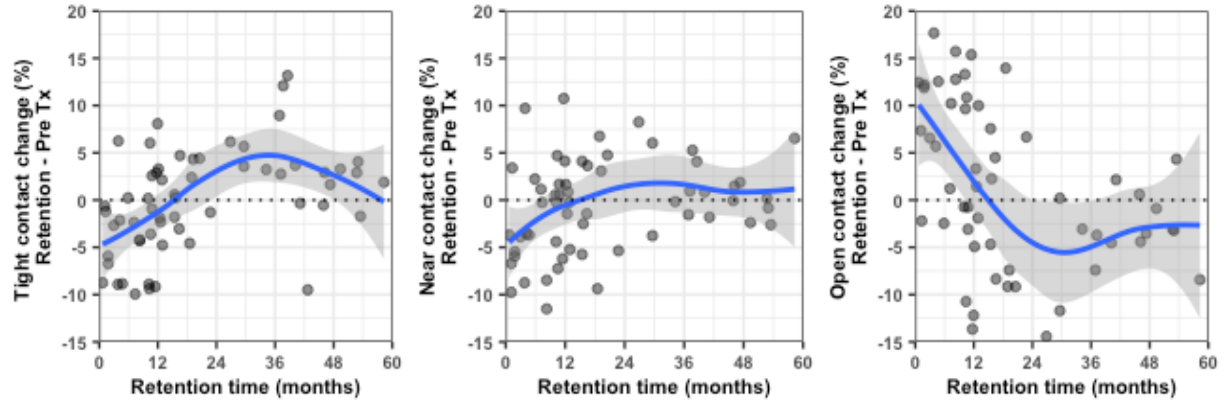
### **3.7.5 Influence of Retention Time on Occlusal Contact Changes from Pre-Treatment to Retention**

From T1-T3, retention time demonstrated an association with occlusal contact changes primarily during the first 24 months of the retention period. For the total and anterior dentition, changes in occlusal contact were associated with retention time up to approximately 24 months, with no clear association observed from 24 to 60 months (Figures 5 and 6). In the posterior dentition, this association extended up to approximately 24 to 36 months (Figure 7).

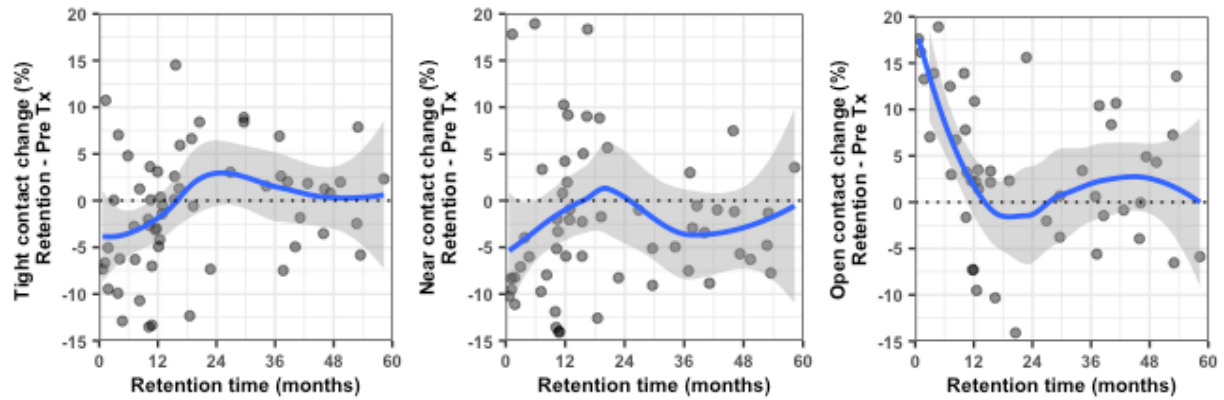
In the total dentition, regression analysis demonstrated a significant association between retention time and both an increase in tight contacts and a decrease in open contacts (Table 12A and C). In the anterior dentition, retention time was significantly associated with an increase in tight contacts only (Table 15), with no significant associations observed for near or open contacts (Appendix Table 7).

Within the posterior dentition, retention time was significantly associated with both an increase in tight contacts and a decrease in open contacts (Table 16 A and B). No significant association was observed between retention time and near contact changes in the posterior dentition (Table 14).

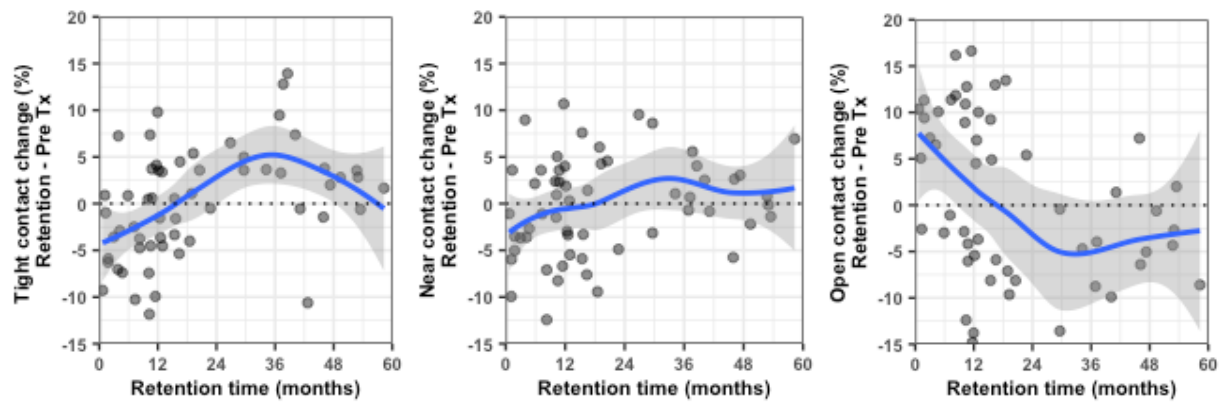
**Figure 6.** *Change in Contact Area (%) from T1 (pre-treatment) to T3 (into retention) for Total Dentition Tight, Near, and Open Contacts based on Retention Time*



**Figure 7.** Change in Contact Area (%) from T1 (pre-treatment) to T3 (into retention) for Anterior Dentition Tight, Near, and Open Contacts based on Retention Time



**Figure 8.** Change in Contact Area (%) from T1 (pre-treatment) to T3 (into retention) for Posterior Dentition Tight, Near, and Open Contacts based on Retention Time



**Table 15.** *Regression Results for Tight Contact Area with Quadratic for Retention Time in the Anterior Dentition*

<b>Variable</b>	<b>Regression coefficient (β)</b>	<b>SE</b>	<b>95% CI</b>	<b>p-value</b>
Treatment time, months	0.14	0.123	-0.11, 0.38	0.267
Retention time (linear), months	0.22	0.078	0.06, 0.38	0.007
Retention time (quadratic), months	-0.01	0.005	-0.02, 0.00	0.111
Growing				
Growing	—	—	—	
Not growing	-3.1	3.16	-9.4, 3.3	0.338
Initial malocclusion				
Class I	—	—	—	
Class II or III	-0.21	1.85	-3.9, 3.5	0.912
Extraction				
No extractions	—	—	—	
Extractions	0.08	1.99	-3.9, 4.1	0.969
Retainer type				
Essix	—	—	—	
Hawley	-0.28	2.40	-5.1, 4.5	0.907

**Table 16.** *Regression Results for Tight and Open Contact Area with Quadratic for Retention Time in the Posterior Dentition*

A) Tight

<b>Variable</b>	<b>Regression coefficient (β)</b>	<b>SE</b>	<b>95% CI</b>	<b>p-value</b>
Treatment time, months	0.11	0.126	-0.14, 0.37	0.373
Retention time (linear), months	0.30	0.087	0.13, 0.48	0.001
Retention time (quadratic), months	-0.01	0.004	-0.02, 0.00	0.016
Growing				
Growing	—	—	—	
Not growing	-3.1	3.23	-9.6, 3.3	0.335
Initial malocclusion				

Variable	Regression coefficient (β)	SE	95% CI	p-value
Class I	—	—	—	
Class II or III	0.59	1.81	-3.0, 4.2	0.747
Extraction				
No extractions	—	—	—	
Extractions	2.6	1.77	-0.93, 6.2	0.145
Retainer type				
Essix	—	—	—	
Hawley	2.4	2.47	-2.6, 7.3	0.342

## B) Open

Variable	Regression coefficient (β)	SE	95% CI	p-value
Treatment time, months	-0.18	0.200	-0.58, 0.22	0.379
Retention time (linear), months	-0.40	0.125	-0.65, -0.15	0.002
Retention time (quadratic), months	0.01	0.006	0.00, 0.03	0.036
Growing				
Growing	—	—	—	
Not growing	5.0	4.38	-3.8, 14	0.263
Initial malocclusion				
Class I	—	—	—	
Class II or III	-4.3	3.00	-10, 1.7	0.158
Extraction				
No extractions	—	—	—	
Extractions	-4.1	3.02	-10, 2.0	0.183
Retainer type				
Essix	—	—	—	
Hawley	-5.1	4.27	-14, 3.5	0.240

## 4. DISCUSSION

### 4.1 Summary of Findings

The primary purpose of this study was to measure changes in occlusal contact surface area resulting from orthodontic treatment with fixed appliances and into retention using 3D

digital scans. Overall, orthodontic treatment was associated with a reduction in tight and near contacts and an increase in open contacts from pre-treatment values, followed by partial rebound of these contacts during retention, resulting in no statistically significant net change from pre-treatment to retention. Retention time showed a non-linear (quadratic) relationship with beneficial contact changes, including a decrease in open contacts and an increase in tight and near contacts, which leveled off around 24 to 36 months following debond. Malocclusion had limited, but specific influence, primarily affecting near and open contacts, with a greater increase in near contacts and a greater decrease in open contacts in those with Class II or III malocclusions in comparison to Class I, though there was no significant difference at T1. This study found minimal influence of age, sex, and retainer type on occlusal contacts.

#### **4.2 Occlusal Contact Changes During Orthodontic Treatment (T1-T2)**

During active orthodontic treatment with fixed appliances, this study's findings of reduced tight and near contacts with an increase in open contacts are consistent with the current literature that orthodontic mechanics temporarily disrupts intercuspation. Prior research measuring bite force and number of teeth in contact has shown that both parameters decrease during fixed appliance therapy in comparison with pre-treatment values, indicating occlusal contact worsening during active tooth movement (23,24). Studies that directly quantify occlusal contact area and occlusal force at the completion of orthodontic treatment reported significant reductions at the end of treatment with gradual increases over long-term follow-up, further supporting that treatment may induce the opening of occlusal contacts (25). A retrospective analysis of digital models examining occlusal contacts before and immediately following orthodontic treatment also showed significant reductions in tight, near, and approximating contacts alongside an increase in open occlusal contacts, again finding that active treatment

mechanics temporarily compromise interdigitation (10,26). The observations in this study align with the current literature finding that as teeth are moved with orthodontic treatment, contact relationships from pre-treatment are temporarily altered, decreasing occlusal interdigitation until functional settling occurs in retention.

### **4.3 Occlusal Settling During Retention (T2-T3)**

After the removal of orthodontic appliances into the retention period, tight and near contacts increased and open contacts decreased. These changes occurred across the total, anterior, and posterior dentition: functional occlusal settling following the removal of orthodontic fixed appliances. These findings emphasize that occlusal relationships immediately after debond do not represent a stable endpoint and should be interpreted with the context of ongoing physiologic adaptation during retention. When the teeth are in orthodontic appliances, the bracket position and wire engagement decreases the ability for teeth to move freely, potentially leading to appliance-induced disclusion. Once the appliances are removed, it allows for functional eruption and occlusal settling, or as the data showed, an increase in tight contacts and reduction in open contacts when compared to the occlusion at the time of appliance removal. The findings of this study are consistent with other longitudinal studies which also report an increase in the settling of teeth vertically, resulting in an increase in posterior occlusal contacts during the first 1 to 2 years of retention compared with measurements immediately at debond (14,27,28).

The non-linear association between retention time and occlusal contact changes found in this study suggests that most of the occlusal settling occurs within the first 24 to 36 months following the removal of orthodontic appliances. After 36 months, there seemed to be a plateau of changes, and time proves to be a critical variable in outcome assessment for occlusal settling.

Although the overall pattern of occlusal settling was consistent across regions, the timing and magnitude of changes differed slightly between the anterior and posterior dentition. Posterior teeth demonstrated greater and more sustained changes in tight and open contacts during early retention, whereas the anterior dentition exhibited more limited and earlier stabilization, particularly for near contacts. These findings highlight retention as an active phase of occlusal adaptation and provide important context for interpreting overall treatment effects across the full pre-treatment to retention timeline. This study's findings are in line with prior research showing increases in contacts following removal of appliances, further supporting the notion that the retention period represents an active phase of occlusal adaptation rather than a fixed endpoint (14,27,28).

#### **4.4 Net Effect of Treatment and Retention (T1-T3)**

Orthodontic treatment temporarily disrupts occlusal contacts, while retention allows for recovery, resulting in a net equilibrium from pre-treatment to retention. The present findings demonstrate that although occlusal contacts are disrupted during active treatment (T1-T2), most of the recovery occurs within the first 24 to 36 months following appliance removal, allowing occlusal contact relationships to return to baseline levels. These results are consistent with existing literature reporting occlusal disruption associated with orthodontic mechanics and provide clinically relevant insight into the time required for physiologic occlusal settling (24,25). Occlusal contacts improved during retention resulting in stabilization rather than a net increase in occlusal contact area relative to pre-treatment levels. A worsening of contacts immediately at debond should not be considered treatment failure, as the retention period allows for a re-establishment of occlusal contact equilibrium comparable to pre-treatment. These findings reinforce the importance of evaluating orthodontic outcomes across the full treatment and

retention timeline rather than at a single post-treatment time point. However, it is important to note that these data were not longitudinal, and it is not possible to definitively say when these changes occurred exactly. It is possible that most of the settling happens early on, even in the first month as other studies have shown (29), but there are still changes over the next 24 to 36 months that lead to the eventual plateau and return to pre-treatment contact.

#### **4.5 Influence of Malocclusion**

This study demonstrated that patients with Class II and III malocclusions exhibited greater increases in near contact and greater reductions in open contact during the retention period compared with Class I patients. Although these effects were modest and region- and contact- specific, the findings suggest an association between malocclusions classification and patterns of occlusal contact change during retention. Previous studies have reported that patients with a Class I occlusion exhibit the greatest number of occlusal contacts among malocclusion groups (30), and that posterior occlusal contacts at the completion of orthodontic treatment tend to be more favorable in Class I compared with Class II finishes, with Class I cases demonstrating larger occlusal contact areas (31), though our study showed no difference between the malocclusion groups at T1. This could suggest that orthodontic treatment seems to be more beneficial for the Class II and III malocclusion patients, who start out similarly to Class I malocclusions, but have a greater increase in contact area in retention. However, further longitudinal studies are needed to clarify the mechanisms influencing these malocclusion-specific differences.

#### **4.6 Influence of Age, Extractions, and Retainer Type**

Age, extraction versus non-extraction treatment, and retainer type demonstrated limited influence on occlusal contact changes according to the results of this study. Age, categorized as growing versus non-growing, was not associated with statistically significant differences in occlusal contact changes at any of the evaluated time points. Similarly, retainer type did not significantly influence occlusal contact changes; however, interpretation of this finding should be made with caution, as retainer groups were unevenly distributed, reflecting contemporary retention practices with a higher prevalence of clear plastic retainers with full occlusal coverage. Some evidence suggested that extraction treatment was associated with increased tight contact in the posterior dentition and a greater decrease in open contacts from T1 to T3. This finding may be related to differences in pre-treatment occlusal contact potential, as extraction cases are often treated to alleviate crowding and may therefore exhibit greater opportunity for occlusal contact improvement during treatment and retention. However, this interpretation should be considered exploratory and warrants further investigation.

#### **4.7 Clinical Implications**

The findings of this study have important clinical implications for the evaluation of occlusal outcomes following orthodontic treatment. In particular, the results highlight that immediate post-debond occlusion is not final, and that occlusal contact relationships continue to change during the retention period. Post-debond occlusal relationships should be interpreted within the context of physiologic occlusal settling, which continues for up to 2 to 3 years. Therefore, occlusal discrepancies observed immediately following appliance removal should be interpreted with caution. Additionally, retention protocols should allow for functional settling. Consideration of the time-dependent nature of occlusal adaptation is important when assessing treatment success and long-term stability.

## **4.8 Strengths and Limitations**

This study has several limitations that should be considered when interpreting the results. To begin with, the cross-sectional nature of this study is a limitation. Since we are not measuring these patients' contacts longitudinally, it is unclear exactly when they may have reached the point of contact with which they present at the time for their new retainers. The sample size was relatively small, and due to limited representation of Class II and III patients, these malocclusion groups were analyzed together rather than independently. In addition, occlusal contact area was used as a surrogate measure and assumed to be positively associated with masticatory function; however, no direct occlusal force or functional data were collected. Also, there was no assessment of the quality of the provided orthodontic treatment, and it can be postulated that better finished cases may have resulted in less disruption of solid interdigitation during treatment. Another limitation is that the study population was limited to patients treated with fixed appliances, excluding clear aligner therapy, which represents a substantial and growing portion of contemporary orthodontic treatment. The uneven distribution of retainer types and the absence of direct measures of retainer compliance further limit interpretation.

Despite these limitations, this study provides novel longitudinal data evaluating occlusal contact changes across orthodontic treatment and into retention, with follow-up extending up to 60 months following appliance removal. This study also included a broad age range, from 11 to 39 years, allowing evaluation of occlusal contact changes across both adolescent and adult patients. These strengths contribute valuable insight into the time-dependent nature of occlusal settling following orthodontic treatment.

## **5. CONCLUSIONS**

- Orthodontic treatment with fixed appliances results in a temporary disruption of occlusal contacts, with decreased tight and near contacts and increased open contacts immediately following appliance removal.
- During the retention phase, occlusal settling occurs, characterized by increased tight and near contacts and decreased open contacts across the total, anterior, and posterior dentition.
- Occlusal settling is time-dependent and non-linear, with changes occurring up to 24 to 36 months following appliance removal, with minimal change thereafter.
- When evaluated from pre-treatment through retention, no significant net change in occlusal contact area was observed, indicating a return to pre-treatment occlusal equilibrium. This was not related to patient age, treatment type or retainer type.
- Immediate post-debond occlusal contact relationships do not represent a stable endpoint and should not be interpreted as treatment failure.

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## APPENDIX

**Appendix Table 1. Inter-examiner Reliability for examiners AS, MP, SR**

### Contact at each time point

Measure	AS Mean (SD)	MP Mean (SD)	SR Mean (SD)	ICC (95% CI)	D. Error (Min, Max)
Total tight	12.9 (5.1)	12.4 (5.3)	12.1 (5.3)	0.99 (0.95, 1.00)	0.6 (0.0, 1.5)
Total near	28.1 (3.7)	26.5 (5.4)	26.8 (5.4)	0.90 (0.69, 0.98)	1.4 (0.1, 5.5)
Total open	59.0 (8.3)	61.1 (10.5)	61.8 (10.5)	0.95 (0.83, 0.99)	2.1 (0.1, 6.1)
Anterior tight	4.1 (4.8)	5.1 (4.2)	4.0 (4.2)	0.91 (0.70, 0.99)	1.4 (0.0, 6.3)
Anterior near	18.9 (5.8)	15.9 (6.6)	17.0 (6.6)	0.85 (0.56, 0.98)	2.5 (0.2, 8.2)
Anterior open	77.0 (10.4)	79.0 (9.9)	79.0 (9.9)	0.94 (0.79, 0.99)	2.6 (0.0, 9.4)
Posterior tight	13.7 (5.4)	13.2 (5.6)	13.1 (5.6)	0.99 (0.97, 1.00)	0.5 (0.0, 1.5)
Posterior near	29.0 (3.7)	27.5 (5.5)	28.0 (5.5)	0.90 (0.67, 0.98)	1.5 (0.0, 5.8)
Posterior open	57.3 (8.5)	59.3 (10.8)	58.9 (10.8)	0.97 (0.90, 1.00)	1.6 (0.1, 5.9)

### Change in contact between time points

Measure	AS Mean (SD)	MP Mean (SD)	SR Mean (SD)	ICC (95% CI)	D. Error (Min, Max)
Total tight	4.0 (7.6)	4.1 (8.0)	4.1 (8.0)	0.99 (0.97, 1.00)	0.7 (0.0, 2.1)
Total near	2.4 (5.5)	3.7 (8.0)	2.6 (8.0)	0.92 (0.73, 0.99)	1.9 (0.1, 5.6)
Total open	-6.4 (12.1)	-7.8 (15.5)	-6.6 (15.5)	0.97 (0.90, 1.00)	2.3 (0.1, 6.7)
Anterior tight	4.0 (5.0)	1.8 (1.5)	2.7 (1.5)	0.72 (0.30, 0.95)	2.0 (0.1, 7.0)
Anterior near	5.6 (6.9)	7.5 (6.8)	3.5 (6.8)	0.84 (0.52, 0.97)	3.2 (0.2, 11.5)
Anterior open	-9.6 (11.5)	-9.3 (8.3)	-6.2 (8.3)	0.89 (0.64, 0.98)	3.7 (0.5, 12.3)
Posterior tight	4.4 (8.0)	4.5 (8.4)	4.8 (8.4)	0.99 (0.98, 1.00)	0.6 (0.0, 1.7)
Posterior near	2.4 (5.7)	3.8 (8.5)	3.0 (8.5)	0.91 (0.70, 0.99)	2.2 (0.1, 6.8)
Posterior open	-6.8 (12.6)	-8.3 (16.2)	-7.8 (16.2)	0.98 (0.92, 1.00)	2.1 (0.1, 5.4)

**Appendix Table 2. Intra-examiner reliability for AS**

### Contact at each time point

Measure	1st Mean (SD)	2nd Mean (SD)	Diff. (SD) [95% CI]	ICC (95% CI)	D. Error (Min, Max)
Total tight	13.0 (5.0)	12.9 (5.1)	0.1 (0.3) [-0.3, 0.4]	1.00 (0.99, 1.00)	0.2 (0.1, 0.4)
Total near	28.1 (3.6)	28.1 (3.7)	0.0 (0.6) [-0.6, 0.7]	0.99 (0.93, 1.00)	0.4 (0.2, 1.0)
Total open	58.9 (8.0)	59.0 (8.3)	-0.1 (0.7) [-0.9, 0.7]	1.00 (0.98, 1.00)	0.5 (0.0, 1.2)
Anterior tight	4.4 (5.1)	4.1 (4.8)	0.2 (0.3) [-0.1, 0.5]	1.00 (0.98, 1.00)	0.3 (0.0, 0.6)
Anterior near	18.9 (6.7)	18.9 (5.8)	0.0 (1.8) [-1.9, 1.9]	0.97 (0.81, 0.99)	1.2 (0.1, 2.6)
Anterior open	76.7 (11.4)	77.0 (10.4)	-0.3 (1.9) [-2.3, 1.7]	0.99 (0.92, 1.00)	1.2 (0.5, 2.6)
Posterior tight	13.8 (5.2)	13.7 (5.4)	0.1 (0.3) [-0.3, 0.4]	1.00 (0.99, 1.00)	0.2 (0.0, 0.4)
Posterior near	29.0 (3.7)	29.0 (3.7)	0.0 (0.6) [-0.6, 0.6]	0.99 (0.94, 1.00)	0.4 (0.0, 0.8)
Posterior open	57.3 (8.3)	57.3 (8.5)	0.0 (0.6) [-0.7, 0.6]	1.00 (0.99, 1.00)	0.4 (0.0, 1.0)

### Change in contact between time points

Measure	1st Mean (SD)	2nd Mean (SD)	Diff. (SD) [95% CI]	ICC (95% CI)	D. Error (Min, Max)
Total tight	4.0 (7.1)	4.0 (7.6)	-0.1 (0.4) [-0.5, 0.4]	1.00 (0.99, 1.00)	0.3 (0.0, 0.6)
Total near	2.5 (5.6)	2.4 (5.5)	0.1 (0.8) [-0.7, 0.9]	0.99 (0.95, 1.00)	0.5 (0.0, 1.0)
Total open	-6.5 (11.4)	-6.4 (12.1)	0.0 (1.2) [-1.3, 1.2]	1.00 (0.98, 1.00)	0.8 (0.2, 1.5)
Anterior tight	4.3 (5.2)	4.0 (5.0)	0.3 (0.3) [0.0, 0.6]	1.00 (0.98, 1.00)	0.3 (0.0, 0.6)
Anterior near	5.8 (9.2)	5.6 (6.9)	0.2 (3.1) [-3.1, 3.4]	0.94 (0.69, 0.99)	2.0 (1.5, 4.2)
Anterior open	-10.0 (14.0)	-9.6 (11.5)	-0.4 (3.2) [-3.8, 3.0]	0.97 (0.85, 1.00)	2.1 (1.5, 4.8)
Posterior tight	4.3 (7.6)	4.4 (8.0)	-0.1 (0.4) [-0.5, 0.4]	1.00 (0.99, 1.00)	0.3 (0.0, 0.6)
Posterior near	2.5 (5.8)	2.4 (5.7)	0.2 (0.5) [-0.4, 0.7]	1.00 (0.98, 1.00)	0.4 (0.3, 0.8)
Posterior open	-6.9 (12.1)	-6.8 (12.6)	-0.1 (0.9) [-1.1, 0.9]	1.00 (0.99, 1.00)	0.6 (0.2, 1.2)

### Appendix Table 3. Intra-examiner Reliability for MP

#### Contact at each time point

Measure	1st Mean (SD)	2nd Mean (SD)	Diff. (SD) [95% CI]	ICC (95% CI)	D. Error (Min, Max)
Total tight	11.0 (3.1)	11.3 (2.3)	-0.3 (1.0) [-1.4, 0.7]	0.94 (0.68, 0.99)	0.7 (0.2, 1.6)
Total near	23.7 (4.9)	23.8 (3.6)	-0.1 (1.8) [-2.0, 1.7]	0.93 (0.63, 0.99)	1.2 (0.5, 2.8)
Total open	65.3 (8.0)	64.9 (5.9)	0.4 (2.6) [-2.3, 3.2]	0.94 (0.68, 0.99)	1.7 (0.4, 4.2)
Anterior tight	7.8 (3.2)	9.2 (3.5)	-1.4 (1.6) [-3.1, 0.3]	0.83 (0.28, 0.97)	1.4 (0.1, 3.8)
Anterior near	21.3 (6.2)	20.2 (6.0)	1.1 (4.2) [-3.3, 5.5]	0.78 (0.16, 0.97)	2.8 (1.8, 5.3)
Anterior open	71.0 (9.2)	70.7 (9.4)	0.3 (5.5) [-5.5, 6.0]	0.85 (0.35, 0.98)	3.5 (0.9, 8.2)
Posterior tight	11.3 (3.5)	11.4 (2.8)	-0.1 (1.0) [-1.2, 0.9]	0.95 (0.75, 0.99)	0.7 (0.2, 1.6)
Posterior near	23.9 (5.4)	24.1 (4.5)	-0.2 (1.6) [-1.9, 1.5]	0.96 (0.76, 0.99)	1.0 (0.2, 2.5)
Posterior open	64.8 (8.8)	64.5 (7.2)	0.4 (2.5) [-2.2, 3.0]	0.96 (0.78, 0.99)	1.6 (0.7, 3.8)

### Change in contact between time points

Measure	1st Mean (SD)	2nd Mean (SD)	Diff. (SD) [95% CI]	ICC (95% CI)	D. Error (Min, Max)
Total tight	1.4 (1.3)	1.1 (1.4)	0.3 (0.8) [-0.5, 1.2]	0.82 (0.25, 0.97)	0.6 (0.1, 1.4)
Total near	0.8 (2.7)	1.7 (1.6)	-0.9 (1.9) [-2.9, 1.1]	0.61 (-0.19, 0.93)	1.4 (0.1, 2.7)
Total open	-2.2 (3.8)	-2.8 (2.7)	0.6 (2.5) [-2.1, 3.2]	0.74 (0.05, 0.96)	1.7 (0.1, 3.3)
Anterior tight	-2.1 (5.1)	-1.7 (5.4)	-0.4 (1.1) [-1.5, 0.7]	0.98 (0.88, 1.00)	0.8 (0.1, 1.8)
Anterior near	-6.6 (7.8)	-3.0 (8.5)	-3.6 (2.9) [-6.7, -0.5]	0.86 (0.36, 0.98)	3.2 (0.5, 7.4)
Anterior open	8.7 (12.7)	4.7 (13.8)	4.0 (3.1) [0.7, 7.3]	0.93 (0.65, 0.99)	3.5 (1.1, 9.0)
Posterior tight	1.9 (1.7)	1.4 (2.0)	0.5 (1.2) [-0.7, 1.8]	0.79 (0.17, 0.97)	0.9 (0.1, 2.2)
Posterior near	1.8 (3.1)	2.3 (2.2)	-0.5 (2.2) [-2.8, 1.8]	0.71 (-0.01, 0.95)	1.4 (0.2, 2.8)
Posterior open	-3.7 (4.7)	-3.7 (4.0)	0.0 (3.2) [-3.4, 3.3]	0.77 (0.12, 0.96)	2.1 (0.2, 4.6)

**Appendix Table 4. Intra-examiner Reliability for SR**

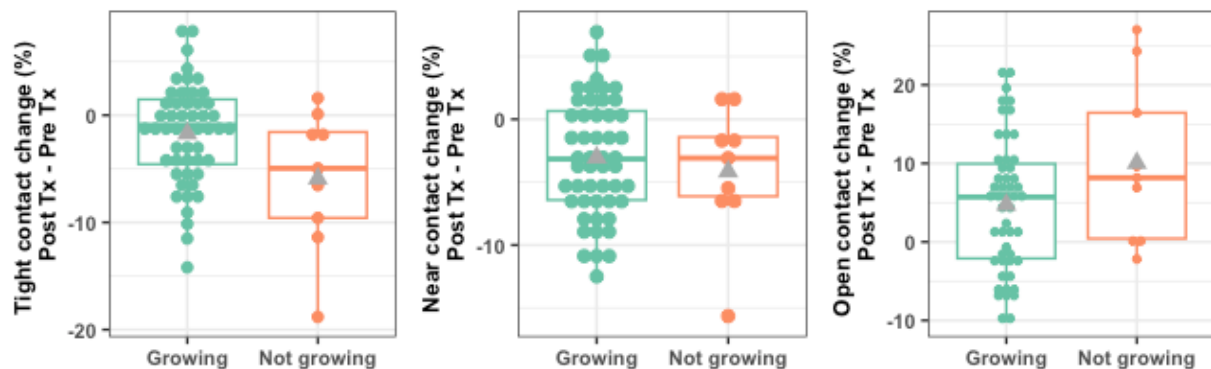
**Contact at each time point**

Measure	1st Mean (SD)	2nd Mean (SD)	Diff. (SD) [95% CI]	ICC (95% CI)	D. Error (Min, Max)
Total tight	7.0 (2.6)	6.6 (2.6)	0.4 (0.6) [-0.3, 1.0]	0.97 (0.83, 1.00)	0.5 (0.1, 1.3)
Total near	18.2 (4.0)	18.2 (4.0)	0.0 (0.8) [-0.9, 0.8]	0.98 (0.90, 1.00)	0.5 (0.0, 1.5)
Total open	74.8 (6.3)	75.1 (6.3)	-0.3 (0.4) [-0.7, 0.1]	1.00 (0.98, 1.00)	0.3 (0.0, 0.7)
Anterior tight	6.2 (2.2)	5.5 (2.6)	0.7 (0.8) [-0.2, 1.5]	0.92 (0.58, 0.99)	0.7 (0.0, 2.0)
Anterior near	17.1 (5.2)	16.8 (4.5)	0.2 (1.2) [-1.0, 1.5]	0.97 (0.84, 1.00)	0.8 (0.1, 2.5)
Anterior open	76.8 (7.2)	77.7 (6.9)	-0.9 (0.9) [-1.8, 0.0]	0.99 (0.92, 1.00)	0.8 (0.0, 2.5)
Posterior tight	7.4 (2.9)	7.2 (2.7)	0.2 (0.5) [-0.3, 0.8]	0.98 (0.90, 1.00)	0.4 (0.0, 1.0)
Posterior near	18.8 (4.0)	18.9 (4.3)	-0.2 (0.7) [-0.9, 0.5]	0.99 (0.94, 1.00)	0.4 (0.0, 1.5)
Posterior open	73.8 (6.7)	73.9 (6.8)	0.0 (0.5) [-0.6, 0.5]	1.00 (0.99, 1.00)	0.3 (0.1, 0.6)

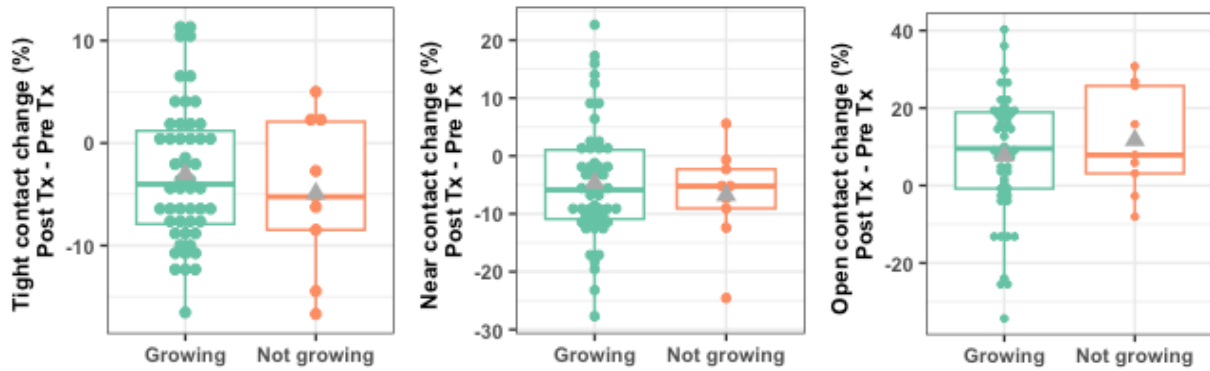
**Change in contact between time points**

Measure	1st Mean (SD)	2nd Mean (SD)	Diff. (SD) [95% CI]	ICC (95% CI)	D. Error (Min, Max)
Total tight	-2.7 (3.4)	-2.2 (3.8)	-0.6 (0.7) [-1.3, 0.2]	0.97 (0.84, 1.00)	0.6 (0.0, 1.7)
Total near	-1.7 (6.1)	-2.3 (5.7)	0.6 (1.2) [-0.6, 1.8]	0.98 (0.88, 1.00)	0.9 (0.1, 2.3)
Total open	4.4 (9.4)	4.5 (9.3)	0.0 (0.6) [-0.7, 0.6]	1.00 (0.99, 1.00)	0.4 (0.2, 0.9)
Anterior tight	-1.6 (3.4)	-1.0 (4.2)	-0.5 (1.0) [-1.6, 0.5]	0.96 (0.79, 0.99)	0.7 (0.3, 2.0)
Anterior near	0.3 (9.0)	-0.7 (7.7)	1.0 (1.8) [-1.0, 2.9]	0.97 (0.85, 1.00)	1.4 (0.3, 3.7)
Anterior open	1.2 (12.3)	1.7 (11.8)	-0.4 (1.0) [-1.5, 0.6]	1.00 (0.98, 1.00)	0.7 (0.2, 1.7)
Posterior tight	-3.3 (3.4)	-2.7 (3.7)	-0.6 (0.6) [-1.3, 0.1]	0.97 (0.85, 1.00)	0.6 (0.0, 1.6)
Posterior near	-2.8 (5.3)	-3.1 (5.4)	0.3 (1.0) [-0.7, 1.3]	0.98 (0.91, 1.00)	0.7 (0.0, 1.6)
Posterior open	6.1 (8.6)	5.8 (8.8)	0.3 (0.8) [-0.5, 1.1]	1.00 (0.98, 1.00)	0.5 (0.1, 1.2)

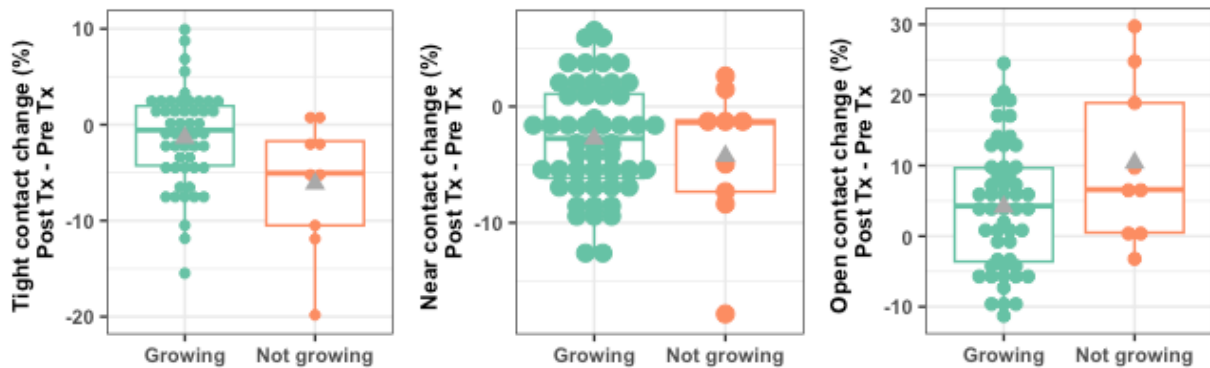
**Appendix Figure 1A. Total Dentition Contact Area Change (%) from Pre- to Post-Treatment Based on Growing vs. Non-Growing Patients**



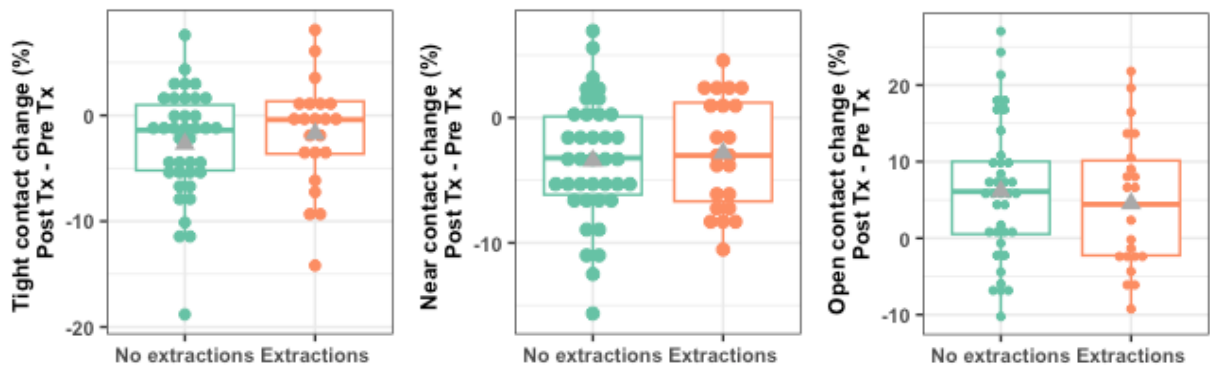
**Appendix Figure 1B.** Anterior Dentition Contact Area Change (%) from Pre- to Post-Treatment Based on Growing vs. Non-Growing Patients



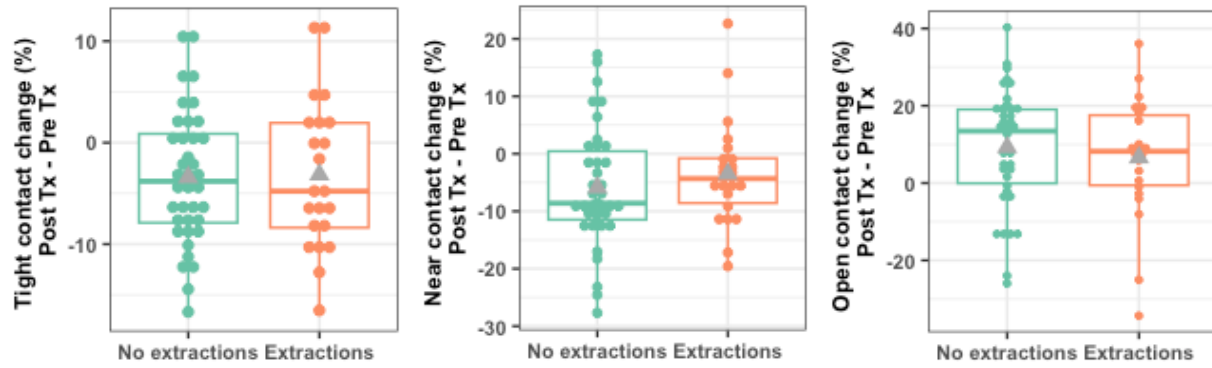
**Appendix Figure 1C.** Posterior Dentition Contact Area Change (%) from Pre- to Post-Treatment Based on Growing vs. Non-Growing Patients



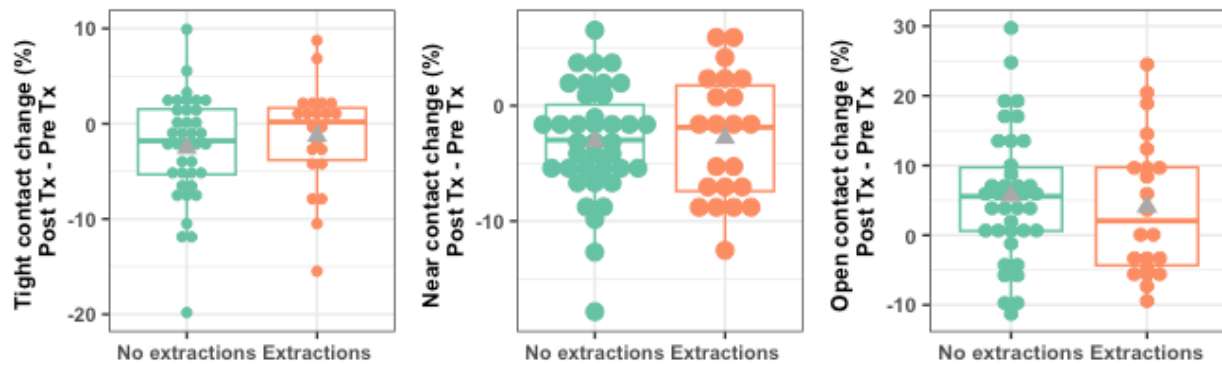
**Appendix Figure 2A.** Total Dentition Contact Area Change (%) from Pre- to Post-Treatment Based on Extraction vs. Non-Extraction Treatment



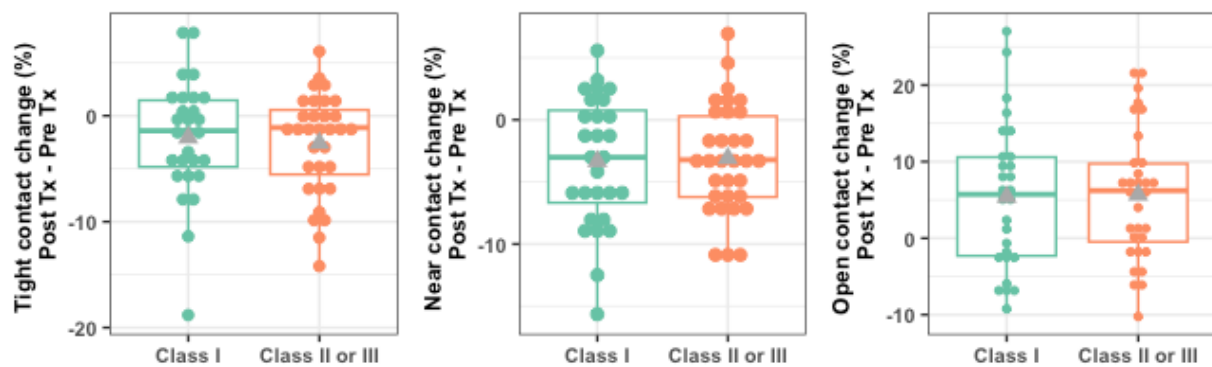
**Appendix Figure 2B.** Anterior Dentition Contact Area Change (%) from Pre- to Post-Treatment Based on Extraction vs. Non-Extraction Treatment



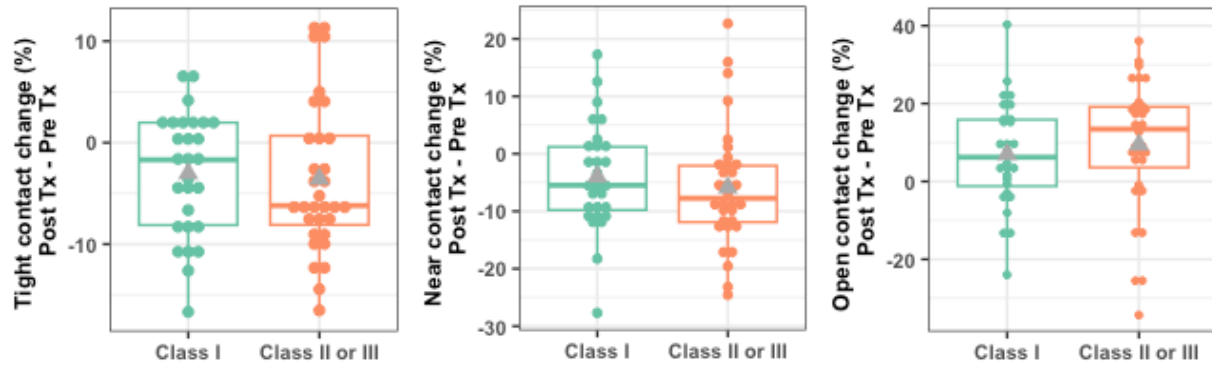
**Appendix Figure 2C.** *Posterior Dentition Contact Area Change (%) from Pre- to Post-Treatment Based on Extraction vs. Non-Extraction Treatment*



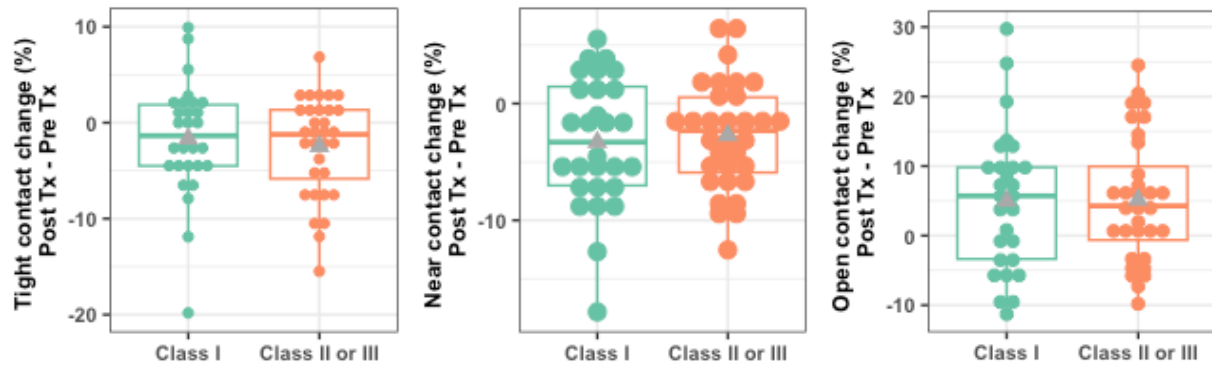
**Appendix Figure 3A.** *Total Dentition Contact Area Change (%) from Pre-to Post-Treatment Based on Malocclusion (Class I vs Class II or III).*



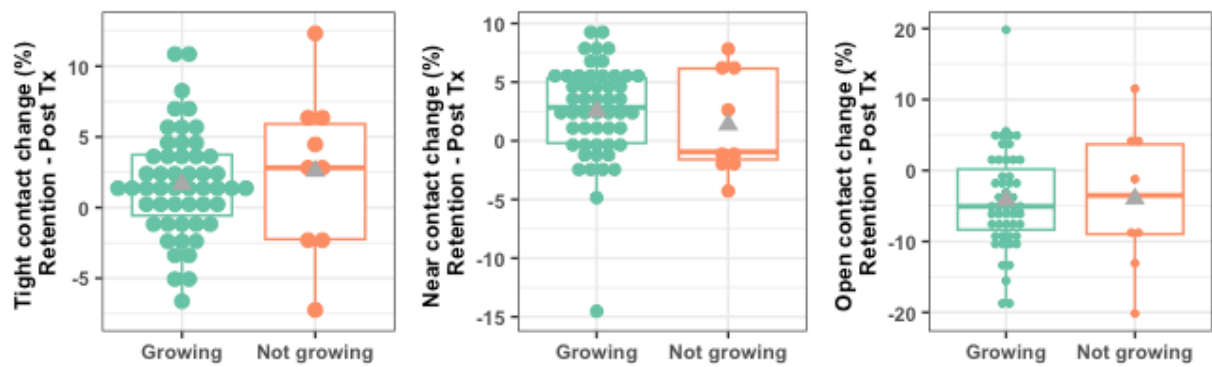
**Appendix Figure 3B.** *Anterior Dentition Contact Area Change (%) from Pre-to Post-Treatment Based on Malocclusion (Class I vs Class II or III).*



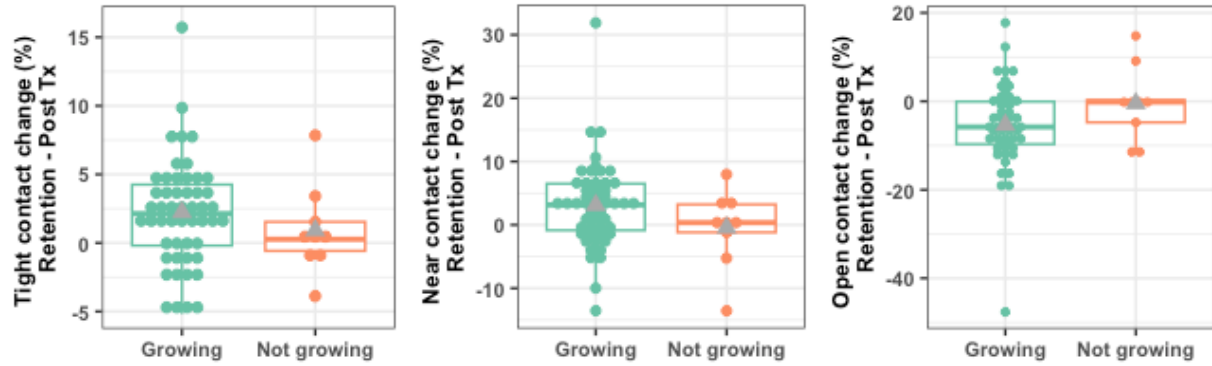
**Appendix Figure 3C.** *Posterior Dentition Contact Area Change (%) from Pre-to Post-Treatment Based on Malocclusion (Class I vs Class II or III).*



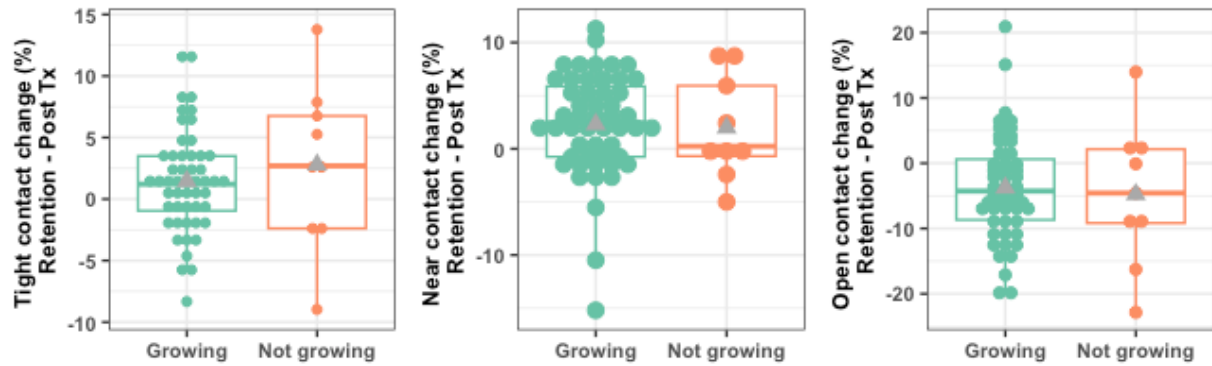
**Appendix Figure 4A.** *Total Dentition Contact Area Change (%) from Post-Treatment to Retention Based on Growing vs. Non-Growing Patients*



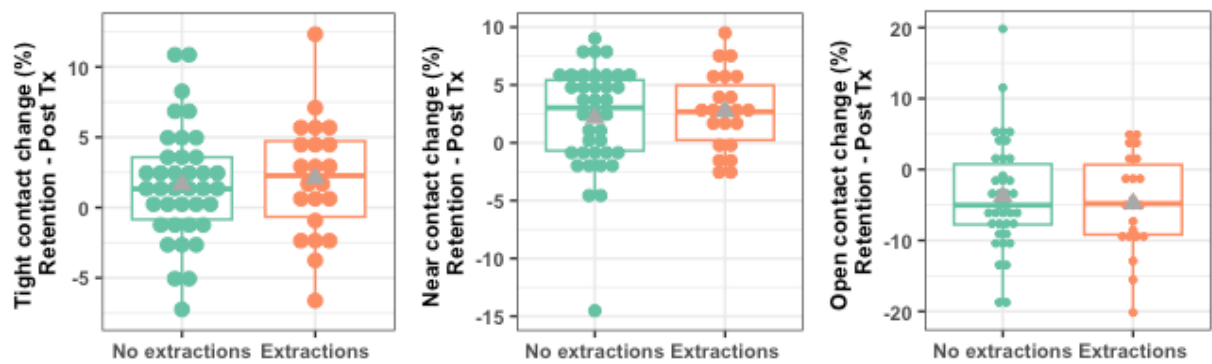
**Appendix Figure 4B.** *Anterior Dentition Contact Area Change (%) from Post-Treatment to Retention Based on Growing vs. Non-Growing Patients*



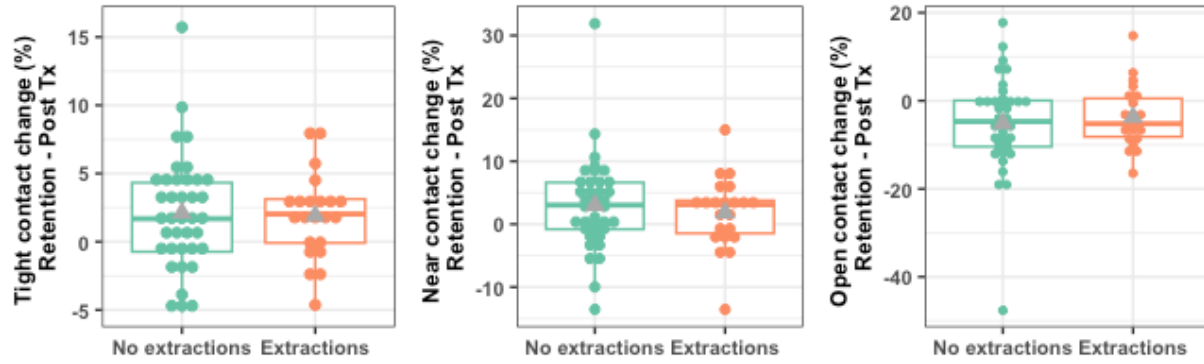
**Appendix Figure 4C.** *Posterior Dentition Contact Area Change (%) from Post-Treatment to Retention Based on Growing vs. Non-Growing Patients*



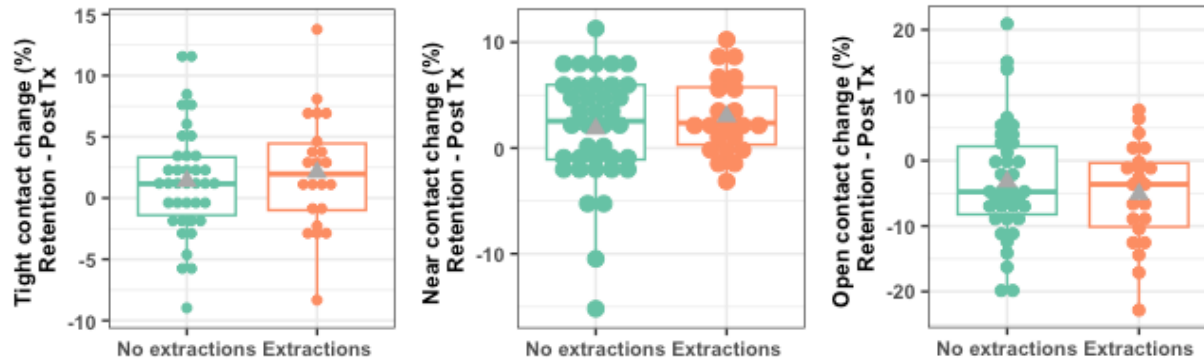
**Appendix Figure 5A.** *Total Dentition Contact Area Change (%) from Post-Treatment to Retention Based on Extraction vs. Non-Extraction Treatment*



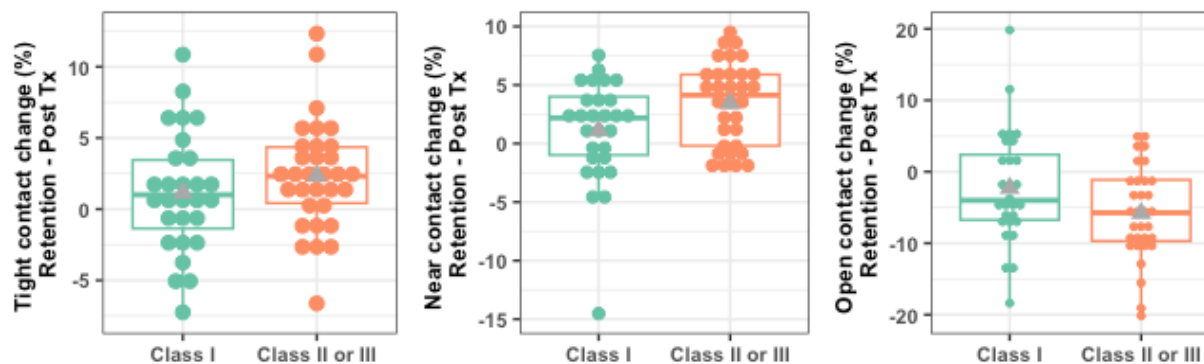
**Appendix Figure 5B.** *Anterior Dentition Contact Area Change (%) from Post-Treatment to Retention Based on Extraction vs. Non-Extraction Treatment*



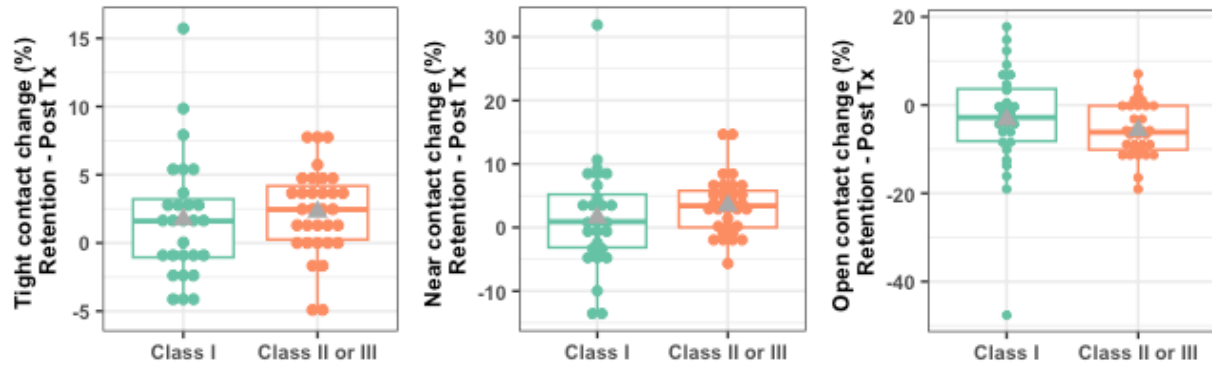
**Appendix Figure 5C.** Posterior Dentition Contact Area Change (%) from Post-Treatment to Retention Based on Extraction vs. Non-Extraction Treatment



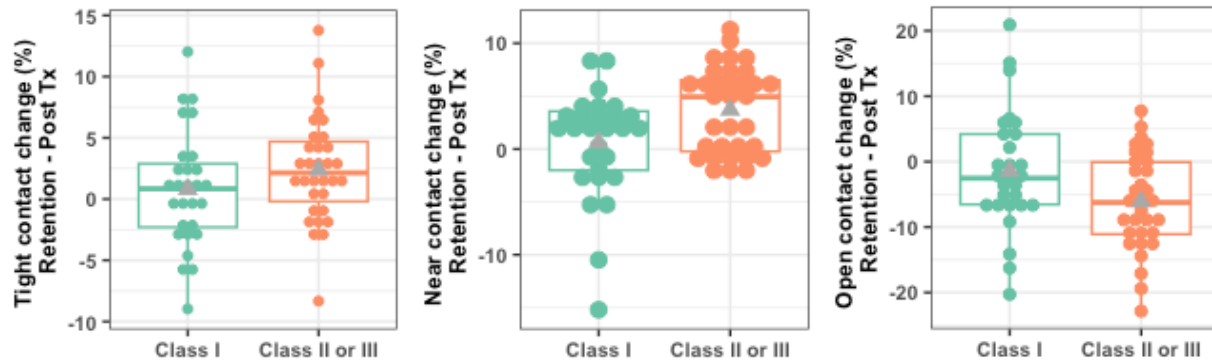
**Appendix Figure 6A.** Total Dentition Contact Area Change (%) from Post-Treatment to Retention Based on Malocclusion (Cl I vs. Cl II or III)



**Appendix Figure 6B.** Anterior Dentition Contact Area Change (%) from Post-Treatment to Retention Based on Malocclusion (Cl I vs Cl II or III).



**Appendix Figure 6C.** Posterior Dentition Contact Area Change (%) from Post-Treatment to Retention Based on Malocclusion (Cl. I vs Cl II or III)



**Appendix Table 5.** Regression Results for Anterior Dentition Tight, Near, and Open Contact Area with Quadratic for Retention Time From T2-T3

A) Tight

Variable	Regression coefficient (β)	SE	95% CI	p-value
Retention time (linear), months	0.10	0.037	0.03, 0.18	0.009
Retention time (quadratic), months	-0.01	0.002	-0.01, 0.00	0.011
Growing				
Growing	—	—	—	
Not growing	-1.1	1.24	-3.6, 1.4	0.380
Initial malocclusion				
Class I	—	—	—	
Class II or III	1.0	1.08	-1.2, 3.2	0.352
Extraction				
No extractions	—	—	—	

<b>Variable</b>	<b>Regression coefficient (β)</b>	<b>SE</b>	<b>95% CI</b>	<b>p-value</b>
Extractions	-0.51	1.00	-2.5, 1.5	0.616
Retainer type				
Essix	—	—	—	
Hawley	0.49	1.40	-2.3, 3.3	0.729

B) Near

<b>Variable</b>	<b>Regression coefficient (β)</b>	<b>SE</b>	<b>95% CI</b>	<b>p-value</b>
Retention time (linear), months	-0.01	0.060	-0.13, 0.11	0.862
Retention time (quadratic), months	0.00	0.004	-0.01, 0.00	0.453
Growing				
Growing	—	—	—	
Not growing	-3.5	2.39	-8.3, 1.3	0.149
Initial malocclusion				
Class I	—	—	—	
Class II or III	2.4	1.88	-1.4, 6.1	0.211
Extraction				
No extractions	—	—	—	
Extractions	-1.7	1.90	-5.5, 2.1	0.383
Retainer type				
Essix	—	—	—	
Hawley	0.59	2.36	-4.2, 5.3	0.804

C) Open

<b>Variable</b>	<b>Regression coefficient (β)</b>	<b>SE</b>	<b>95% CI</b>	<b>p-value</b>
Retention time (linear), months	-0.09	0.084	-0.26, 0.08	0.288
Retention time (quadratic), months	0.01	0.006	0.00, 0.02	0.111
Growing				
Growing	—	—	—	
Not growing	4.6	3.26	-1.9, 11	0.165
Initial malocclusion				
Class I	—	—	—	
Class II or III	-3.4	2.70	-8.8, 2.0	0.215
Extraction				

Variable	Regression coefficient (β)	SE	95% CI	p-value
No extractions	—	—	—	
Extractions	2.2	2.57	-3.0, 7.3	0.400
Retainer type				
Essix	—	—	—	
Hawley	-1.1	3.34	-7.8, 5.6	0.748

**Appendix Table 6.** *Regression Results for Posterior Dentition Tight, Near, and Open Contact Area with Quadratic for Retention Time from T2-T3*

A) Tight

Variable	Regression coefficient (β)	SE	95% CI	p-value
Retention time (linear), months	0.15	0.056	0.04, 0.26	0.011
Retention time (quadratic), months	-0.01	0.003	-0.01, 0.00	0.014
Growing				
Growing	—	—	—	
Not growing	1.5	2.08	-2.7, 5.7	0.467
Initial malocclusion				
Class I	—	—	—	
Class II or III	1.8	1.18	-0.52, 4.2	0.124
Extraction				
No extractions	—	—	—	
Extractions	0.66	1.34	-2.0, 3.3	0.624
Retainer type				
Essix	—	—	—	
Hawley	0.30	1.57	-2.9, 3.5	0.852

B) Near

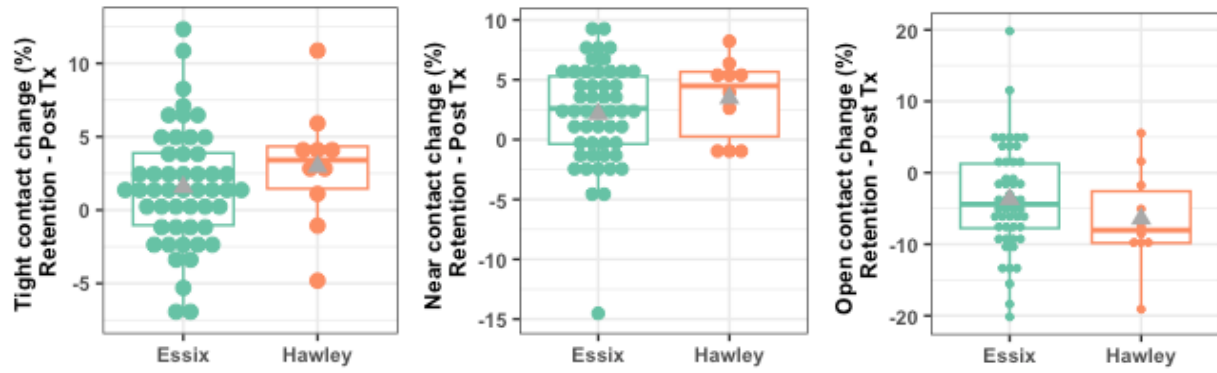
Variable	Regression coefficient (β)	SE	95% CI	p-value
Retention time (linear), months	0.05	0.062	-0.07, 0.17	0.416
Retention time (quadratic), months	0.00	0.003	-0.01, 0.00	0.104
Growing				
Growing	—	—	—	
Not growing	-0.35	1.70	-3.8, 3.1	0.837

Variable	Regression coefficient (β)	SE	95% CI	p-value
Initial malocclusion				
Class I	—	—	—	
Class II or III	3.5	1.36	0.77, 6.2	0.013
Extraction				
No extractions	—	—	—	
Extractions	0.73	1.27	-1.8, 3.3	0.570
Retainer type				
Essix	—	—	—	
Hawley	1.1	1.62	-2.2, 4.3	0.502

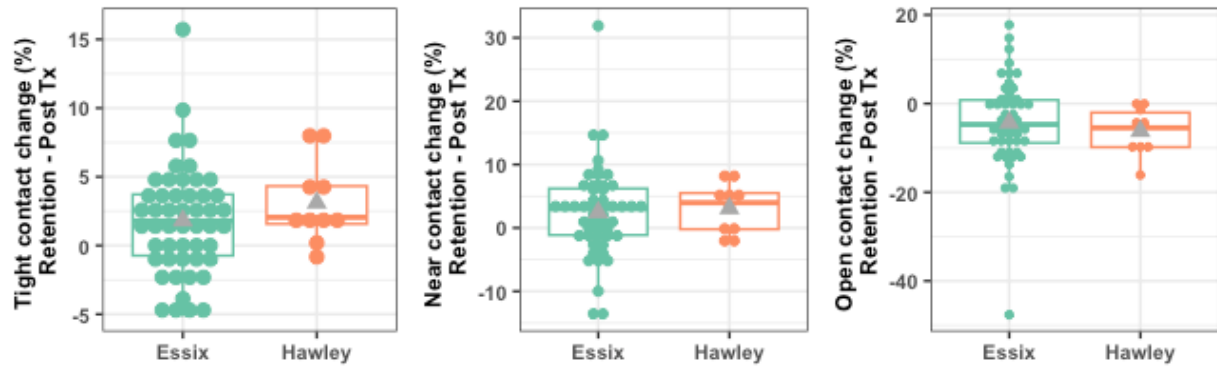
C) Open

Variable	Regression coefficient (β)	SE	95% CI	p-value
Retention time (linear), months	-0.20	0.108	-0.42, 0.02	0.070
Retention time (quadratic), months	0.01	0.005	0.00, 0.02	0.023
Growing				
Growing	—	—	—	
Not growing	-1.2	3.42	-8.0, 5.7	0.732
Initial malocclusion				
Class I	—	—	—	
Class II or III	-5.3	2.28	-9.9, -0.77	0.023
Extraction				
No extractions	—	—	—	
Extractions	-1.4	2.37	-6.1, 3.4	0.562
Retainer type				
Essix	—	—	—	
Hawley	-1.4	2.86	-7.1, 4.4	0.630

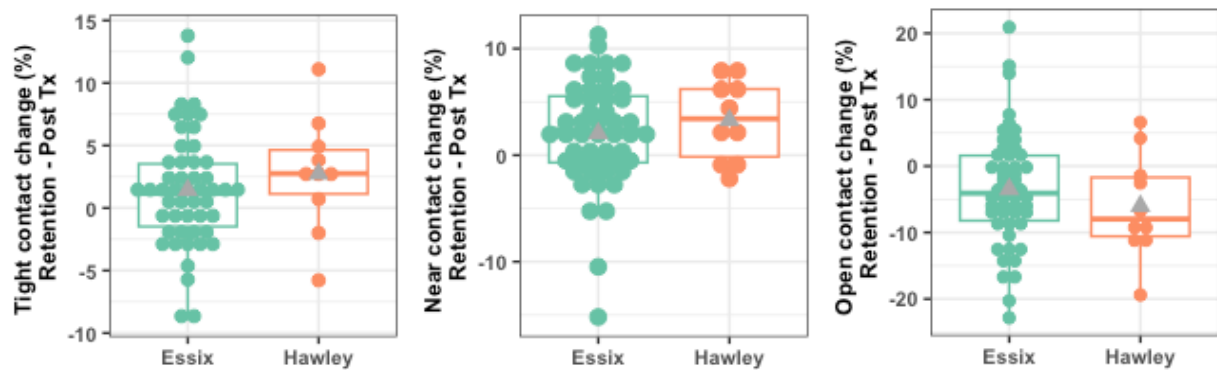
**Appendix Figure 7A.** Total Dentition Contact Area Change (%) from Post-Treatment to Retention Based on Retention Type (Essix vs Hawley Retainer)



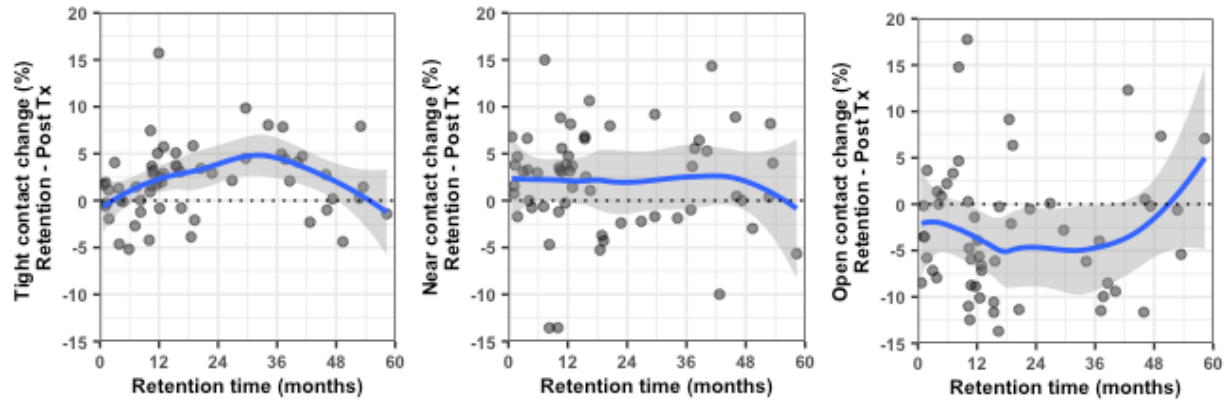
**Appendix Figure 7B.** Anterior Dentition Contact Area Change (%) from Post-Treatment to Retention Based on Retention Type (Essix vs Hawley Retainer)



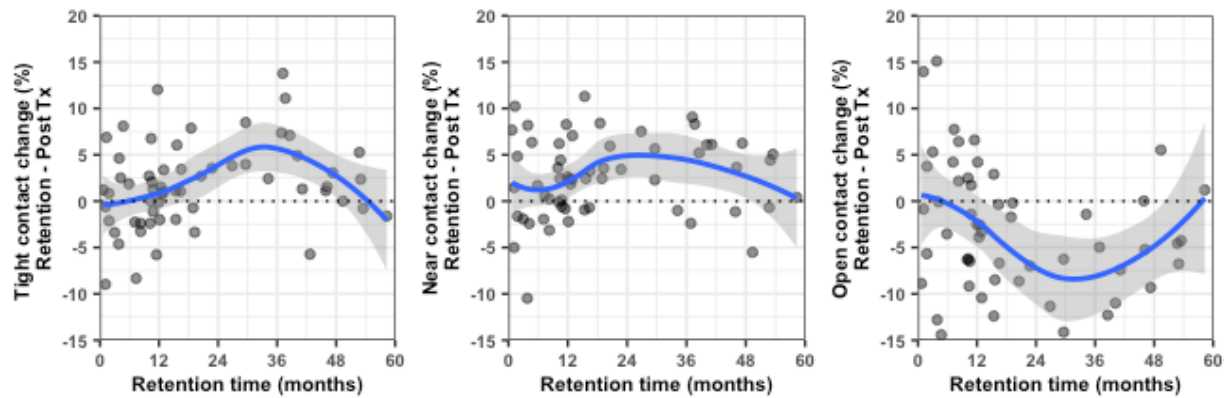
**Appendix Figure 7C.** Posterior Dentition Contact Area Change (%) from Post-Treatment to Retention Based on Retention Type (Essix vs Hawley Retainer)



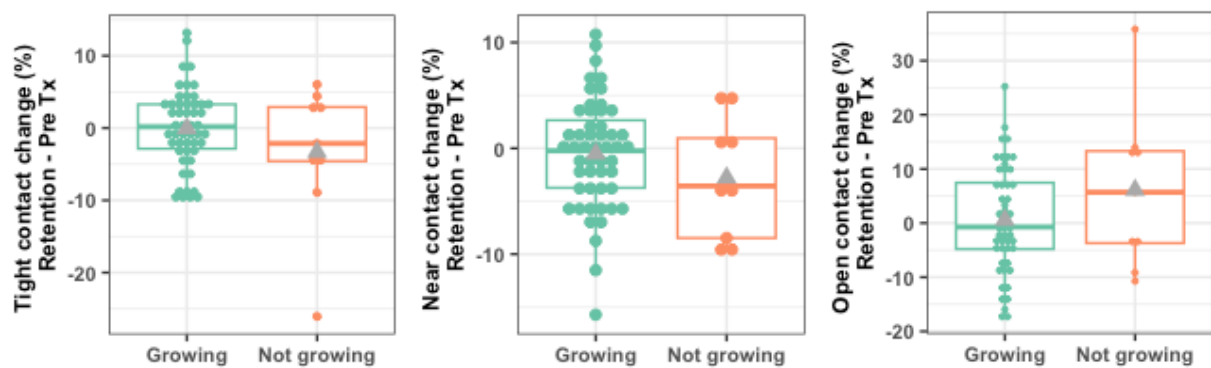
**Appendix Figure 8.** Change in Occlusal Contact Area (%) from T2 (post-treatment) to T3 (into retention) for Anterior Dentition Tight, Near, and Open Contacts based on Retention Time



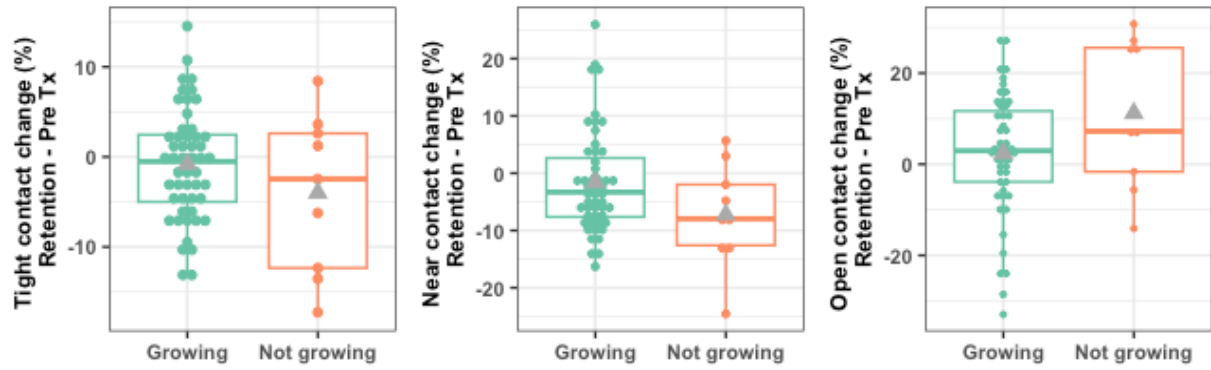
**Appendix Figure 9.** Change in Occlusal Contact Area (%) from T2 (post-treatment) to T3 (into retention) for Posterior Dentition Tight, Near, and Open Contacts based on Retention Time



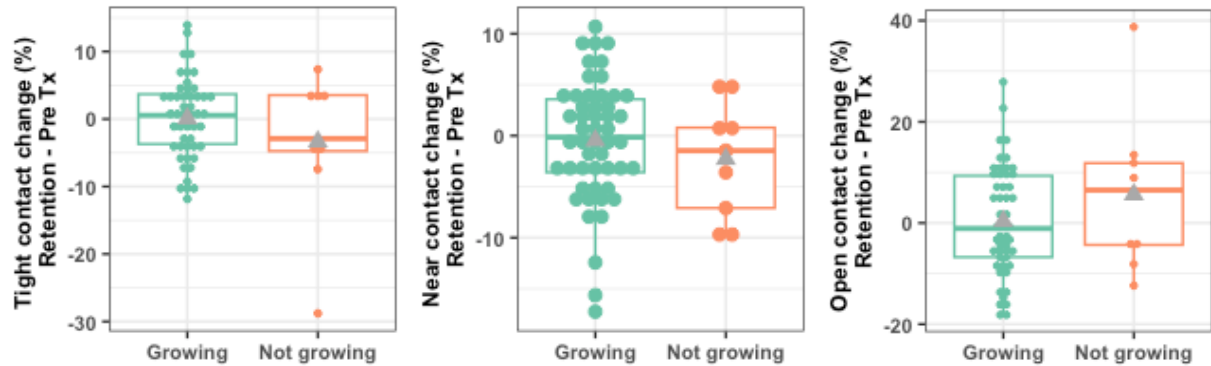
**Appendix Figure 10A.** Total Dentition Contact Area Change (%) from T1 (pre-treatment) to T3 (into retention) Based on Growing vs. Non-Growing Patients



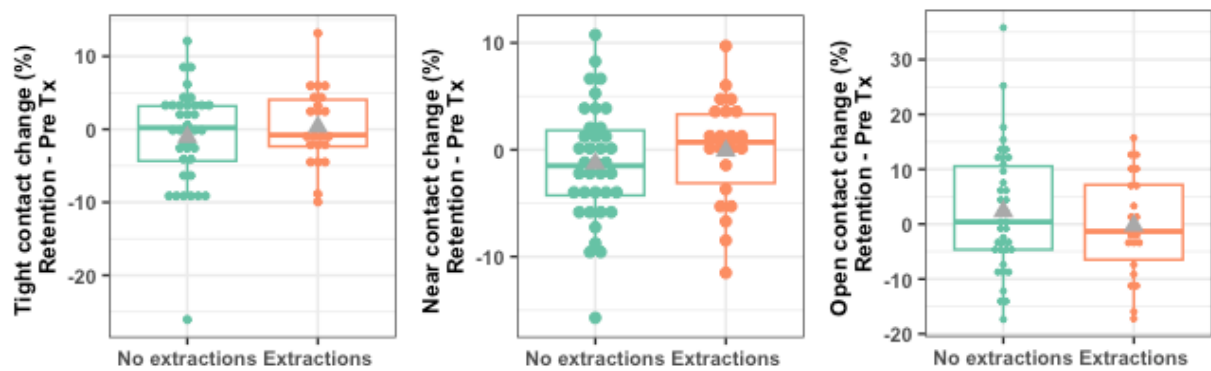
**Appendix Figure 10B.** Anterior Dentition Contact Area Change (%) from T1 (pre-treatment) to T3 (into retention) Based on Growing vs. Non-Growing Patients



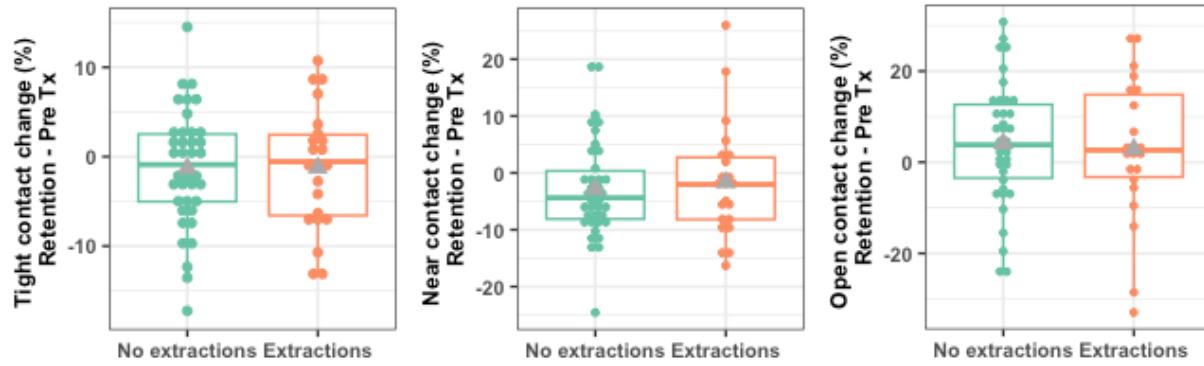
**Appendix Figure 10C.** *Posterior Dentition Contact Area Change (%) from T1 (pre-treatment) to T3 (into retention) Based on Growing vs. Non-Growing Patients*



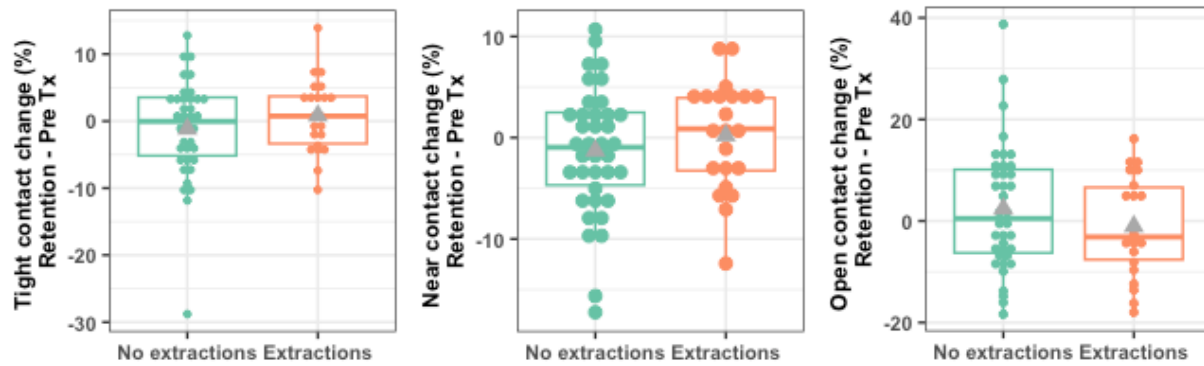
**Appendix Figure 11A.** *Total Dentition Contact Area Change (%) from Pre-Treatment to Retention Based on Extraction vs. Non-Extraction Treatment*



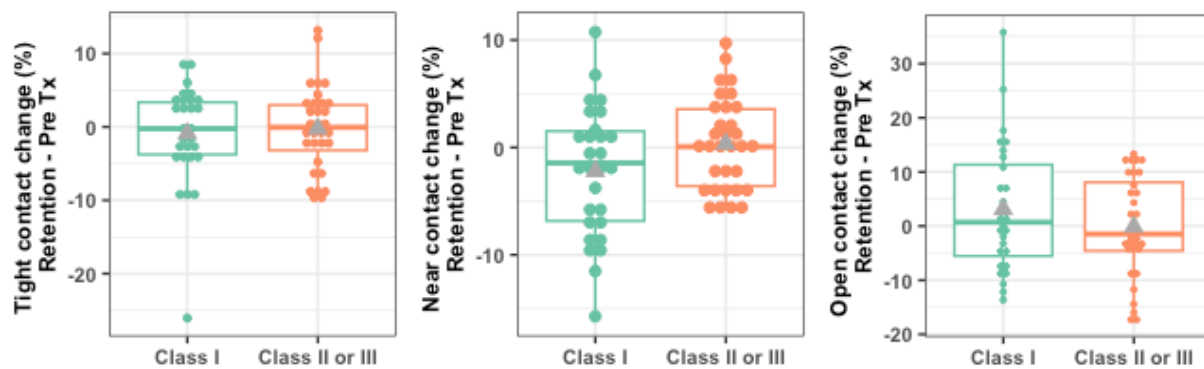
**Appendix Figure 11B.** *Anterior Dentition Contact Area Change (%) from Pre-Treatment to Retention Based on Extraction vs. Non-Extraction Treatment*



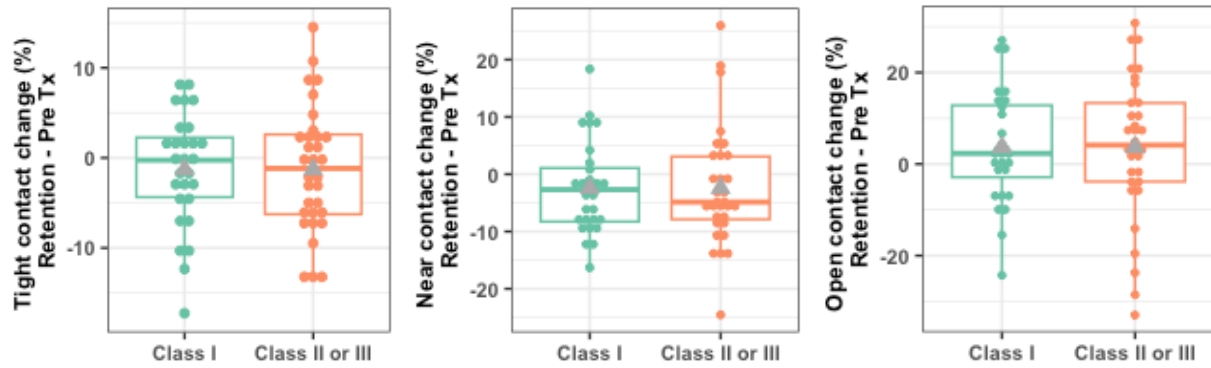
**Appendix Figure 11C.** Posterior Dentition Contact Area Change (%) from Pre-Treatment to Retention Based on Extraction vs. Non-Extraction Treatment



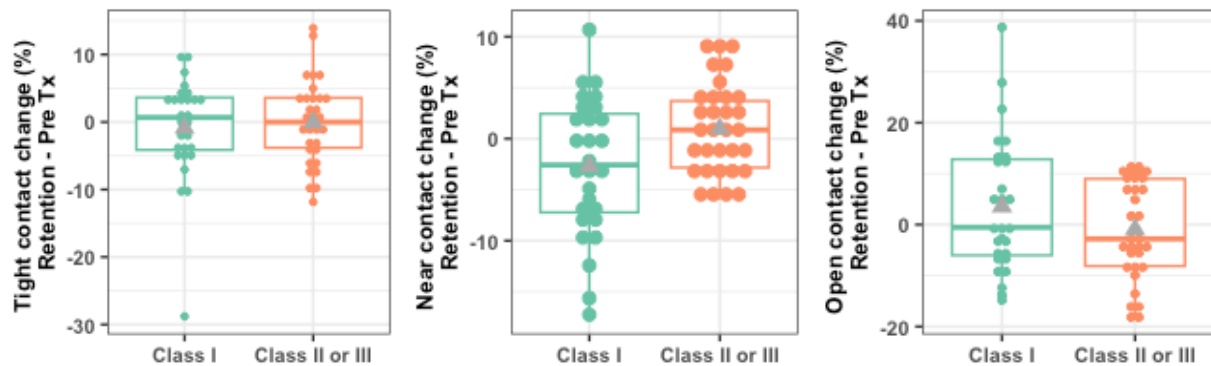
**Appendix Figure 12A.** Total Dentition Contact Area Change (%) from Pre-Treatment to Retention Based on Malocclusion (Cl. I vs Cl II or III)



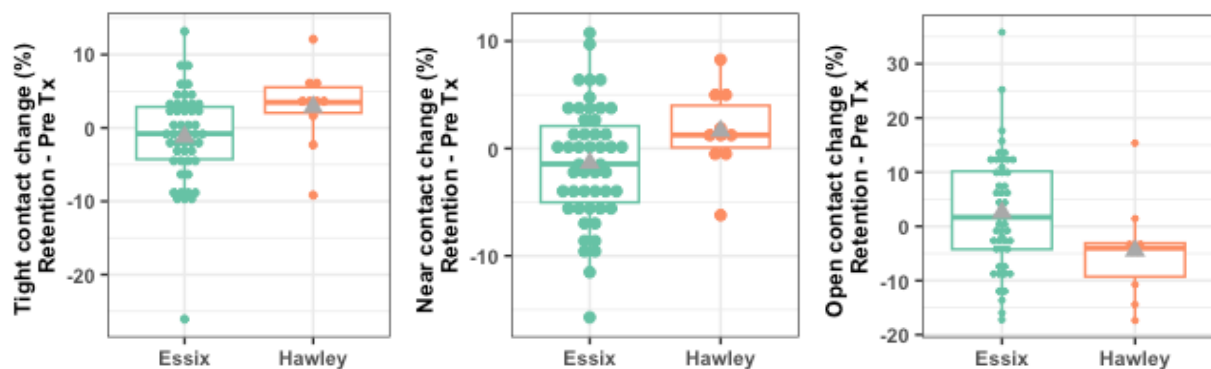
**Appendix Figure 12B.** Anterior Dentition Contact Area Change (%) from Pre-Treatment to Retention Based on Malocclusion (Cl. I vs Cl II or III)



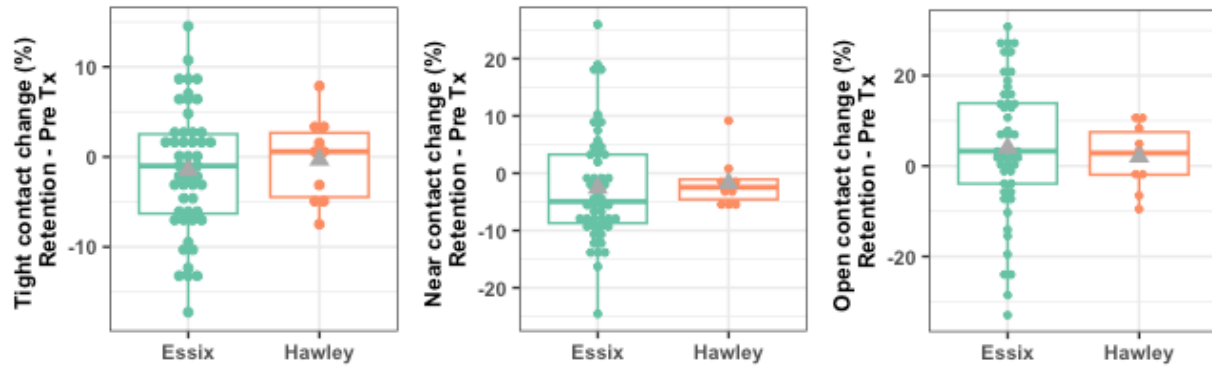
**Appendix Figure 12C.** *Posterior Dentition Contact Area Change (%) from Pre-Treatment to Retention Based on Malocclusion (Cl. I vs Cl II or III)*



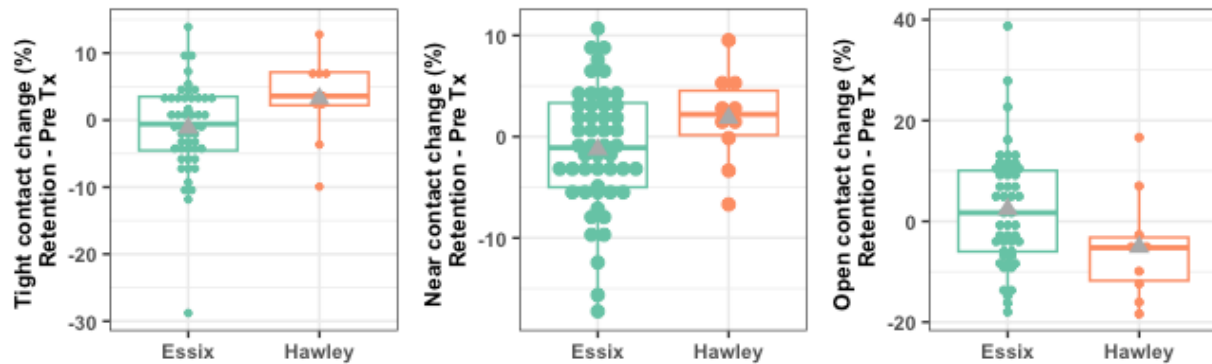
**Appendix Figure 13A.** *Total Dentition Contact Area Change (%) from Pre-Treatment to Retention Based on Retention Type (Essix vs Hawley Retainer)*



**Appendix Figure 13B.** *Anterior Dentition Contact Area Change (%) from Pre-Treatment to Retention Based on Retention Type (Essix vs Hawley Retainer)*



**Appendix Figure 13C.** Posterior Dentition Contact Area Change (%) from Pre-Treatment to Retention Based on Retention Type (Essix vs Hawley Retainer)



**Appendix Table 7.** Regression Results for Anterior Dentition Tight, Near, and Open Contact Area with Quadratic for Retention Time from T1-T3

A) Tight

Variable	Regression coefficient ( $\beta$ )	SE	95% CI	p-value
Treatment time, months	0.14	0.123	-0.11, 0.38	0.267
Retention time (linear), months	0.22	0.078	0.06, 0.38	0.007
Retention time (quadratic), months	-0.01	0.005	-0.02, 0.00	0.111
Growing				
Growing	—	—	—	
Not growing	-3.1	3.16	-9.4, 3.3	0.338
Initial malocclusion				
Class I	—	—	—	
Class II or III	-0.21	1.85	-3.9, 3.5	0.912
Extraction				

<b>Variable</b>	<b>Regression coefficient (β)</b>	<b>SE</b>	<b>95% CI</b>	<b>p-value</b>
No extractions	—	—	—	
Extractions	0.08	1.99	-3.9, 4.1	0.969
Retainer type				
Essix	—	—	—	
Hawley	-0.28	2.40	-5.1, 4.5	0.907

B) Near

<b>Variable</b>	<b>Regression coefficient (β)</b>	<b>SE</b>	<b>95% CI</b>	<b>p-value</b>
Treatment time, months	0.22	0.229	-0.24, 0.68	0.344
Retention time (linear), months	0.07	0.118	-0.17, 0.30	0.563
Retention time (quadratic), months	0.00	0.006	-0.01, 0.01	0.594
Growing				
Growing	—	—	—	
Not growing	-6.0	3.43	-13, 0.89	0.087
Initial malocclusion				
Class I	—	—	—	
Class II or III	-0.40	2.38	-5.2, 4.4	0.867
Extraction				
No extractions	—	—	—	
Extractions	0.63	2.88	-5.2, 6.4	0.827
Retainer type				
Essix	—	—	—	
Hawley	0.98	2.50	-4.0, 6.0	0.696

C) Open

<b>Variable</b>	<b>Regression coefficient (β)</b>	<b>SE</b>	<b>95% CI</b>	<b>p-value</b>
Treatment time, months	-0.36	0.318	-1.0, 0.28	0.268
Retention time (linear), months	-0.29	0.167	-0.63, 0.05	0.089
Retention time (quadratic), months	0.01	0.009	-0.01, 0.03	0.254
Growing				
Growing	—	—	—	
Not growing	9.0	5.60	-2.2, 20	0.113
Initial malocclusion				
Class I	—	—	—	

Variable	Regression coefficient (β)	SE	95% CI	p-value
Class II or III	0.61	3.62	-6.7, 7.9	0.868
Extraction				
No extractions	—	—	—	
Extractions	-0.71	4.40	-9.5, 8.1	0.872
Retainer type				
Essix	—	—	—	
Hawley	-0.70	4.18	-9.1, 7.7	0.868

**Appendix Table 8.** *Patients and Retention Time.*

Characteristic	N = 60 <sup>1</sup>
<b>Retention time, months</b>	
0.7 to <6	12 (20.0%)
6 to <12	14 (23.3%)
12 to <24	15 (25.0%)
24 to <36	4 (6.7%)
36 to <48	10 (16.7%)
48 to <60	5 (8.3%)

<sup>1</sup>n (%)