

Occlusal Contact Changes in Patients Treated with Clear Aligners

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Abstract

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Introduction: Clear aligners are commonly used in orthodontic treatment to correct malocclusions and enhance smile esthetics. There is little quantitative data on how occlusal contacts are altered by clear aligners. This study uses digital intra-oral scans to evaluate how clear aligners affect occlusal contacts and to determine the influence of sex and age on contact changes. Results are compared to contact changes that occur during fixed appliance therapy.

Methods: Patients included in this study were treated at the University of Washington orthodontic clinic between January 2017-August 2021 and in a local private practice between May 2016-February 2021. Inclusion criteria were a Class I malocclusion treated non-extraction with Invisalign and the presence of digital intra-oral scans obtained before treatment was initiated (T1) and post-treatment following debond (T2). Scans were imported into GOM Inspect Software (GOM Precise Industrial 3D Metrology, Braunschweig, Germany) and occlusal contacts were analyzed. Contacts studied ranged from 0-1.25 mm of space between maxillary and mandibular teeth and were grouped into five categories (tight, near, approximating, open, and no contacts). Analysis was done for the total contact area, anterior area, and posterior areas. The

effect of age and sex on contact changes during clear aligner treatment was determined. Changes in occlusal contacts were compared to contact changes that occur during fixed appliance treatment using an existing dataset.

Results: A total of 45 patients fit the eligibility criteria for this study. Clear aligners reduced the percentage of tight, near and approximating contacts while the percentage of open and no contacts increased. These changes in occlusal contacts were greater for the older age group studied. Sex influenced occlusal contact changes in the anterior dentition only where the decrease in near contacts and increase in open contacts was greater for males. These results for patients treated with clear aligners were similar to those for patients treated with fixed appliances; both treatment modalities reduce close occlusal contacts at the time active treatment is completed.

Conclusions: Clear aligners reduce close contacts and increase open contacts. Overall contact changes during clear aligner treatment are influenced by age, and anterior contact changes are influenced by sex. Clear aligners and fixed appliances result in similar occlusal contact changes.

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Introduction

A malocclusion is a condition of “imperfect positioning of the teeth when the jaws are closed”. A malocclusion may influence esthetics, which is often the prime reason for patients to seek orthodontic treatment. However, the lack of a good occlusion (intercuspatation between the upper and lower teeth) can also compromise the ability to chew properly. Having a normal posterior and anterior occlusion is important because studies have shown that masticatory efficiency is significantly reduced when an individual has a malocclusion (Bae et al., 2017; Corrêa et al., 2018; English et al., 2002). By analyzing masticated particles, these studies show that individuals with openbites or Angle Class II/III malocclusions are unable to break down particles to the same degree as individuals with Class I (ideal) occlusions. In addition, these patients report a decreased ability to chew hard or firm foods, such as celery, carrots, and steak. Although improved masticatory efficiency is one of the primary goals of patients undergoing orthodontic treatment, there is limited existing evidence that quantitatively evaluates how occlusal contacts change after this treatment. Occlusal contacts are an especially important factor to examine because masticatory efficiency is directly related to the number and sizes of contacts (Helkimo et al., 1978; Julien et al., 1996; Yurkstas, 1949, Yurkstas, 1965). Lepley et al. found that masticatory performance is dependent on a number of variables, such as bite force and chewing cycle kinematics, but occlusal contact area had the largest influence; better masticatory performance was found in individuals with larger contact areas.

Quantitative methods that have been used to measure occlusal contacts in the existing literature include: 1) Dental Prescale System, where the patient occludes on a digital

sensor that then measures occlusal contact area (Iwase et al., 2006; Makino et al., 2014), 2) Blu Mousse impression of posterior dentition followed by manual tracing of the occlusal contact area (Owens et al., 2002), 3) Black Silicone or dental wax impressions analyzed using specialized devices to quantify the contact area by measuring the amount of light transmitted through the material (Yurkstas, 1949; Wright, 1992). Since digital intra-oral scanning has become a widely accepted method of obtaining dental models, using these scans to assess occlusal contacts is an accurate and reproducible method of occlusal analysis that utilizes preexisting patient data. In addition, this method allows contact analysis to be separated in the anterior and posterior regions of the dentition to better understand how each of these segments are affected by orthodontic treatment.

While orthodontic treatment traditionally used fixed orthodontic appliances, a new methodology using sequential clear removable appliances has become a very popular treatment alternative. Clear aligners are thermoformed appliances that can be used with or without attachments for orthodontic tooth movement. "Tooth positioners," an early form of aligners, have been used since the 1940s for very minor tooth movement, but it wasn't until the 1960s that thermoformed clear aligners were introduced for orthodontic tooth movement (Weir, 2017). The technology of aligners has evolved in the recent decades and the appliances have gone through several iterations since their initial development (Nahoum, 1959; Ponitz, 1971; McNamara et al., 1985; Sheridan et al., 1993, Truax, 1997). Currently, clear aligners are a widely used orthodontic appliance that have the capability of precise crown and root movements.

Although clear aligner technology has significantly improved, the occlusal results obtained with clear aligners is still being investigated. Djeu et al. used the Objective Grading System to evaluate posttreatment records of orthodontic patients who underwent comprehensive, nonextraction treatment with clear aligners or fixed appliances; the group found that occlusal contact scores for patients treated with clear aligners were significantly lower than those treated with fixed appliances. Borda et al., however, analyzed posttreatment records of orthodontic patients who presented with mild malocclusions using the ABO Cast-Radiograph Evaluation and found no significant difference in occlusal contacts between patients treated with clear aligners or fixed appliances. These conflicting results indicate that a more accurate, reproducible and quantifiable method of analyzing occlusal contacts after clear aligner treatment is needed.

To better understand how occlusal contacts change during clear aligner treatment, this retrospective study uses digital intraoral scans as an accurate and reproducible method to: 1) determine how occlusal contacts change during treatment with clear aligners, 2) assess the influence of age and sex on occlusal contact changes during clear aligner treatment, and 3) compare occlusal contact changes between patients treated with clear aligners and patients treated with full fixed appliances.

2. Materials and Methods

2.1 Participants and Eligibility Criteria

Institutional Review Board (IRB) approval was obtained from the University of Washington Human Subjects Divisions before starting data collection. Patients treated in the University of Washington orthodontic clinic between January 2017-August 2021 were screened for eligibility in the study, as well as patients treated by a local private-practice orthodontist in the greater Seattle area between May 2016 – February 2021. Inclusion criteria were: 1) Patient with Class I Angle Classification of Malocclusion, 2) Patient completed Invisalign treatment, 3) pre- and post-treatment digital intraoral scans available that were taken using an iTero scanner (Align Technology, Inc. San José, CA), 4) post-treatment scans were taken the day of debond, 5) presence of permanent dentition from second molar to second molar in both arches. These inclusion criteria were also applied to comparison data on full fixed appliance treatment that was obtained from Dr. Gabriela Aragon-Meyer's research. Angle Classification was determined using the pre-treatment intraoral scan. Occlusion was considered Class I if the mesiobuccal cusp of the maxillary first molar occluded anywhere between the mesiobuccal groove and mesiobuccal line angle of the mandibular first molar. Exclusion criteria were: 1) Patients with craniofacial syndromes, 2) Patients with medical or dental condition that would affect treatment outcome, 3) Patients who had prosthodontic treatment during orthodontic treatment, and 4) Patients who did not complete the recommended clear aligner treatment.

2.3 Data Collection

Digital scans were taken in maximum intercuspation. The T1 intraoral scan is the intraoral scan that was used for the initial Invisalign Clincheck. The T2 intraoral scan is the final scan taken the day of debond. Scans were exported from www.mycadent.com as an open shell STL file with the maxilla and mandible oriented in occlusion. Files were imported into GOM Inspect Software for analysis (GOM Precise Industrial 3D Metrology, Braunschweig, Germany).

2.4 Scan Measurements

The STL of the mandibular teeth was imported into the GOM Inspect software as a “new part” then “mesh” element. The upper model was added as a “CAD body”. All points of the upper model (“element”) were selected then inverted. The upper model was then removed from view so the lower model could be visualized. The dentition on the lower model was outlined. Third molars, if present, were not outlined. A CAD comparison was done to measure the distance between upper and lower contacts; the distance analyzed was 0.25 mm to -1.25. The legend type was changed to “tolerance legend” and “statistics” was used to obtain contact measurements at each distance analyzed. Measurements were recorded in an Excel spreadsheet (Microsoft Excel, Microsoft Office 365, Redmond, Washington). The five distances evaluated were: tight contacts (0.25 to 0 mm), near contacts (<0 to -0.25), approximating contact (-0.26 to -0.50), open contacts (-0.51 to -1.00), and no contact (<-1.00 to -1.25). Three areas of the dentition were analyzed: total (second molar to second molar), anterior (canine to canine) and posterior (first premolar to second molar). A dental student at the University of Washington, assisted with data collection.

2.5 Data Analysis

For analysis of each contact type, the percentage was determined at T1 and T2, then the change from T1 to T2. The mean and standard deviation were computed for T1 and T2, and the change from T1 to T2. A 95% confidence interval for the average change between post- and pre-treatment was also calculated. MANOVA was used to test for any change among the 5 contact types and the paired t-test was used to test for change for each contact type. The Bonferroni method was used to adjust the paired t-test p-values to maintain a significance level of 0.05 for the 5 separate tests. This analysis was done for the total contact area, anterior area, and posterior areas. P-values less than 0.0001 are reported as 0.0000 in all data tables.

The effect of age on contact changes during Invisalign treatment was determined. The patient sample was divided into three approximately equal age groups: 12-16 (N=15), 19-28 (N=14) and 32-53 (N=15). Age groups were determined based on the distribution of ages in the sample and on growth; patients in the youngest age group were expected to be growing, the middle age group is mixed growing and nongrowing, and the oldest age group has completed growth. The same type of analysis as described in the previous paragraph was carried out. The percentage of each type of contact was determined at T1 and T2. MANOVA and one-way ANOVA were used to test for any difference between 3 age groups among the 5 contact types. The Bonferroni method was used to adjust the one-way ANOVA p-values.

The effect of sex on contact changes during Invisalign treatment was also analyzed. Patients were divided into male and female groups and the percentage of each contact type at T1 and T2 was determined. MANOVA was used to test for any difference between females and males among the 5 contact types, and then the two (independent) sample t-test was used to test for a difference between females and males for each contact type. The Bonferroni method was used to adjust the two-sample t-test p-values.

Contact changes that occur during Invisalign treatment and treatment with full fixed appliances were compared. Because results indicate that age influences contact changes during Invisalign treatment, the Invisalign sample was limited to patients under 23 years old to match the age of patients in the full fixed appliance sample. Twenty-one Invisalign patients were used for this analysis. The same analysis as described previously was carried out to determine the percent of each contact at T1 and T2. MANOVA was used to test for any difference between full fixed appliances and Invisalign among the 5 contact types, and then two (independent) sample t-test were used to test for a difference between full fixed appliances and Invisalign for each contact type. The Bonferroni method was used to adjust the two-sample t-test p-values.

2.6 Measurement Error Analysis

To evaluate intra- and inter-rater reliability, T1 and T2 measurements for 5 patients were remeasured, independently, by two investigators (EF and MM). The measurements were done 5 months apart. To compare the two measurements, the following were computed: the mean and standard deviation (SD) for each set of

measurements (either within a rater or between the two raters), the mean (SD) of the differences, 95% confidence interval (CI) for the mean difference, the intraclass correlation coefficient (ICC), 95% CI for the ICC, Dahlberg's error, and minimum and maximum for the absolute value of the difference between the two measurements (Cicchetti et al., 1994, Kim, 2013).

The ICC is a relative measure of agreement, indicating how much of the variation in a measure is due to differences between subjects and differences between the two measurements. An ICC > 0.75 indicates excellent agreement. The Dahlberg's error is an absolute measure of error and gives the average error of the measurements in units of the variable being measured.

3. Results

3.1 Sample Population Characteristics

A total of 45 patients treated with clear aligners and 37 patients treated with fixed appliances met the inclusion criteria for this study. One patient was excluded from the clear aligner sample due to poor quality intraoral scan. One patient was excluded from the fixed appliance group because the patient was significantly older than the rest of the sample.

3.2 Patient Demographics

The mean age of patients in the clear aligner sample was 27 years old, there were a higher percentage of females (66%) versus males (34%), and the mean treatment time

was 15 months. The mean age of patients in the fixed appliance group was 14 years old, there were more males (58%) than females (42%) and the mean treatment time was 21 months (Table 1).

Table 1. *Demographics of patients included in the Invisalign and fixed appliance groups*

Characteristic	Fixed, N = 36	Invisalign, N = 44
Age, years		
Mean (SD)	14 (3)	27 (14)
Median (IQR)	13 (12, 16)	24 (15, 34)
Range	12, 23	12, 56
Sex		
F	15 (42%)	29 (66%)
M	21 (58%)	15 (34%)
Treatment time, months		
Mean (SD)	21 (4)	15 (7)
Median (IQR)	21 (19, 24)	13 (10, 18)
Range	10-29	5-31

3.3 Inter- and intra-rater reliability of contact area measurements

Reliability measurements indicate excellent intra- and inter-rater reliability. Intra-rater reliability ICC values for pre-treatment measurements, post-treatment measurements and post-pre treatment percent change was 1.00 for examiner 1 (Appendix Table 1) and ranged from 0.84-1.00 for examiner 2 (Appendix Table 2). ICC values for intra-rater reliability ranged from 0.88-1.00 (Appendix Table 3).

3.4 Post-pre treatment change in contact area (%) for total, anterior and posterior dentition after clear aligner treatment

Figure 1 shows the change in tight, near, approximate, open and no contact between pre-treatment and post-treatment Invisalign patients. Measurements were done for the total dentition (Figure 1A), posterior dentition (Figure 1B), and anterior dentition (Figure 1C). Bars extending above zero indicate an increase in the percent of contacts while bars extending below the zero line show a decrease in the percent of that contact type. Results indicate that the percent of open and no contacts increased in the total, posterior and anterior dentition after clear aligner treatment. The percent of tight, near, and approximate contacts decreased after treatment. Statistical analysis for post-pre treatment change in contact area is displayed in Table 2.

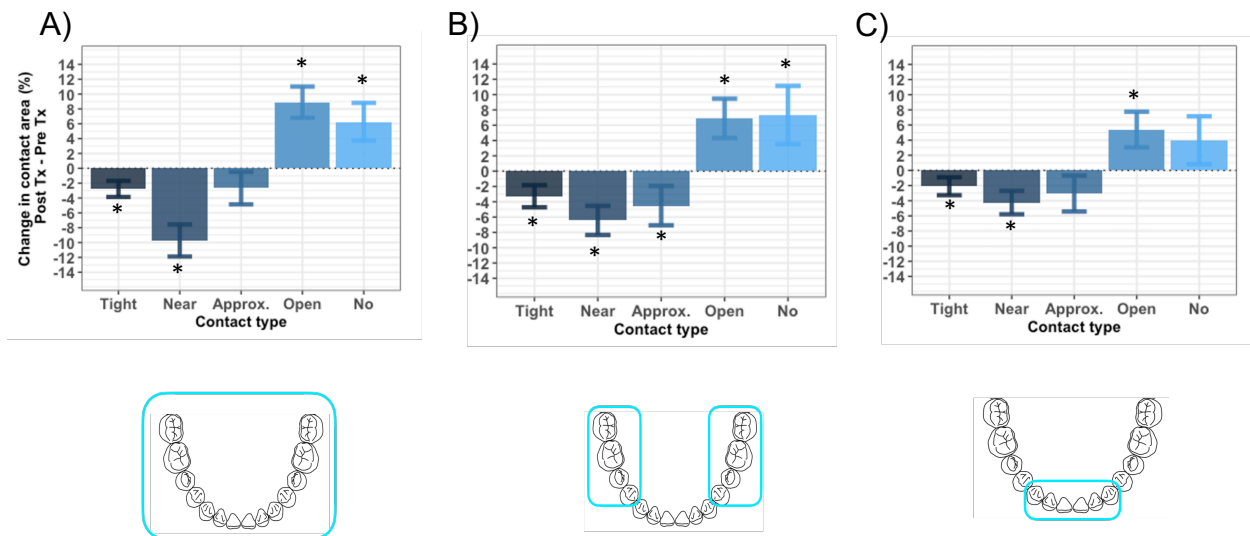
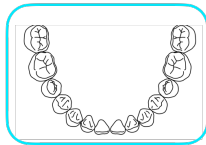
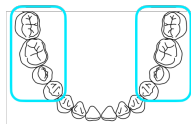


Figure 1. Post-pre treatment change in contact area (%) for total, posterior and anterior dentition after clear aligner treatment. *, adjusted P<0.05

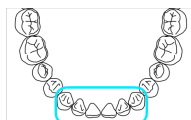
Table 2. Summary of pre-treatment, post-treatment and post-pre treatment statistical results for clear aligner patients. Multivariate analysis of variance (MANOVA) indicated significant post-pre treatment changes for total, posterior and anterior contacts ($P < .0001$).



Contact	N	Pre Tx		Post Tx		Post-Pre Tx	
		Mean (SD)	Mean (SD)	Mean (SD)	95% CI	Adj. P-value	
Tight	44	3.7 (3.7)	0.9 (1.1)	-2.8 (3.6)	(-3.9, -1.7)	0.0000	
Near	44	16.8 (7.2)	7.0 (4.5)	-9.7 (7.1)	(-11.9, -7.6)	0.0000	
Approx.	44	20.8 (3.1)	18.1 (6.0)	-2.7 (7.2)	(-4.9, -0.5)	0.0898	
Open	44	40.6 (6.1)	49.5 (5.6)	8.9 (6.9)	(6.8, 11)	0.0000	
No	44	18.1 (5.1)	24.4 (7.3)	6.3 (8.4)	(3.7, 8.8)	0.0001	



Contact	N	Pre Tx		Post Tx		Post-Pre Tx	
		Mean (SD)	Mean (SD)	Mean (SD)	95% CI	Adj. P-value	
Tight	44	4.0 (5.0)	0.8 (1.2)	-3.3 (4.8)	(-4.7, -1.8)	0.0002	
Near	44	12.7 (6.0)	6.3 (5.0)	-6.4 (6.3)	(-8.3, -4.5)	0.0000	
Approx.	44	21.8 (3.6)	17.3 (7.5)	-4.5 (8.4)	(-7.1, -1.9)	0.0048	
Open	44	42.4 (6.2)	49.3 (7.6)	6.9 (8.4)	(4.3, 9.5)	0.0000	
No	44	19.0 (6.3)	26.3 (11.9)	7.3 (12.5)	(3.5, 11.1)	0.0018	



Contact	N	Pre Tx		Post Tx		Post-Pre Tx	
		Mean (SD)	Mean (SD)	Mean (SD)	95% CI	Adj. P-value	
Tight	44	3.4 (3.8)	1.4 (1.7)	-2.1 (3.9)	(-3.3, -0.9)	0.0046	
Near	44	11.0 (4.8)	6.8 (3.9)	-4.2 (5.1)	(-5.8, -2.7)	0.0000	
Approx.	44	20.7 (4.9)	17.7 (7.0)	-3.1 (7.8)	(-5.4, -0.7)	0.0639	
Open	44	43.6 (5.6)	49.0 (6.4)	5.4 (7.8)	(3.0, 7.8)	0.0002	
No	44	21.2 (6.8)	25.2 (10.6)	4.0 (10.4)	(0.8, 7.1)	0.0750	

3.5 Influence of age on occlusal contact changes after clear aligner treatment

Pre-treatment and post-treatment percentages of each contact type are shown for three age groups: 12-16, 19-28, and 32-53 years old in Figure 2. The analysis was completed for the total (Figure 2A, D), posterior (Figure 2B, E) and anterior dentition (Figure 2C, F). For the pre-treatment total dentition, there were significantly more near contacts in the 19-28 year old group versus 12-16 year old group and more open contacts in the 12-16 year old group versus 19-28 and 32-53 year old groups (Figure 2A). In the pre-

treatment posterior dentition, there were significantly greater open contacts in the 12-16 year old group compared to the oldest age group (Figure 2B). In the pre-treatment anterior dentition there were no significant differences in contact types between the age groups (Figure 2C). Post-treatment, there were no significant differences in occlusal contacts among the age groups for the total, posterior and anterior dentition (Figure 2D, E, F). Statistical analysis for pre-treatment and post-treatment results are displayed in Tables 3-6.

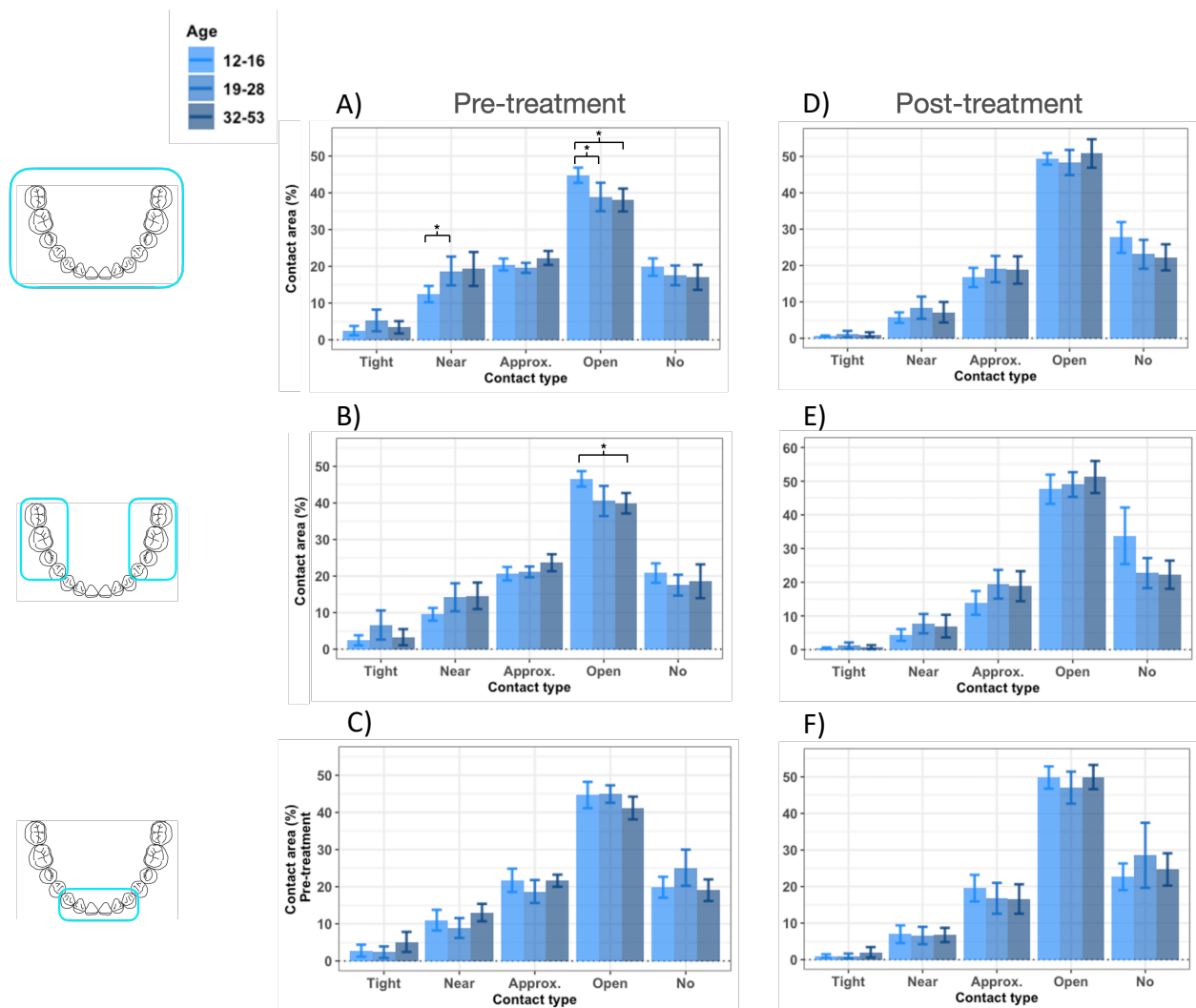
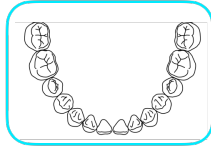
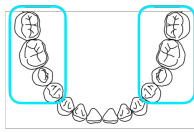


Figure 2. Pre-treatment and post-treatment contact area (%) by age for total, posterior and anterior dentition. *, adjusted P<0.05

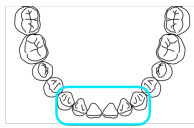
Table 3. Summary of statistical results for differences in pre-treatment total, posterior, and anterior occlusal contacts between all age groups.



Contact	12-16 N=15 ¹	19-28 N=14 ¹	32-53 N=15 ¹	p-value ²	Adj. p-value ³
Tight	2.5 (2.3)	5.3 (5.1)	3.4 (3.0)	0.12	0.62
Near	12.4 (4.0)	18.7 (6.8)	19.3 (8.3)	0.012	0.062
Approx.	20.5 (2.9)	19.6 (2.4)	22.3 (3.4)	0.052	0.26
Open	44.8 (3.7)	38.9 (6.7)	38.0 (5.6)	0.003	0.015*
No contact	19.8 (4.3)	17.5 (4.7)	17.0 (6.1)	0.30	>0.99

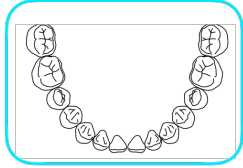


Contact	12-16 N=15 ¹	19-28 N=14 ¹	32-53 N=15 ¹	p-value ²	Adj. p-value ³
Tight	2.4 (2.5)	6.6 (6.9)	3.3 (4.0)	0.055	0.28
Near	9.5 (3.1)	14.2 (6.6)	14.6 (6.6)	0.034	0.17
Approx.	20.7 (3.3)	21.1 (2.5)	23.6 (4.2)	0.051	0.25
Open	46.6 (3.8)	40.5 (7.1)	39.9 (5.1)	0.003	0.015*
No contact	20.8 (4.8)	17.5 (4.9)	18.6 (8.3)	0.36	>0.99

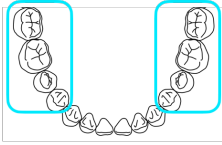


Contact	12-16 N=15 ¹	19-28 N=14 ¹	32-53 N=15 ¹	p-value ²	Adj. p-value ³
Tight	2.8 (2.9)	2.3 (2.7)	5.1 (4.9)	0.10	0.48
Near	11.0 (5.0)	8.9 (4.6)	13.0 (4.2)	0.066	0.33
Approx.	21.7 (5.7)	18.7 (5.3)	21.6 (3.0)	0.18	0.88
Open	44.7 (6.4)	45.0 (4.1)	41.2 (5.5)	0.12	0.61
No contact	19.8 (5.1)	25.1 (8.4)	19.0 (5.3)	0.030	0.15

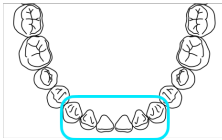
Table 4. Summary of statistical results for differences in pre-treatment total, posterior, and anterior occlusal contacts between pairs of age groups.



Contact	12-16 vs 19-28		12-16 vs 32-53		19-28 vs 32-53	
	P-value ¹	Adj. p-value ¹	P-value ²	Adj. p-value ²	P-value ³	Adj. p-value ³
Tight	0.08	0.39	0.37	1.00	0.24	1.00
Near	0.01	0.03*	0.01	0.05	0.85	1.00
Approx.	0.36	1.00	0.14	0.68	0.02	0.10
Open	0.01	0.04*	0.00	0.00*	0.72	1.00
No contact	0.19	0.94	0.16	0.81	0.79	1.00



Contact	12-16 vs 19-28		12-16 vs 32-53		19-28 vs 32-53	
	P-value ¹	Adj. p-value ¹	P-value ²	Adj. p-value ²	P-value ³	Adj. p-value ³
Tight	0.05	0.23	0.48	1.00	0.13	0.65
Near	0.03	0.14	0.01	0.07	0.87	1.00
Approx.	0.66	1.00	0.04	0.20	0.06	0.32
Open	0.01	0.05	0.00	0.00*	0.79	1.00
No contact	0.08	0.39	0.38	1.00	0.68	1.00



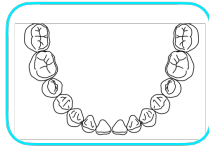
Contact	12-16 vs 19-28		12-16 vs 32-53		19-28 vs 32-53	
	P-value ¹	Adj. p-value ¹	P-value ²	Adj. p-value ²	P-value ³	Adj. p-value ³
Tight	0.69	1.00	0.12	0.61	0.07	0.34
Near	0.25	1.00	0.24	1.00	0.02	0.09
Approx.	0.15	0.76	0.95	1.00	0.09	0.44
Open	0.89	1.00	0.12	0.60	0.05	0.23
No contact	0.06	0.28	0.68	1.00	0.03	0.16

¹Mean (SD)

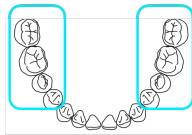
²One-way ANOVA

³Bonferroni correction for multiple testing

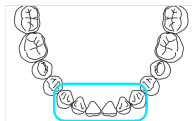
Table 5. Summary of statistical results for differences in post-treatment total, posterior, and anterior occlusal contacts between all age groups.



Contact	12-16 N=15 ¹	19-28 N=14 ¹	32-53 N=15 ¹	p-value ²	Adj. p-value ³
Tight	0.6 (0.3)	1.1 (1.5)	1.0 (1.1)	0.35	>0.99
Near	5.7 (2.6)	8.4 (5.3)	7.1 (5.1)	0.26	>0.99
Approx.	16.7 (4.8)	19.0 (6.3)	18.8 (6.8)	0.53	>0.99
Open	49.3 (2.9)	48.3 (6.0)	50.8 (7.1)	0.49	>0.99
No contact	27.7 (7.6)	23.1 (6.9)	22.3 (6.5)	0.085	0.43

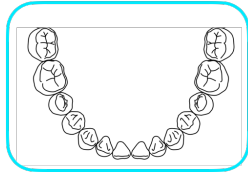


Contact	12-16 N=15 ¹	19-28 N=14 ¹	32-53 N=15 ¹	p-value ²	Adj. p-value ³
Tight	0.4 (0.4)	1.2 (1.6)	0.7 (1.1)	0.21	>0.99
Near	4.3 (3.2)	7.7 (5.0)	7.0 (6.1)	0.16	0.78
Approx.	13.9 (6.3)	19.4 (7.4)	18.8 (8.0)	0.089	0.44
Open	47.6 (7.8)	49.0 (6.3)	51.2 (8.6)	0.43	>0.99
No contact	33.8 (15.2)	22.7 (7.7)	22.2 (7.6)	0.008	0.041

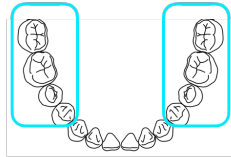


Contact	12-16 N=15 ¹	19-28 N=14 ¹	32-53 N=15 ¹	p-value ²	Adj. p-value ³
Tight	1.0 (0.8)	1.0 (1.2)	2.0 (2.6)	0.18	0.90
Near	6.9 (4.4)	6.6 (4.1)	6.7 (3.5)	0.97	>0.99
Approx.	19.6 (6.6)	16.8 (7.3)	16.6 (7.3)	0.45	>0.99
Open	49.8 (5.5)	47.1 (7.6)	50.0 (6.0)	0.40	>0.99
No contact	22.7 (6.6)	28.6 (15.4)	24.7 (8.0)	0.33	>0.99

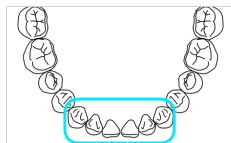
Table 6. Summary of statistical results for differences in post-treatment total, posterior, and anterior occlusal contacts between pairs of age groups.



Contact	12-16 vs 19-28		12-16 vs 32-53		19-28 vs 32-53	
	P-value ¹	Adj. p-value ¹	P-value ²	Adj. p-value ²	P-value ³	Adj. p-value ³
Tight	0.20	1.00	0.15	0.76	0.83	1.00
Near	0.09	0.47	0.33	1.00	0.52	1.00
Approx.	0.28	1.00	0.35	1.00	0.92	1.00
Open	0.58	1.00	0.46	1.00	0.32	1.00
No contact	0.10	0.49	0.04	0.22	0.74	1.00



Contact	12-16 vs 19-28		12-16 vs 32-53		19-28 vs 32-53	
	P-value ¹	Adj. p-value ¹	P-value ²	Adj. p-value ²	P-value ³	Adj. p-value ³
Tight	0.11	0.57	0.28	1.00	0.41	1.00
Near	0.04	0.21	0.15	0.75	0.72	1.00
Approx.	0.04	0.20	0.07	0.36	0.84	1.00
Open	0.60	1.00	0.24	1.00	0.43	1.00
No contact	0.02	0.10	0.02	0.08	0.87	1.00



Contact	12-16 vs 19-28		12-16 vs 32-53		19-28 vs 32-53	
	P-value ¹	Adj. p-value ¹	P-value ²	Adj. p-value ²	P-value ³	Adj. p-value ³
Tight	0.94	1.00	0.16	0.82	0.17	0.86
Near	0.83	1.00	0.89	1.00	0.93	1.00
Approx.	0.30	1.00	0.25	1.00	0.94	1.00
Open	0.28	1.00	0.95	1.00	0.27	1.00
No contact	0.20	1.00	0.46	1.00	0.41	1.00

¹Mean (SD)

²One-way ANOVA

³Bonferroni correction for multiple testing

3.6 Influence of sex on occlusal contact changes after clear aligner treatment

Pre-treatment and post-treatment percentages of each contact type are shown in Figure 3 for males and females. The analysis was completed for the total, posterior and anterior dentition. Sex did not influence total or posterior occlusal contacts in the pre-treatment or post-treatment analysis (Figure 3A, B, D, E). In the pre-treatment anterior, males had significantly greater percent of near contacts whereas females had

significantly greater open contacts (Figure 3C). Post-treatment, there were no significant occlusal differences between males and females in the anterior dentition (Figure 3F). Statistical analysis for pre-treatment and post-treatment results for sex are displayed in Tables 7 and 8.

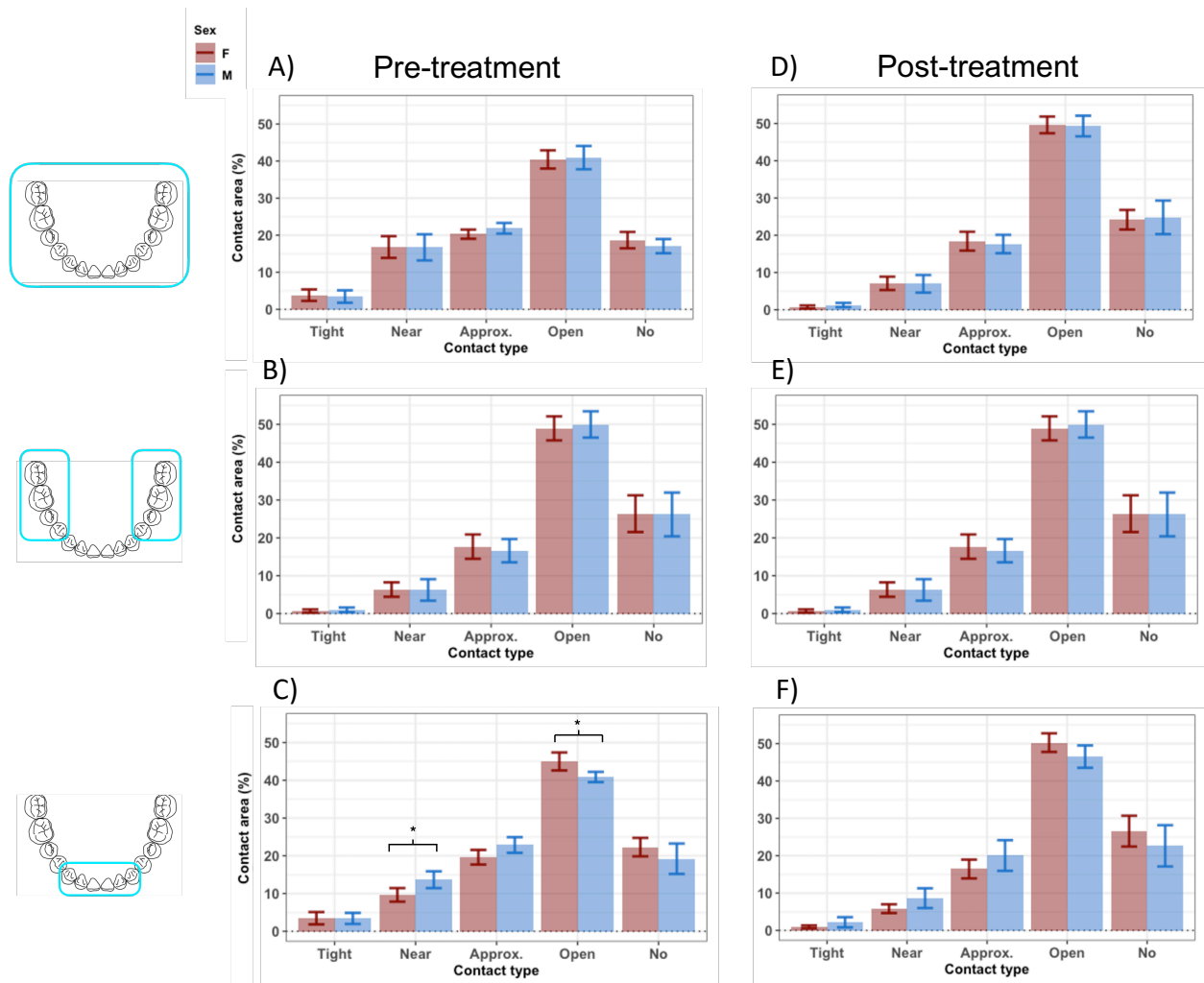
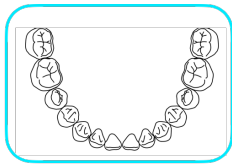
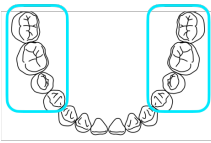


Figure 3. Pre-treatment and post-treatment contact area (%) by sex for total, posterior and anterior dentition. *, adjusted P<0.05

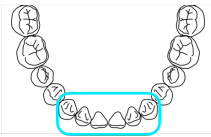
Table 7. Summary of statistical results for differences in pre-treatment total, posterior, and anterior occlusal contacts between sexes.



Contact	Female N=29 ¹	Male N=15 ¹	Difference ²	95% CI ^{2,3}	p-value ²	Adj. p-value ⁴
Tight	3.8 (4.1)	3.4 (3.0)	0.38	-1.83, 2.59	0.73	>0.99
Near	16.8 (7.7)	16.7 (6.4)	0.09	-4.34, 4.52	0.97	>0.99
Approx.	20.3 (3.2)	21.9 (2.6)	-1.59	-3.42, 0.24	0.087	0.43
Open	40.4 (6.5)	40.9 (5.7)	-0.50	-4.36, 3.36	0.79	>0.99
No contact	18.7 (5.8)	17.0 (3.5)	1.62	-1.20, 4.44	0.25	>0.99



Contact	Female N=29 ¹	Male N=15 ¹	Difference ²	95% CI ^{2,3}	p-value ²	Adj. p-value ⁴
Tight	4.2 (5.4)	3.7 (4.3)	0.52	-2.50, 3.53	0.73	>0.99
Near	13.2 (6.4)	11.8 (5.1)	1.43	-2.19, 5.06	0.43	>0.99
Approx.	21.5 (3.7)	22.5 (3.5)	-0.95	-3.28, 1.38	0.41	>0.99
Open	41.9 (6.4)	43.3 (5.7)	-1.46	-5.30, 2.38	0.45	>0.99
No contact	19.2 (6.3)	18.7 (6.6)	0.45	-3.76, 4.66	0.83	>0.99



Contact	Female N=29 ¹	Male N=15 ¹	Difference ²	95% CI ^{2,3}	p-value ²	Adj. p-value ⁴
Tight	3.5 (4.3)	3.4 (2.7)	0.05	-2.07, 2.17	0.96	>0.99
Near	9.6 (4.7)	13.7 (4.0)	-4.01	-6.78, -1.25	0.006	0.029 *
Approx.	19.6 (5.1)	22.9 (3.7)	-3.24	-5.98, -0.50	0.022	0.11
Open	45.0 (6.3)	40.9 (2.5)	4.12	1.45, 6.80	0.003	0.017 *
No contact	22.3 (6.4)	19.2 (7.3)	3.08	-1.49, 7.65	0.18	0.89

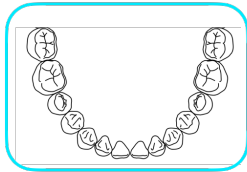
¹Mean (SD)

²Welch Two Sample t-test

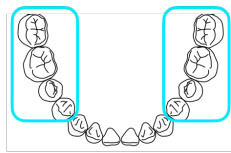
³CI = Confidence Interval

⁴Bonferroni correction for multiple testing

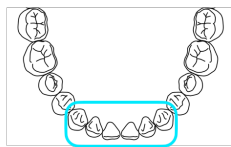
Table 8. Summary of statistical results for differences in post-treatment total, posterior, and anterior occlusal contacts between sexes.



Contact	Female N=29 ¹	Male N=15 ¹	Difference ²	95% CI ^{2,3}	p-value ²	Adj p-value ⁴
Tight	0.7 (1.1)	1.3 (1.0)	-0.53	-1.22, 0.15	0.12	0.61
Near	7.1 (4.7)	7.0 (4.3)	0.12	-2.75, 2.99	0.93	>0.99
Approx.	18.4 (6.7)	17.7 (4.4)	0.75	-2.67, 4.16	0.66	>0.99
Open	49.6 (5.9)	49.3 (5.0)	0.31	-3.14, 3.75	0.86	>0.99
No contact	24.2 (6.9)	24.8 (8.1)	-0.64	-5.72, 4.43	0.80	>0.99



Contact	Female N=29 ¹	Male N=15 ¹	Difference ²	95% CI ^{2,3}	p-value ²	Adj p-value ⁴
Tight	0.6 (1.2)	1.0 (1.1)	-0.34	-1.07, 0.40	0.35	>0.99
Near	6.3 (5.0)	6.2 (5.1)	0.09	-3.22, 3.41	0.95	>0.99
Approx.	17.7 (8.5)	16.6 (5.6)	1.07	-3.23, 5.38	0.62	>0.99
Open	48.9 (8.3)	50.0 (6.3)	-1.03	-5.58, 3.51	0.65	>0.99
No contact	26.4 (12.7)	26.2 (10.4)	0.21	-7.07, 7.49	0.95	>0.99



Contact	Female N=29 ¹	Male N=15 ¹	Difference ²	95% CI ^{2,3}	p-value ²	Adj p-value ⁴
Tight	0.9 (1.0)	2.2 (2.5)	-1.24	-2.64, 0.16	0.079	0.39
Near	5.8 (3.1)	8.6 (4.8)	-2.82	-5.65, 0.01	0.051	0.26
Approx.	16.4 (6.6)	20.0 (7.4)	-3.62	-8.29, 1.05	0.12	0.62
Open	50.3 (6.5)	46.5 (5.4)	3.75	-0.02, 7.51	0.051	0.25
No contact	26.6 (10.8)	22.6 (10.0)	3.93	-2.74, 10.60	0.24	>0.99

¹Mean (SD)

²Welch Two Sample t-test

³CI = Confidence Interval

⁴Bonferroni correction for multiple testing

3.7 Comparison of occlusal contact changes between patients treated with clear aligners and patients treated with full fixed appliances

Pre-treatment and post-treatment percentages of each contact type are shown for Invisalign and fixed appliances (Figure 4). The analysis was completed for the total (Figure 4A, D), posterior (Figure 4B, E) and anterior dentition (Figure 4C, F). There were no significant pre-treatment differences in contacts between patients treated with Invisalign and fixed appliances (Figure 4A, B, C). Post-treatment, there were significant

differences between aligners and fixed appliances for tight contacts only; there were greater percentages of tight contacts in the posterior and total dentition for patients treated with fixed appliances (Figure 4D, E). These differences in post-treatment tight contacts between Invisalign and fixed appliances, however, was only 0.45% for the total dentition and 0.6% for posterior dentition, which is likely not clinically significant (Table 10A, B). Statistical analysis for pre-treatment and post-treatment results for Invisalign and fixed appliances are displayed in Tables 9 and 10.

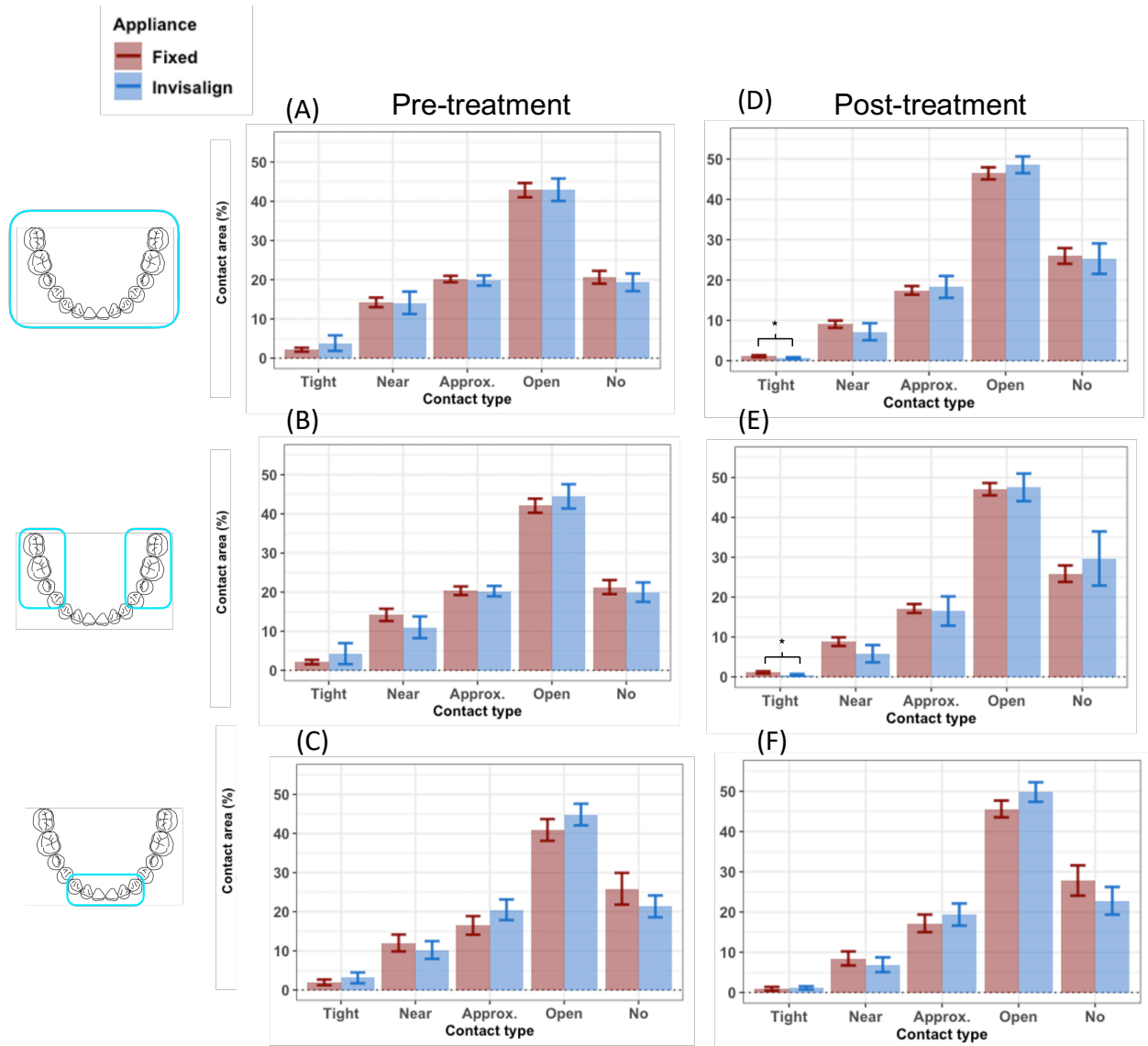
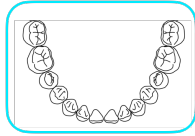
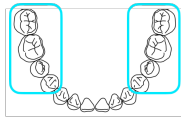


Figure 4. Pre-treatment and post-treatment contact area (%) of Invisalign and fixed appliances for total, posterior and anterior dentition. *, adjusted P<0.05

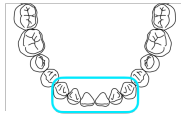
Table 9. Summary of statistical results for differences in pre-treatment total, posterior, and anterior occlusal contacts between Invisalign and fixed appliances.



Contact	Fixed N=36 ¹	Invisalign N=21 ¹	Difference ²	95% CI ^{2,3}	p-value ²	Adj. p-value ⁴
Tight	2.1 (1.5)	3.8 (4.4)	-1.69	-3.72, 0.35	0.10	0.50
Near	14.2 (3.6)	14.1 (6.3)	0.12	-2.95, 3.18	0.94	>0.99
Approx.	20.2 (2.4)	19.8 (2.8)	0.38	-1.11, 1.88	0.61	>0.99
Open	42.8 (5.4)	42.9 (6.3)	-0.10	-3.43, 3.22	0.95	>0.99
No contact	20.6 (4.8)	19.3 (4.9)	1.29	-1.41, 4.00	0.34	>0.99



Contact	Fixed N=36 ¹	Invisalign N=21 ¹	Difference ²	95% CI ^{2,3}	p-value ²	Adj. p-value ⁴
Tight	2.1 (1.7)	4.3 (5.9)	-2.16	-4.88, 0.55	0.11	0.56
Near	14.2 (4.6)	11.0 (6.1)	3.17	0.04, 6.30	0.047	0.24
Approx.	20.3 (3.3)	20.2 (2.9)	0.11	-1.59, 1.80	0.90	>0.99
Open	42.1 (5.3)	44.5 (6.8)	-2.40	-5.92, 1.12	0.17	0.87
No contact	21.3 (5.3)	20.0 (5.4)	1.29	-1.70, 4.27	0.39	>0.99



Contact	Fixed N=36 ¹	Invisalign N=21 ¹	Difference ²	95% CI ^{2,3}	p-value ²	Adj. p-value ⁴
Tight	1.9 (2.1)	3.1 (3.0)	-1.15	-2.68, 0.38	0.13	0.67
Near	12.0 (6.4)	10.2 (5.0)	1.80	-1.26, 4.86	0.24	>0.99
Approx.	16.5 (7.0)	20.5 (5.8)	-4.00	-7.46, -0.54	0.025	0.12
Open	40.9 (8.2)	44.8 (6.1)	-3.94	-7.75, -0.12	0.043	0.22
No contact	25.9 (12.0)	21.4 (6.1)	4.51	-0.32, 9.33	0.066	0.33

¹Mean (SD)

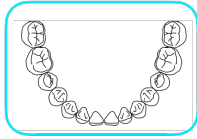
²Welch Two Sample t-test

³CI = Confidence Interval

⁴Bonferroni correction for multiple testing

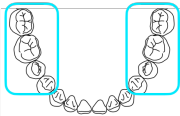
Table 10. Summary of statistical results for differences in post-treatment total, posterior, and anterior occlusal contacts between Invisalign and fixed appliances.

A)



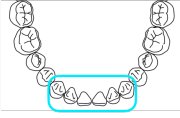
Contact	Fixed N=36 ¹	Invisalign N=21 ¹	Difference ²	95% CI ^{2,3}	p-value ²	Adj p-value ⁴
Tight	1.1 (0.8)	0.7 (0.4)	0.45	0.13, 0.76	0.006	0.032*
Near	9.1 (2.7)	7.2 (4.7)	1.87	-0.41, 4.14	0.10	0.52
Approx.	17.4 (3.2)	18.3 (6.0)	-0.85	-3.73, 2.03	0.55	>0.99
Open	46.4 (4.4)	48.6 (4.6)	-2.12	-4.62, 0.38	0.094	0.47
No contact	26.0 (5.8)	25.3 (8.3)	0.66	-3.51, 4.83	0.75	>0.99

B)



Contact	Fixed N=36 ¹	Invisalign N=21 ¹	Difference ²	95% CI ^{2,3}	p-value ²	Adj p-value ⁴
Tight	1.1 (0.9)	0.5 (0.5)	0.60	0.25, 0.96	0.001	0.007*
Near	8.8 (3.2)	5.8 (4.7)	3.02	0.64, 5.40	0.015	0.073
Approx.	17.1 (3.3)	16.5 (8.1)	0.64	-3.16, 4.44	0.73	>0.99
Open	47.1 (4.6)	47.5 (7.6)	-0.47	-4.20, 3.27	0.80	>0.99
No contact	25.9 (6.1)	29.7 (14.9)	-3.80	-10.84, 3.24	0.28	>0.99

C)



Contact	Fixed N=36 ¹	Invisalign N=21 ¹	Difference ²	95% CI ^{2,3}	p-value ²	Adj p-value ⁴
Tight	0.9 (1.4)	1.1 (0.9)	-0.22	-0.83, 0.39	0.48	>0.99
Near	8.5 (5.2)	6.9 (4.0)	1.57	-0.90, 4.04	0.21	>0.99
Approx.	17.2 (6.5)	19.4 (6.0)	-2.19	-5.62, 1.24	0.21	>0.99
Open	45.6 (6.2)	49.8 (5.3)	-4.20	-7.32, -1.07	0.010	0.048
No contact	27.8 (11.1)	22.8 (7.6)	5.03	0.06, 10.00	0.048	0.24

¹Mean (SD)

²Welch Two Sample t-test

³CI = Confidence Interval

⁴Bonferroni correction for multiple testing

Discussion

The primary purpose of this study was to determine occlusal contact changes that occur during clear aligner treatment. Five types of occlusal contacts were compared between pre-treatment and post-treatment digital models and the influence of age and sex was determined. Occlusal contact changes with clear aligners were then compared to contact changes that occur during treatment with full fixed appliances.

Results indicate that during clear aligner treatment, there is an increase in open and no contacts in the total, posterior and anterior dentition, while the percentage of tight, near

and approximate contacts decrease. These findings indicate that clear aligners reduce contacts between maxillary and mandibular teeth during treatment. Because the tooth movements programmed into the aligner treatment were not analyzed prior to including patients in this study, we can conclude that regardless of the tooth movement programmed, the percentage of open and no contacts increases. This increase could be due to programmed intrusion of teeth or because opposing dentitions do not mesh together as well immediately after the end of treatment as compared to pre-treatment. Post-treatment settling may be needed for the occlusion to be as “tight” as it was prior to treatment.

Age had a significant impact on the percentage of open and no contacts in the total and posterior dentition; younger individuals had greater percentages of open contacts and fewer near contacts prior to treatment. After treatment, however, the percentages of near and open contacts among the age groups studied was the same; this was primarily due to a large increase in the percentage of open contacts and decrease in the percentage of near contacts in older individuals. Younger individuals had changes in the occlusal contacts during treatment, but it was not as large as those seen in the oldest age group. These findings indicate that there are more changes occurring in older individuals “bite” compared to younger individuals during clear aligner treatment, which could explain why older orthodontic patients are sometimes more aware of changes in their occlusion and may experience greater discomfort during treatment.

Based on the study results, sex has a minor influence on occlusal contacts, although there are significant variations in chewing cycle kinematics between males and females (Lepley, et al., 2011). Pre-treatment, females had a greater percentage of open contacts in the anterior compared to males, whereas males had a greater percentage of near contacts. Post-treatment, however, there were no differences in occlusal contacts between males and females.

When comparing fixed appliances and clear aligners, there were no pre-treatment or post-treatment differences in occlusal contacts, indicating that these appliances cause similar changes in occlusal contacts. Both clear aligners and fixed appliances cause a reduction in contacts between maxillary and mandibular teeth. Some clinicians believe that clear aligners may be more likely to cause posterior or anterior openbite, but the results of this study indicate that the occlusal changes that occur with clear aligners and fixed appliances are the same; this reduces the likelihood that posterior open bites are caused by intrusion of the posterior teeth due to occlusal coverage with aligner material. One study suggested that the cause of openbites during clear aligner treatment are likely due to plunging lingual cusps on posterior maxillary molars and/or premature anterior contacts (Morton et al. 2017).

Strengths and Limitations

This study has several strengths and limitations. Strengths of the study are that included patients were treated both in an academic and private practice setting so there is a wide range of clinician experience. In addition, the ages of patients treated in this study

covers a wide range; the youngest patient was 12 and the oldest patient was 56 years old which allowed us to analyze the effects of age on contact changes. Another strength of this study is that because the data analysis for clear aligners was conducted in the same way as for the fixed appliance sample, the occlusal contact data for these appliances could be compared. On the other hand, one limitation of the study is that it had a small sample size and only patients with Class I occlusion were included. In addition, occlusal contacts are only a surrogate for masticatory efficiency, although they have been shown to be directly related. Finally, occlusal contacts were analyzed immediately post debond, therefore changes in occlusal contacts that occur with settling were not incorporated into the data analysis.

Conclusions

- Clear aligners and fixed appliances result in similar occlusal contact changes
- Clear aligners reduce the percentage of near contacts and increase the percentage of open contacts
- Patient age influences how occlusal contacts change during clear aligner treatment; greater changes occur in older individuals
- Sex only influences anterior occlusal contact changes during clear aligner treatment

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Appendix

Table 1. Intra-rater reliability for examiner 1

Measure (%)	1st Measurement Mean (SD)	2nd Measurement Mean (SD)	Diff. (SD) [95% CI]	ICC (95% CI)	D. Error (Min, Max)
PreTx Tight	3.9 (5.1)	3.8 (5.0)	0.0 (0.0) [0.0, 0.1]	1.00 (1.00, 1.00)	0.0 (0.0, 0.1)
PreTx Near	11.1 (9.4)	11.0 (9.4)	0.1 (0.0) [0.0, 0.1]	1.00 (1.00, 1.00)	0.0 (0.0, 0.1)
PreTx Approx.	17.5 (4.2)	17.4 (4.1)	0.1 (0.1) [0.0, 0.1]	1.00 (1.00, 1.00)	0.0 (0.0, 0.1)
PreTx Open	43.8 (9.3)	43.8 (9.3)	-0.1 (0.1) [-0.1, 0.0]	1.00 (1.00, 1.00)	0.1 (0.0, 0.1)
PreTx None	23.8 (9.3)	23.9 (9.3)	-0.1 (0.1) [-0.2, 0.0]	1.00 (1.00, 1.00)	0.1 (0.0, 0.2)
PostTx Tight	0.5 (0.3)	0.5 (0.3)	0.0 (0.0) [0.0, 0.0]	1.00 (1.00, 1.00)	0.0 (0.0, 0.0)
PostTx Near	8.4 (4.7)	8.4 (4.7)	0.0 (0.0) [0.0, 0.1]	1.00 (1.00, 1.00)	0.0 (0.0, 0.1)
PostTx Approx.	20.6 (8.1)	20.6 (8.1)	0.0 (0.1) [-0.1, 0.2]	1.00 (1.00, 1.00)	0.1 (0.0, 0.2)
PostTx Open	47.4 (5.8)	47.4 (5.7)	-0.1 (0.2) [-0.3, 0.1]	1.00 (1.00, 1.00)	0.1 (0.0, 0.3)
PostTx None	23.1 (7.3)	23.1 (7.4)	0.0 (0.2) [-0.3, 0.3]	1.00 (1.00, 1.00)	0.2 (0.0, 0.4)
Post-Pre Tight	-3.3 (5.1)	-3.3 (5.1)	0.0 (0.0) [-0.1, 0.0]	1.00 (1.00, 1.00)	0.0 (0.0, 0.1)
Post-Pre Near	-2.7 (6.6)	-2.7 (6.6)	0.0 (0.0) [-0.1, 0.0]	1.00 (1.00, 1.00)	0.0 (0.0, 0.1)
Post-Pre Approx.	3.2 (9.1)	3.2 (9.1)	0.0 (0.1) [-0.2, 0.1]	1.00 (1.00, 1.00)	0.1 (0.0, 0.2)
Post-Pre Open	3.6 (5.0)	3.6 (5.1)	0.0 (0.1) [-0.2, 0.1]	1.00 (1.00, 1.00)	0.1 (0.0, 0.2)
Post-Pre None	-0.7 (12.2)	-0.8 (12.0)	0.1 (0.3) [-0.2, 0.4]	1.00 (1.00, 1.00)	0.2 (0.1, 0.5)

Table 2. Intra-rater reliability for examiner 2

Measure (%)	1st Measurement Mean (SD)	2nd Measurement Mean (SD)	Diff. (SD) [95% CI]	ICC (95% CI)	D. Error (Min, Max)
PreTx Tight	6.7 (3.7)	6.6 (3.7)	0.1 (0.3) [-0.3, 0.5]	1.00 (0.98, 1.00)	0.2 (0.0, 0.6)
PreTx Near	19.2 (5.8)	21.3 (5.3)	-2.0 (2.7) [-5.4, 1.3]	0.84 (0.23, 0.98)	2.2 (0.0, 6.0)
PreTx Approx.	23.3 (3.6)	22.7 (2.9)	0.6 (0.9) [-0.5, 1.6]	0.96 (0.72, 1.00)	0.7 (0.0, 2.0)
PreTx Open	36.3 (5.8)	35.4 (6.1)	0.9 (1.1) [-0.5, 2.3]	0.98 (0.83, 1.00)	0.9 (0.0, 2.5)
PreTx None	14.6 (2.7)	14.1 (2.8)	0.5 (0.5) [-0.2, 1.1]	0.97 (0.80, 1.00)	0.5 (0.0, 1.1)
PostTx Tight	1.3 (1.3)	1.3 (1.3)	0.0 (0.0) [0.0, 0.0]	1.00 (1.00, 1.00)	0.0 (0.0, 0.0)
PostTx Near	9.3 (7.0)	9.3 (7.0)	0.0 (0.1) [-0.2, 0.2]	1.00 (1.00, 1.00)	0.1 (0.0, 0.2)
PostTx Approx.	21.3 (7.4)	21.4 (7.5)	-0.1 (0.3) [-0.4, 0.3]	1.00 (1.00, 1.00)	0.2 (0.0, 0.5)
PostTx Open	46.7 (7.0)	46.7 (7.0)	0.0 (0.2) [-0.2, 0.2]	1.00 (1.00, 1.00)	0.1 (0.0, 0.2)
PostTx None	21.4 (9.1)	21.3 (9.1)	0.1 (0.3) [-0.3, 0.5]	1.00 (1.00, 1.00)	0.2 (0.0, 0.5)
Post-Pre Tight	-5.4 (2.6)	-5.3 (2.5)	-0.1 (0.3) [-0.5, 0.3]	0.99 (0.95, 1.00)	0.2 (0.0, 0.6)
Post-Pre Near	-9.9 (5.5)	-12.0 (5.3)	2.0 (2.6) [-1.2, 5.2]	0.84 (0.22, 0.98)	2.2 (0.0, 5.8)
Post-Pre Approx.	-2.0 (8.1)	-1.3 (8.0)	-0.6 (1.1) [-2.0, 0.8]	0.99 (0.92, 1.00)	0.8 (0.0, 2.5)
Post-Pre Open	10.5 (5.0)	11.4 (4.8)	-0.9 (1.0) [-2.1, 0.3]	0.97 (0.78, 1.00)	0.9 (0.0, 2.3)
Post-Pre None	6.8 (7.3)	7.2 (7.6)	-0.4 (0.5) [-1.0, 0.3]	1.00 (0.98, 1.00)	0.4 (0.0, 1.1)

Table 3. Inter-rater reliability for examiners 1 and 2

Measure (%)	1st Mean (SD)	2nd Mean (SD)	Diff. (SD) [95% CI]	ICC (95% CI)	D. Error (Min, Max)
PreTx Tight	0.8 (1.0)	0.8 (1.0)	0.0 (0.0) [0.0, 0.0]	1.00 (1.00, 1.00)	0.0 (0.0, 0.0)
PreTx Near	8.6 (5.8)	9.0 (5.7)	-0.5 (1.2) [-2.0, 1.1]	0.98 (0.85, 1.00)	0.8 (0.0, 2.7)
PreTx Approx.	17.6 (4.3)	17.3 (4.1)	0.2 (0.3) [-0.1, 0.5]	1.00 (0.98, 1.00)	0.2 (0.0, 0.7)
PreTx Open	47.7 (4.8)	47.3 (4.5)	0.3 (0.7) [-0.5, 1.1]	0.99 (0.93, 1.00)	0.5 (0.0, 1.5)
PreTx None	25.4 (8.1)	25.5 (8.1)	-0.1 (0.4) [-0.5, 0.3]	1.00 (0.99, 1.00)	0.2 (0.1, 0.5)
PostTx Tight	0.3 (0.2)	0.4 (0.3)	-0.1 (0.1) [-0.2, 0.1]	0.88 (0.37, 0.99)	0.1 (0.0, 0.3)
PostTx Near	5.9 (3.8)	5.9 (3.7)	0.0 (0.1) [-0.1, 0.1]	1.00 (1.00, 1.00)	0.1 (0.0, 0.2)
PostTx Approx.	17.6 (7.9)	17.5 (7.8)	0.1 (0.1) [0.0, 0.2]	1.00 (1.00, 1.00)	0.1 (0.0, 0.2)
PostTx Open	51.3 (4.5)	51.2 (4.4)	0.1 (0.2) [-0.2, 0.4]	1.00 (0.99, 1.00)	0.2 (0.0, 0.5)
PostTx None	24.9 (7.9)	25.0 (7.8)	-0.1 (0.1) [-0.2, 0.0]	1.00 (1.00, 1.00)	0.1 (0.0, 0.2)
Post-Pre Tight	-0.4 (1.1)	-0.4 (1.1)	-0.1 (0.1) [-0.2, 0.1]	0.99 (0.96, 1.00)	0.1 (0.0, 0.3)
Post-Pre Near	-2.7 (6.7)	-3.2 (6.5)	0.5 (1.3) [-1.1, 2.1]	0.98 (0.88, 1.00)	0.9 (0.0, 2.8)
Post-Pre Approx.	0.1 (8.9)	0.2 (8.8)	-0.1 (0.2) [-0.4, 0.1]	1.00 (1.00, 1.00)	0.2 (0.1, 0.5)
Post-Pre Open	3.6 (5.6)	3.9 (5.2)	-0.2 (0.8) [-1.2, 0.7]	0.99 (0.93, 1.00)	0.5 (0.0, 1.6)
Post-Pre None	-0.5 (12.1)	-0.5 (12.1)	0.0 (0.4) [-0.5, 0.5]	1.00 (1.00, 1.00)	0.3 (0.1, 0.7)