Short-term changes in the occlusal contacts during anterior segmental orthodontic treatment with clear aligners in adult patients

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2024년 12월
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Short-term changes in the occlusal contacts during anterior segmental orthodontic treatment with clear aligners in adult patients

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(Directed by Professor Kyung-Ho Kim)

This study evaluated the differences between the predicted and actual occlusal contact areas in adult patients who underwent short-term anterior segmental orthodontic treatment using clear aligners. Since posterior teeth were not subjected to intentional orthodontic forces, this study also enabled a comparative analysis with the initial occlusal state. This retrospective study analyzed digital models obtained from 31 female patients who wore 14 clear aligners. Occlusal contact areas were measured using predicted outcomes from the 14th-stage three-dimensional virtual models (ClinCheck) and actual outcomes from digital models obtained with an intraoral scanner after wearing 14 aligners. The occlusal contact areas were quantified using the ImageJ software, and the

following results were derived:

1. Compared to the predicted occlusal contact areas, the actual occlusal contact areas showed a significant increase in the anterior region (*P* < 0.05*) and a significant decrease in the posterior region (*P* < 0.001***), with the reductions increasing progressively toward the most posterior teeth. Specifically, the actual occlusal contact area exceeded the predicted values by 0.49 mm^2 for central incisors (*P* < 0.01**) and by 0.18 mm^2 for lateral incisors (*P* < 0.05*). The actual contact area was smaller than predicted by 3.09 mm^2 for the first premolars (*P* < 0.01**), 5.44 mm^2 for the second premolars (*P* < 0.001***), 11.46 mm^2 for the first molars (*P* < 0.001***), and 13.42 mm^2 for the second molars (*P* < 0.001***).
2. No significant correlation was found between the differences in anterior and posterior occlusal contact areas. This lack of correlation persisted regardless of the presence or absence of anterior bite ramps.
3. The differences between the predicted and actual occlusal contact areas in both the anterior and posterior regions were not significantly affected by the presence or absence of anterior bite ramps.
4. A significant correlation was observed between the initial overjet and the discrepancy in anterior occlusal contact areas (r = -0.447, *P* < 0.05*). Aside from this, no significant correlations were found between the differences in predicted and actual values and any skeletal or dental characteristics.
5. As age increased, the initial posterior occlusal contact area was larger (r = 0.499, *P* < 0.01**), and a larger initial posterior contact area was associated with a more significant reduction in posterior occlusal contact area (r = -0.868, *P* < 0.001***).

In conclusion, this study demonstrated a significant reduction in posterior occlusal contact areas during short-term anterior segmental orthodontic treatment with clear aligners. This reduction was most pronounced in the following order: second molars > first molars > second premolars > first premolars. Additionally, older patients exhibited more significant reductions in posterior occlusal contact areas.

Keywords: clear aligner, short-term anterior segment orthodontic treatment, predicted and actual occlusal contact areas

I. Introduction

Some patients seeking orthodontic treatment for aesthetic reasons prefer treatment limited to the anterior teeth to shorten the treatment duration, reduce costs, or preserve the existing posterior occlusion. Recently, clear aligners, initially introduced by Harold D. Kesling as a tooth positioner concept during the finishing stage (Kesling, 1945), have gained popularity as an alternative orthodontic appliance for anterior segmental treatments. Since their inception, aligners have evolved through multiple iterations, accompanied by significant technological advancements in recent decades. A prominent example is the Invisalign system, introduced in 1999 by Align Technology (Santa Clara, Calif), which utilizes computer-aided design and manufacturing (CAD/CAM) technology for treatment planning and production. However, due to the morphological characteristics of removable clear aligners that cover all teeth, unintended posterior tooth movement can occur even in anterior segmental orthodontic treatments. Boyd et al. reported that aligners covering the occlusal surfaces may cause slight posterior intrusion, ranging from approximately 0.25 to 0.5 mm (Boyd, Miller, & Vlaskalic, 2000). A study used lateral cephalograms to assess the vertical movement of molars after clear aligner treatment, where neither molar intrusion nor distal movement was planned. An average unplanned molar intrusion of 0.94 mm was observed in 74.2% of the patients. In 15.5% of patients, intrusion occurred only in the maxillary molars, while 32.8% of patients experienced intrusion only in the mandibular molars. In 25.9% of patients, molar intrusion was present in both arches (Talens-Cogollos et al., 2022). This indicates that despite efforts to avoid posterior tooth movement, molar intrusion can occur during clear aligner treatment.

This study employed occlusal contact area as a primary metric to assess the influence of vertical posterior tooth movements on occlusal alterations. Occlusal contact area is widely regarded as an intuitive and reliable method for evaluating occlusal changes as perceived by patients. Quantitative methods for measuring occlusal contacts in the literature include assessing the amount of light passing through holes in dental impression wax, foil, or silicone bite-registration material (Horton, Buschang, Oliver, & Behrents, 2009; Varga et al., 2017; Yurkstas & Manly, 1949) and measuring using digital sensors such as T-scan devices (Tepedino, Colasante, Staderini, Masedu, & Ciavarella, 2023). Numerous studies have investigated occlusal contacts using these methods. One study evaluating Invisalign treatment outcomes for mild to moderate malocclusion using the Model Grading System (MGS) of the American Board of Orthodontics reported that the mean scores improved across all MGS categories after treatment, except for occlusal contacts and occlusal relationships (Kassas, Al-Jewair, Preston, & Tabbaa, 2013). Similarly, a retrospective cohort analysis comparing Invisalign with braces found that while Invisalign and fixed appliances achieved comparable Objective Grading System (OGS) scores for alignment, marginal ridges, interproximal contacts, and root angulation, braces demonstrated significantly superior outcomes in correcting buccolingual inclination, occlusal contacts, occlusal relationships, and overjet (Djeu, Shelton, & Maganzini, 2005).

Digital intraoral scans have become a widely accepted method for obtaining dental models, offering an accurate and reproducible approach to occlusal analysis by leveraging existing patient data (Flügge, Schlager, Nelson, Nahles, & Metzger, 2013). Solaberrieta et al. evaluated a virtual occlusion procedure, comparing it with the conventional method. Various reverse engineering software programs were employed to align the images and calculate deviations. The scanner's software, GOM Inspect Professional (GOM, Braunschweig, Germany), specialized in inspection and mesh processing, while additional software used included Rapidform 3 (Rapidform; INUS Technology) and Geomagic Studio (Geomagic Design X; 3D Systems). Their study concluded that virtual occlusion procedures provide greater accuracy compared to traditional physical interocclusal records (Solaberrieta, Otegi, Goicoechea, Brizuela, & Pradies, 2015). A recent study assessing the effect of clear aligner treatment on occlusal contacts through digital intraoral scans reported a decrease in the percentage of tight, near, and approximating contacts, while the proportion of open and no contacts increased (Frenkel et al., 2024).

A stereolithography (STL) file, generated by scanning the patient's intraoral condition, produces a three-dimensional (3D) digital model. This system incorporates virtual orthodontic treatment (VOT) software, such as ClinCheck (Align Technology, Santa Clara, Calif), which allows clinicians to visualize the progression of 3D treatment models from the initial to the final stages (Wong, 2002). Earlier studies compared the differences between actual and predicted treatment outcomes of three-dimensional ClinCheck models using STL files. Results demonstrated significantly fewer point deductions for occlusal contacts in ClinCheck models compared to posttreatment models (2.0 versus 3.0), based on the Objective Grading System (OGS; American Board of Orthodontics) (Buschang, Ross, Shaw, Crosby, & Campbell, 2015). Bowman et al. analyzed the occlusal contacts of 33 adult patients with Class I mild-to-moderate malocclusion (spacing <4 mm or crowding <6 mm) treated with Invisalign. Their findings revealed that achieved occlusal contacts were significantly less than predicted, both overall and in posterior regions (Bowman, Bowman, Weir, Dreyer, & Meade, 2023). These results align with previous research indicating that ClinCheck models do not accurately represent patients' final occlusion based on OGS criteria at the end of treatment. Furthermore, the achieved posterior occlusal contact was notably less than the pretreatment initial posterior occlusal contact.

Although numerous studies have investigated clear aligner therapy, no research has specifically examined changes in the occlusal contact of molars following short-term orthodontic treatment using aligners while restricting molar movement. Molar movements, such as tipping, rotation, intrusion, and extrusion, can significantly alter the occlusion area during treatment. Therefore, a research design that restricts molar movement is essential for isolating and evaluating the specific effects of clear aligners. This retrospective study aims to address the following objectives: (1) To compare the occlusal contact area predicted by three-dimensional simulations with the actual occlusal contact area after treatment for each tooth; (2) To evaluate the impact of anterior bite ramps on discrepancies between predicted and actual values in the anterior and posterior regions; (3) To assess the influence of age, skeletal, and dental characteristics on discrepancies between predicted and actual occlusal contact areas; (4) To analyze the correlation between age and the initial posterior occlusal contact area, as well as the relationship between the initial posterior occlusal contact area and the differences between predicted and actual occlusal contact areas. The null hypothesis posits that no significant differences exist between the predicted occlusal contacts in the three-dimensional digital treatment plan and the achieved occlusal contacts following clear aligner therapy, under conditions where posterior tooth movement is restricted.

II. Materials and Methods

The study design was approved by the Institutional Review Board of Gangnam Severance Hospital (Institutional Review Board no.3-2024-0390).

1. Subjects

This retrospective study on patients who visited a private dental clinic for orthodontic treatment using Invisalign between February 2022 and February 2024. Informed consent was obtained from all participants before orthodontic treatment. The sample size was calculated using G*Power (version 3.1.9.7; Universität Kiel, Germany) with a 5% significance level and 95% power based on a previous study (Bowman et al., 2023). It suggested that 25 subjects were required as the minimum sample size.

The inclusion criteria were as follows: (1) Digital models scanned intraorally using iTero® Element™ 2 scanner (2017, Align Technology, Santa Clara, Calif; Fig1) at the initial time and after wearing the 14 series of aligners on the upper and lower jaw, (2) patients were treated with Invisalign, a 0.030" thick material called SmartTrack (LD30; Align Technology), (3) Patients aged 18 years or older with completed growth development, (4) Angle Class I to mild Class II molar key, (5) mild-to-moderate malocclusion (spacing <4 mm or crowding of <4 mm), (6) 10-day aligner wearing protocol, (7) Patient compliance with >18-20 hours per day.

Fig 1. Intraoral scanning with the iTero® Element™ 2 scanner

The exclusion criteria were as follows: (1) Patients with at least one moved posterior tooth, (2) patients with a history of premolar extraction or with at least one missing posterior tooth, (3) using inter-arch elastics, (4) Periodontally compromised patients, (5) Patients who received prosthetic treatment during orthodontic treatment, (6) Patients who have a bridge or dental implant on posterior teeth.

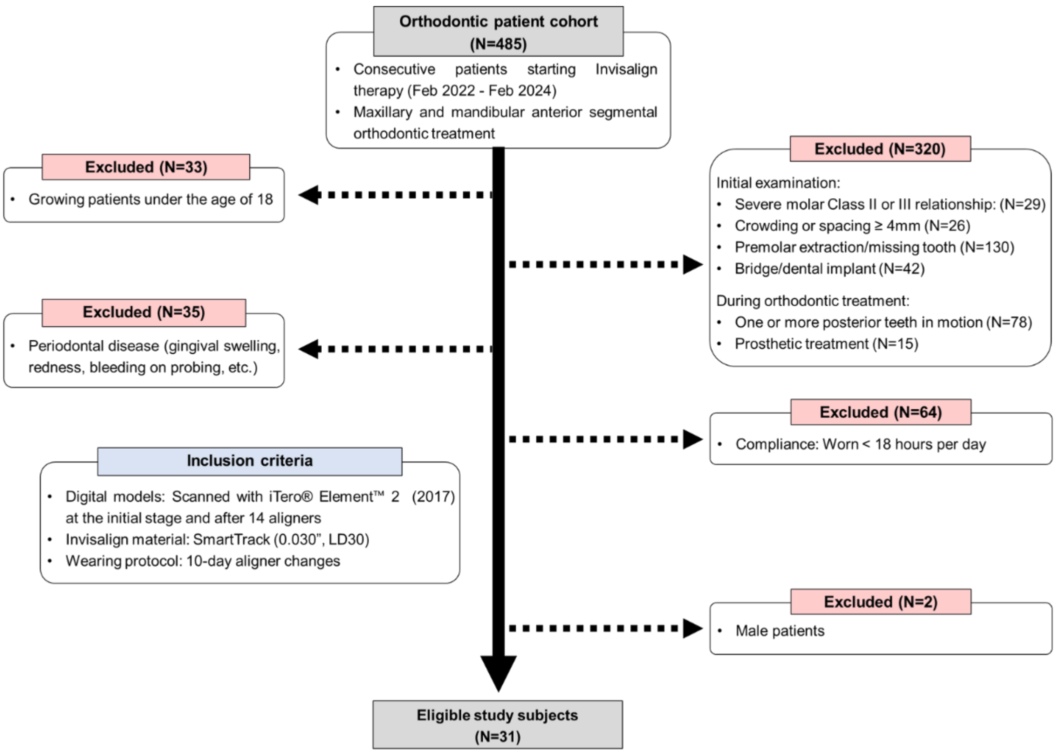

Fig 2. Flow diagram of patients selected in this retrospective study

Of the 2440 patients received at the clinic, 33 (2 males, 31 females) patients satisfied the inclusion criteria (Fig 2). However, because of a gender imbalance, it was decided to exclude the male patients from the statistical analysis. Most patients (28 out of 31) exhibited pretreatment crowding, while three showed mild spacing. When mild crowding was resolved, incisor movement was primarily prescribed using interproximal reduction (IPR) to maintain the initial anteroposterior position. Additionally, to achieve an ideal overbite (OB), slight intrusive movement occurred in the anterior teeth. Attachments on the maxillary posterior teeth were automatically placed on the first premolars only when necessary for appliance retention or when the anterior intrusion was required.

The clinician manually applied the precision bite ramps on the lingual surface of the maxillary anterior aligners when it was determined during treatment that the anterior overbite had deepened significantly. Of the patients, 16 had the anterior bite ramps applied, while 15 did not.

2. Measurement of occlusal contact areas

The occlusal contact area was obtained in the maxilla before treatment and after wearing the 14 series of aligners. Previous studies that primarily examined the initial treatment effects of clear aligners generally observed treatment durations between 3 to 6 months (Tepedino et al., 2023; Winocur, Davidov, Gazit, Brosh, & Vardimon, 2007). Consequently, this study focused on patients who wore 14 aligners, each replaced on a 10-day schedule. The initial view is based on the frontal view (canting, frontal inclination, and midline deviation) to determine the initial position. The program algorithm automatically generates the occlusal view by selecting the 'Maxillary Occlusal Surface' button in the top toolbar of ClinCheck (version 6.0, Align Technology). Pressing the 'Grid' button generates a 1 mm scale grid on the maxillary occlusal surface. In this occlusal view, pressing the 'Occlusion' button displays the occlusal contact points. Using the ' occlusion map ' tool, these red contact points indicate areas with an occlusal clearance of 0.00 mm in the heatmap. This tool displays occlusal contacts through a color scale—a feature introduced in ClinCheck version 6.0 (Fig 3). A simpler view is also available, where green areas on the occlusal surface indicate an occlusal clearance of 0.00 mm in the heatmap, while teeth marked in gray represent no movement (Fig 4). These images were captured and used for occlusal contact area measurements. Captured images were imported into the image analysis software (ImageJ; version 1.54k, National Institutes of Health, Bethesda, Md) for calibration and area measurements. The occlusal contact area outline was selected by clicking with the wand (tracing) tool, and the ImageJ program automatically calculated the area in square millimeters (mm^2) (Fig 5) (Kara & Yilmaz, 2020). All digital scan data showed occlusal contacts at the initial and final stages at maximum intercuspation.

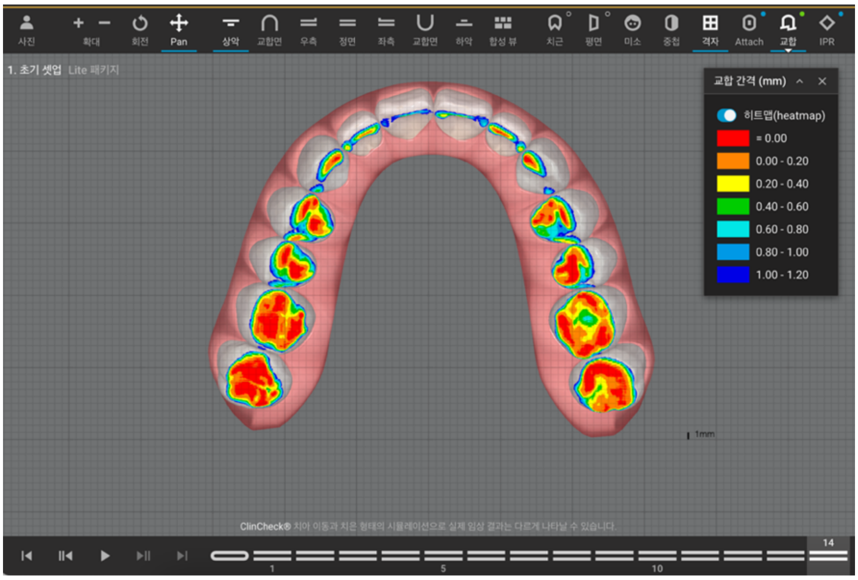

Fig 3. Occlusion map tool showing occlusal contacts using a color scale

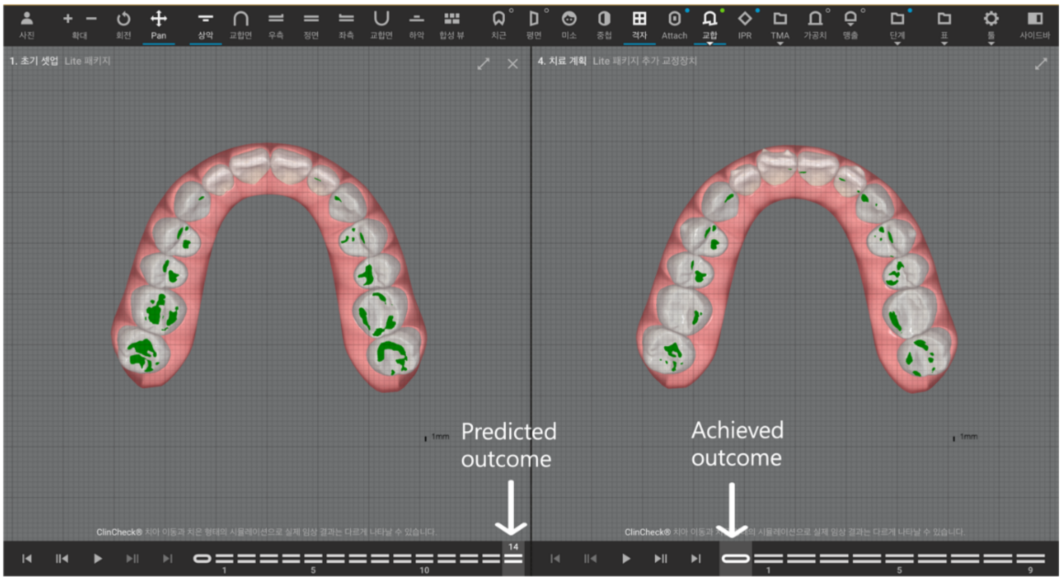

Fig 4. Green points matching red points on the color-scale heatmap, indicating occlusal clearance of 0.00 mm, with light gray teeth representing no movement (Left: Predicted status after wearing 14-series aligners; Right: Actual status after wearing 14-series aligners)

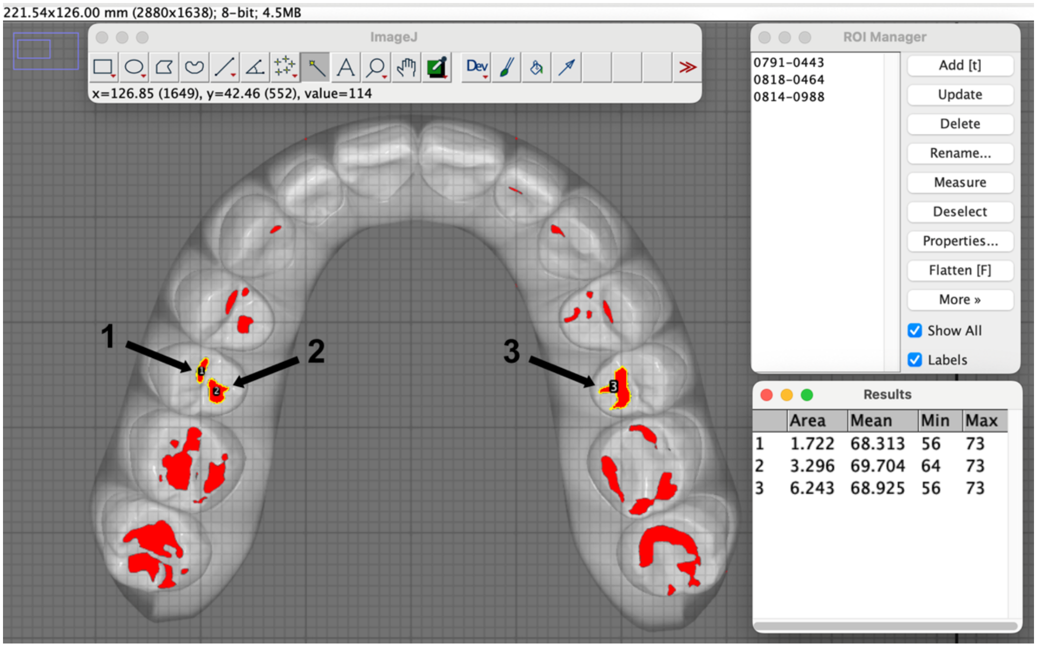

Fig 5. Occlusal contact area measurement of left and right second premolars using ImageJ: Red areas represent threshold-adjusted measurements, yellow lines indicate selected regions (show all enabled), and the results box displays values for regions 1, 2, and 3

3. Skeletal and dental evaluation

To evaluate skeletal characteristics, we measured the following parameters on lateral cephalograms at baseline: SNA (angle formed by the Sella-nasion plane and nasion-A point line), SNB (angle formed by the Sella-nasion plane and nasion-B point line), ANB (angle formed by the nasion-A point line and nasion-B point line), Wits appraisal, posterior facial height (distance from the Sella to the Gonion), anterior facial height (distance from the anterior nasal spine to the Menton), Facial Height Ratio (PFH/AFH), SN-GoMe (angle formed by the Sella-nasion plane and mandibular plane), Gonial angle. The dental characteristics were measured by assessing the overjet and overbite.

4. Statistical Analysis

SPSS software (version 29.0; IBM, Armonk, NY) was used for all statistical analyses in this study. To assess intraexaminer reliability, 20% of the sample was randomly selected and remeasured two weeks after the initial assessment. An intraclass correlation coefficient with Shrout–Fleiss derivation evaluated the measures' reliability. Normality was assessed using the Shapiro-Wilks test. Changes in skeletal and dental characteristics before and after treatment were assessed using a paired t-test. Wilcoxon signed-rank test was performed to determine statistically significant differences between the predicted and achieved occlusal contacts. The correlation analysis between the anterior and posterior occlusal area changes was conducted using the Spearman rank-order correlation coefficient. Pearson's correlation coefficient and simple linear regression analyses were employed to investigate whether changes in occlusal contact area are influenced by the patient's age, skeletal characteristics, dental characteristics, and initial occlusal contact area. P <0.05 was regarded as statistically significant.

III. Results

The same operator repeated all measurements after a 2-week interval to calculate intraoperator error using intraclass correlations. The intraclass correlation coefficient demonstrated excellent reproducibility for the angular measurements (0.97), linear measurements (0.95) on lateral cephalograms, and area measurements (0.94).

1. Skeletal and dental changes with clear aligner treatment

The ages of female patients in the clear aligner sample ranged from the teens to the sixties. The age was 36.3 ± 13.0 years (mean ± standard deviation), and the 95% confidence interval ranged from 31.6 to 41.1 years. The treatment duration was 142.5 ± 9.9 days (mean ± standard deviation), and the 95% confidence interval ranged from 139.3 to 145.8 days. The lateral cephalogram shows pretreatment and posttreatment skeletal and dental characteristics. Table I shows no statistically significant differences in skeletal and dental measurements before and after wearing 14 aligner devices.

Table I. Pretreatment and posttreatment characteristics in lateral cephalometric analysis

Variables	***Pretreatment***	***Posttreatment***	**P** ***value***
Skeletal			
A-P relationships			
SNA (°)	81.9 ± 2.6 (80.9 - 82.8)	82.0 ± 2.7 (81.1 - 83.0)	0.121
SNB (°)	78.5 ± 3.7 (77.1 - 79.8)	78.7 ± 3.6 (77.3 - 80.0)	0.141
ANB difference (°)	3.4 ± 2.4 (2.5 - 4.3)	3.4 ± 2.2 (2.6 - 4.2)	0.817
Wits appraisal (mm)	-1.6 ± 3.2 (-2.7 - -0.4)	-1.1 ± 2.8 (-2.1 - -0.1)	0.135
Vertical relationships			
PFH (mm)	75.6 ± 1.7 (75.0 - 76.3)	75.5 ± 1.8 (74.8 - 76.2)	0.306
AFH (mm)	116.1 ± 4.7 (114.4 - 117.8)	115.9 ± 4.6 (114.2 - 117.6)	0.405
Facial Height Ratio	0.7 ± 0.0 (0.6 - 0.7)	0.7 ± 0.0 (0.6 - 0.7)	0.874
SN-GoMe (°)	36.2 ± 3.9 (34.8 - 37.6)	35.9 ± 4.4 (34.3 - 37.5)	0.202
Gonial angle (°)	123.4 ± 5.3 (121.5 - 125.3)	123.2 ± 5.2 (121.2 - 125.1)	0.644
Dental			
Overjet (mm)	3.6 ± 1.0 (3.2 - 3.9)	3.4 ± 0.7 (3.2 - 3.7)	0.372
Overbite (mm)	2.2 ± 1.4 (1.7 - 2.8)	2.3 ± 0.9 (2.0 - 2.6)	0.792

Note. Values are mean ± standard deviation (95% confidence interval).

PFH, posterior facial height; AFH, anterior facial height

Paired sample t-test

2. Predicted versus actual occlusal contact areas

Table II presents the mean predicted and actual contact areas for each tooth, as well as for the grouped anterior and posterior segments, along with the differences between these values. Statistically significant changes were observed in all teeth except for the canines. The actual contact area exceeded the predicted value by 0.49 mm^2 (P <0.01**) for the central incisors and by 0.18 mm^2 (P <0.05*) for the lateral incisors. The actual contact area was smaller than predicted by 3.09 mm^2 (P <0.01**) for the first premolars, 5.44 mm^2 (P <0.001***) for the second premolars, 11.46 mm^2 (P <0.001***) for the first molars, and 13.42 mm^2 (P <0.001***) for the second molars. Within the posterior tooth group, the discrepancies in occlusal contact area were found to increase significantly toward the most posterior teeth. When divided into anterior and posterior tooth groups, the differences in the occlusal area of the anterior teeth increased considerably by a total of 0.89 mm^2 (P <0.05*). In contrast, the differences in the occlusal contacts of the posterior teeth decreased significantly by a total of 33.41 mm^2 (P <0.001***) (Fig 6, 7). The captured samples of four patients in the measurement demonstrate this trend (Fig 8).

Table II. Predicted and actual maxillary occlusal contact areas and differences

Variables	*Contact area (mm^2)*			
	Predicted	***Actual***	***Actual - predicted***	**P** ***value***
Individual teeth				
central incisors	0.21 ± 0.58 (-0.38~0.79)	0.70 ± 1.23 (0~1.93)	0.49 ± 0.81 (-0.32~1.29)	<0.01**
lateral incisors	0.22 ± 0.49 (-0.27~0.71)	0.40 ± 0.45 (0~0.85)	0.18 ± 0.58 (-0.4~0.76)	<0.05*
canines	1.16 ± 1.94 (-0.78~3.11)	1.39 ± 1.59 (0~2.98)	0.22 ± 2.16 (-1.94~2.38)	0.284
first premolars	10.02 ± 7.89 (2.12~17.91)	6.93 ± 4.89 (2.04~11.82)	-3.09 ± 6.29 (-9.37~3.2)	<0.01**
second premolars	9.15 ± 6.96 (2.19~16.12)	3.71 ± 3.17 (0.54~6.88)	-5.44 ± 6.65 (-12.09~1.2)	<0.001***
first molars	18.95 ± 14.6 (4.36~33.55)	7.50 ± 9.36 (0~16.86)	-11.46 ± 12.32 (-23.78~0.86)	<0.001***
second molars	25.58 ± 15.58 (10~41.16)	12.16 ± 9.78 (2.38~21.94)	-13.42 ± 12.46 (-25.88~-0.96)	<0.001***
Anteriors	1.59 ± 2.30 (0.75~2.44)	2.48 ± 2.21 (1.67~3.29)	0.89 ± 2.69 (-0.10~1.88)	<0.05*
Posteriors	63.71 ± 36.56 (50.30~77.16)	30.30 ± 18.26 (23.60~37.00)	-33.41 ± 30.02 (-44.42~-22.40)	<0.001***

Note. Values are mean ± standard deviation (95% confidence interval).

Anteriors, canine to canine; Posteriors, first premolars to second molars on both sides

*Statistically significant differences between predicted and actual outcomes (Wilcoxon signed-rank test: **P* <0.05, ***P* <0.01, ****P* <0.001)

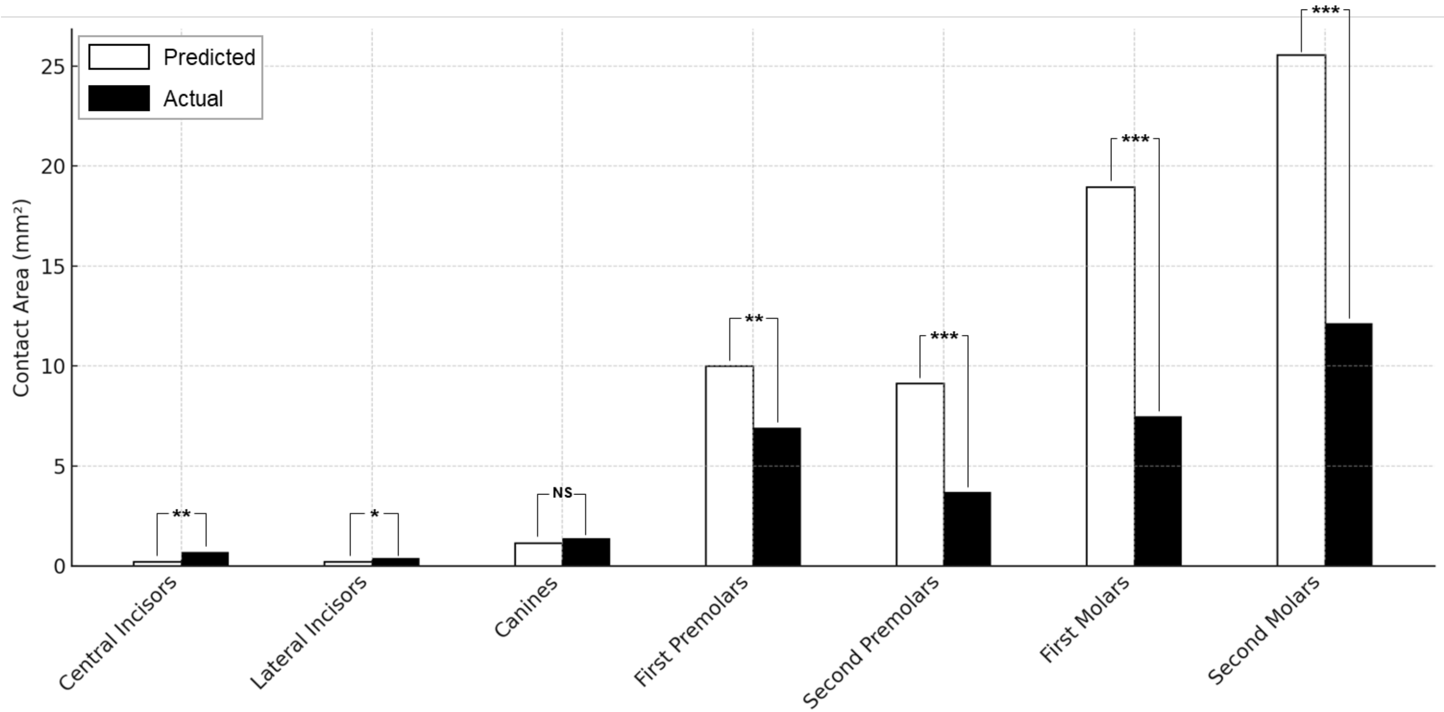

Fig 6. Predicted and actual mean maxillary occlusal contact areas for each tooth after 14 clear aligners (*Statistically significant differences: *P <0.05, **P <0.01, ***P <0.001; NS: Not significant)

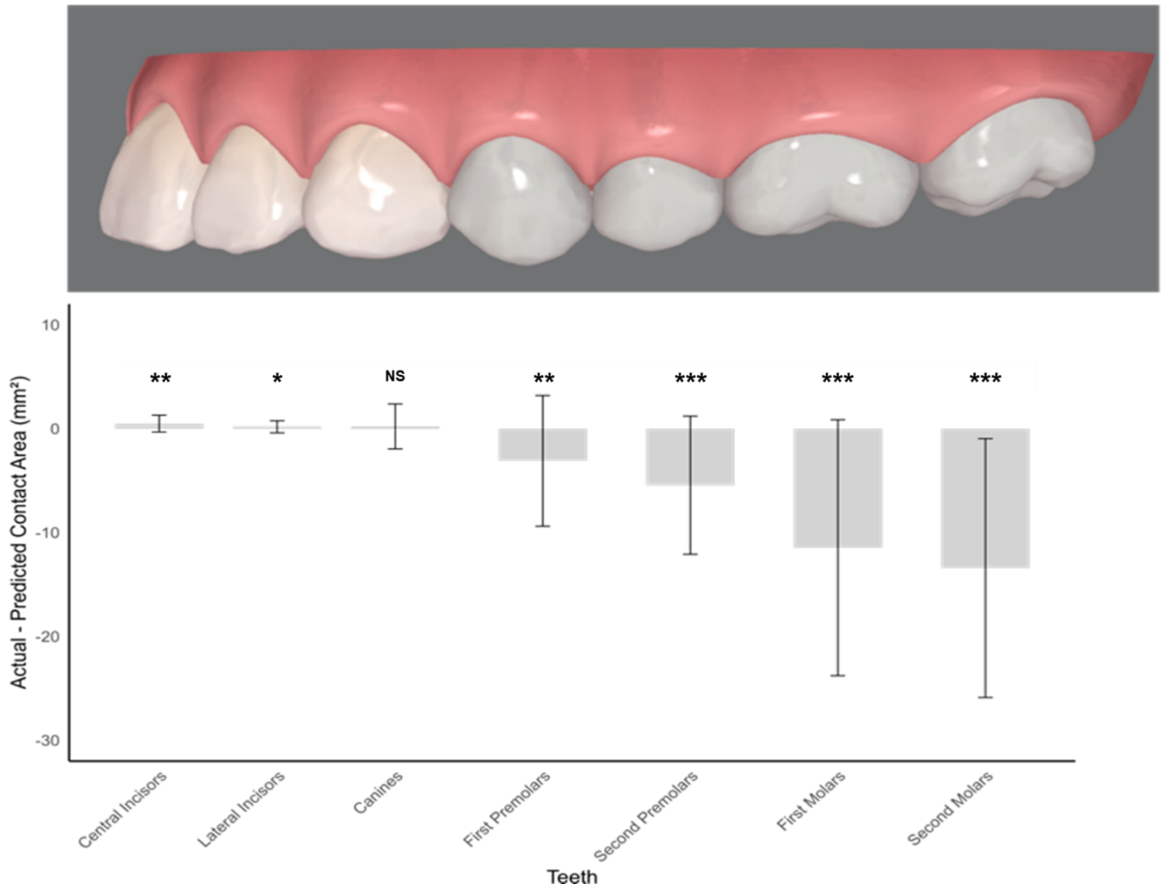

Fig 7. Differences between predicted and actual maxillary occlusal contact areas after wearing 14 clear aligners (*Statistically significant differences: *P <0.05, **P <0.01, ***P <0.001; NS: Not significant)

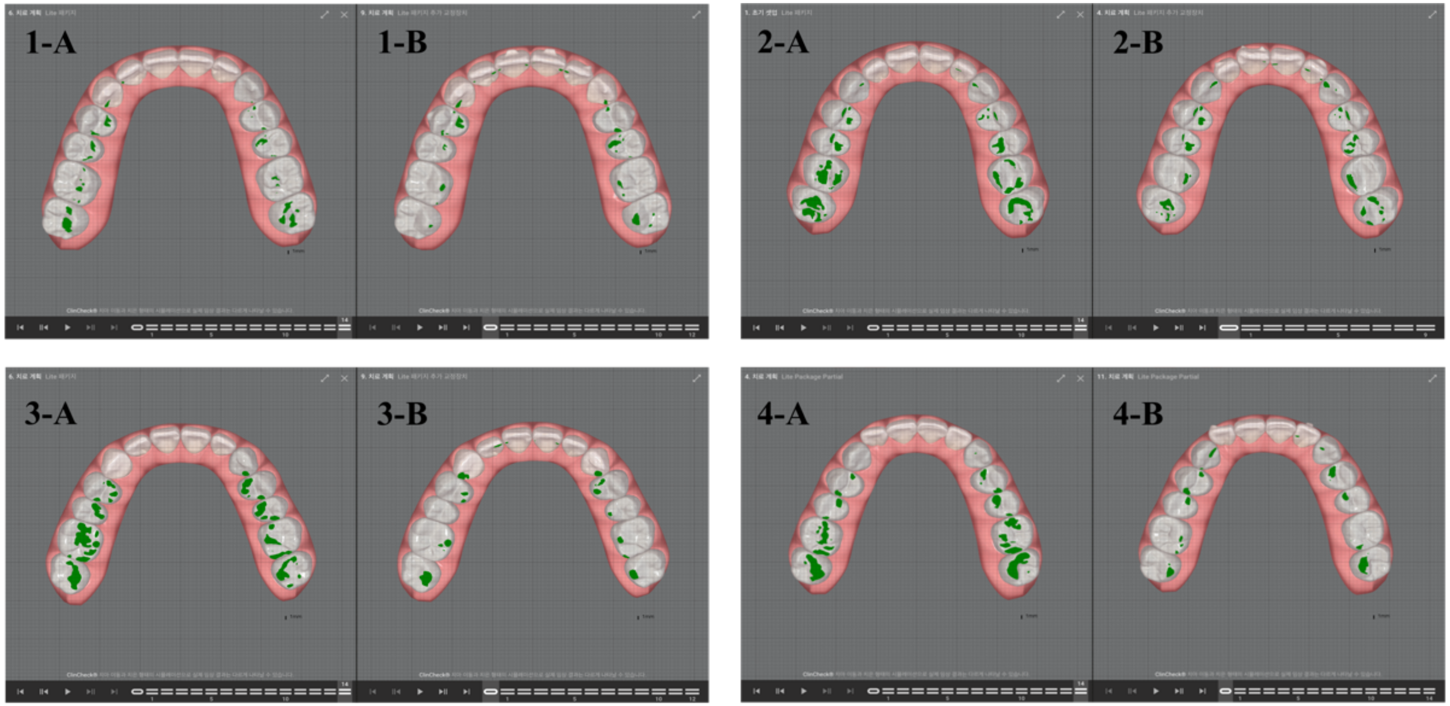

Fig 8. The four representative samples of patients demonstrating study trends: A, predicted occlusal surface; B, actual occlusal surface after wearing 14 aligners

3. Correlation analysis of anterior and posterior occlusal contact differences and impact of anterior Bite Ramps

The correlation analysis between the predicted and actual occlusal contact area differences in the anterior and posterior regions revealed a weak positive correlation. However, the correlation coefficient was minimal ($\rho < 0.00001$), indicating that the contact area differences between the two regions do not significantly influence each other. To further explore this, each region's differences in occlusal contact areas were analyzed by dividing the groups based on the presence or absence of bite ramps. This approach allowed for examining how the presence or absence of bite ramps influences the relationship between anterior and posterior contact area differences. When bite ramps were absent, the Spearman correlation coefficient between anterior and posterior occlusal contact area differences was -0.097. This value indicated a weak negative correlation. However, as the coefficient was very close to zero, it suggests that there is likely no significant relationship between the two variables. When bite ramps were present, the Spearman correlation coefficient was 0.102, indicating a weak positive correlation. Nevertheless, this value was also very close to zero, suggesting that there is likely no significant relationship between the two variables. In conclusion, the presence or absence of bite ramps does not appear to result in a significant correlation between anterior and posterior occlusal contact area differences (Table III).

Table III. Correlation analysis of predicted versus actual anterior and posterior occlusal contact areas and impact of anterior Bite ramps

		Contact area (mm^2)								
		Predicted		***Actual***		***Actual - predicted***			***ρ***	**P'** ***value***
		Mean	***SD***	***Mean***	***SD***	***Mean***	***SD***	**P** ***value***		
Total (n=31)	Anteriors	1.59	2.30	2.48	2.21	0.89	2.69	<0.05*	0.00002102	<0.001***
	Posteriors	63.71	36.56	30.30	18.26	-33.41	30.02	<0.001***		
without Bite ramps (n=15)	Anteriors	0.45	1.05	0.85	1.36	0.40	1.23	<0.01**	-0.097	0.528
	Posteriors	16.38	13.75	6.99	7.65	-9.39	11.58	<0.001***		
with Bite ramps (n=16)	Anteriors	0.61	1.46	0.81	1.14	0.20	1.48	<0.05*	0.102	0.489
	Posteriors	15.50	13.51	8.12	8.12	-7.38	9.69	<0.001***		

Anteriors, canine to canine; Posteriors, first premolars to second molars on both sides

*Statistically significant differences between predicted and achieved outcomes (Wilcoxon signed-rank test: **P* <0.05, ***P* <0.01, ****P* <0.001)

*Statistically significant correlation between predicted and achieved outcomes in the anterior and posterior areas

(ρ, Spearman rank-order correlation coefficient: ****P'* <0.001)

4. Effect of anterior Bite Ramps on occlusal contact area discrepancies in the anterior and posterior regions

Table IV shows that regardless of bite ramps, the actual contact areas exceeded the predicted values in the anterior region. In contrast, the actual contact areas were smaller than the predicted values in the posterior region. The differences based on the presence or absence of bite ramps are not statistically significant (P >0.05) (Fig 9).

Table IV. Effect of anterior Bite ramps on predicted and actual occlusal contact area discrepancies in anterior and posterior teeth

Variables	*Bite ramps*	*Actual - predicted contact area (mm²)* Mean	SD	P *value*
Anteriors	without (n=15)	0.40	1.23	0.828
	with (n=16)	0.20	1.48	
Posteriors	without (n=15)	-9.39	11.58	0.467
	with (n=16)	-7.38	9.69	

Anteriors, canine to canine; Posteriors, first premolars to second molars on both sides

The Mann-Whitney U Test compared the with and without bite ramp groups in anterior teeth.

The independent t-test compared the with and without bite ramp groups in posterior teeth.

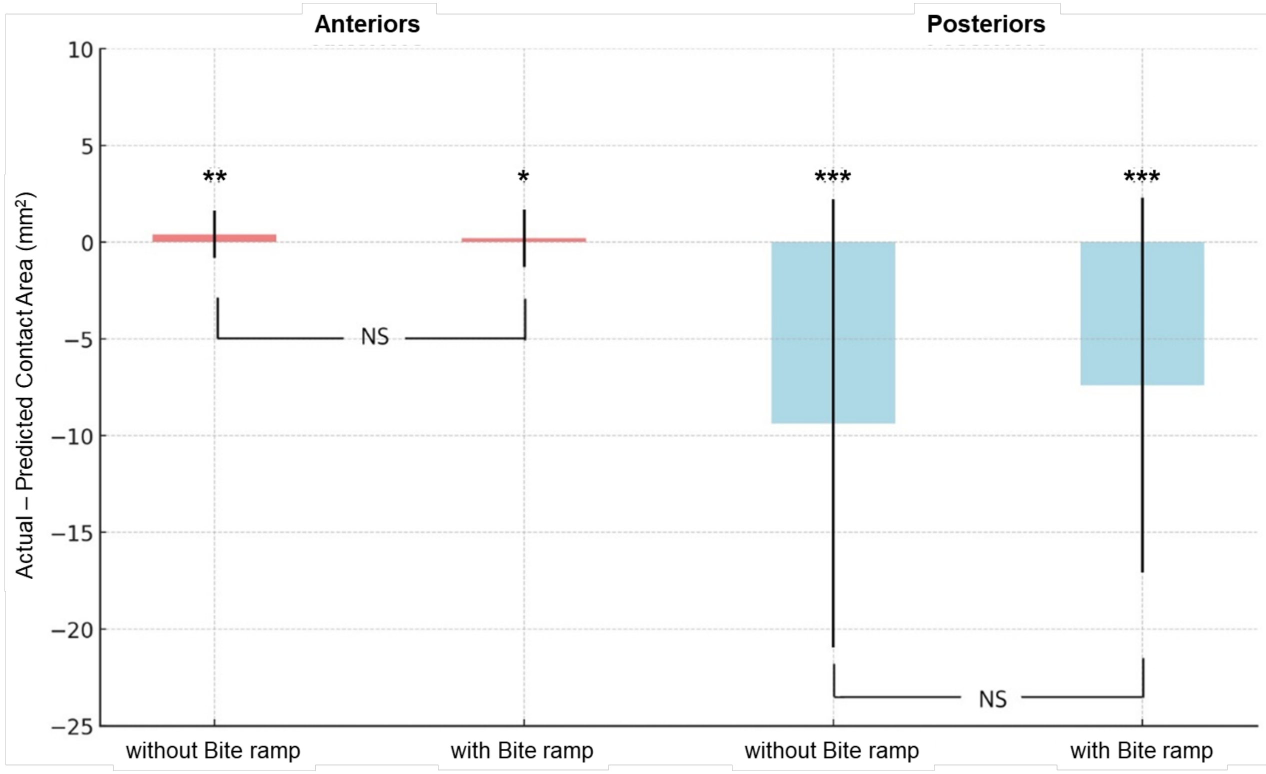

Fig 9. Discrepancies between predicted and actual occlusal contact areas in anterior and posterior teeth based on the presence or absence of Bite ramps (*Statistically significant differences: *P <0.05, **P <0.01, ***P <0.001; NS: Not significant)

5. Correlation between age, skeletal and dental characteristics, and occlusal contact area discrepancies

Table V presents Pearson's correlation analysis results examining the relationship between initial patient age, skeletal or dental characteristics, and the discrepancies between the predicted and actual occlusal contact areas. The study revealed a statistically significant negative correlation between posterior occlusal contact area discrepancies and age ($r = -0.434$, $P < 0.05$*), indicating that the reduction in posterior contact area increases with age (Fig 10). For anterior teeth, the discrepancies between the predicted and actual contact area showed a statistically significant negative correlation only with overjet (OJ) ($r = -0.447$, $P < 0.05$*), suggesting that as OJ increases, the extent of increase in anterior contact area decreases (Fig 11).

Table V. Correlation between baseline characteristics and discrepancies of predicted and actual occlusal contact areas

	Actual - predicted contact area (mm²)			
	Anteriors		***Posteriors***	
Variables	***r***	**P** ***value***	***r***	**P** ***value***
Age (y)	-0.302	0.098	-0.428	0.016*
Skeletal				
A-P relationships				
SNA (°)	0.248	0.179	-0.267	0.146
SNB (°)	0.301	0.100	-0.223	0.228
ANB difference (°)	-0.192	0.300	0.052	0.783
Wits (mm)	-0.139	0.457	0.044	0.813
Vertical relationships				
PFH (mm)	0.044	0.813	0.106	0.569
AFH (mm)	0.080	0.670	0.051	0.785
Facial Height Ratio	-0.061	0.744	0.017	0.930
SN-GoMe (°)	-0.017	0.927	0.162	0.384
Gonial angle (°)	0.016	0.933	-0.286	0.119
Dental				
Overjet (mm)	-0.447	0.012*	0.160	0.390
Overbite (mm)	-0.189	0.308	0.057	0.761

Anteriors, canine to canine; Posteriors, first premolars to second molars on both sides

PFH, posterior facial height; AFH, anterior facial height

*Statistically significant (Pearson's Correlation coefficient: *P <0.05).

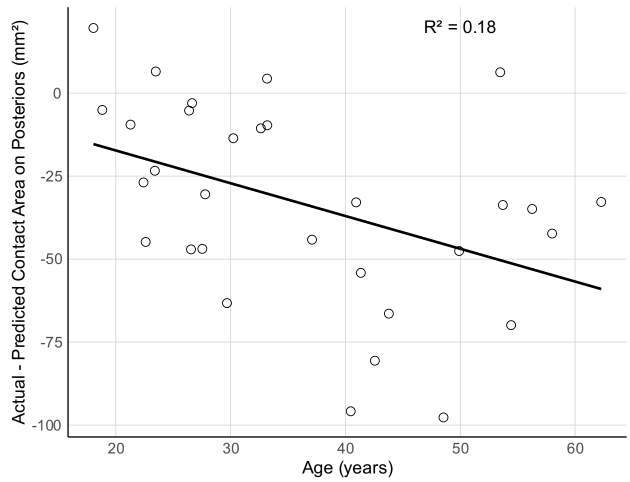

Fig 10. Correlation between patient age and discrepancies between predicted and actual maxillary posterior occlusal contacts

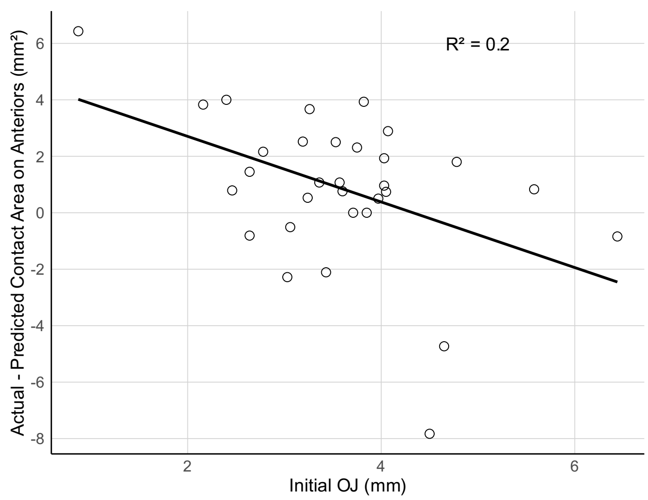

Fig 11. Correlation between initial overjet and discrepancies between predicted and actual maxillary anterior occlusal contacts

6. Correlation between age, initial posterior contact area, and changes in posterior occlusal contact

The age distribution of the patients was as follows: two patients were aged 18 to 19 years, eleven were aged 20 to 29 years, five were aged 30 to 39 years, seven were aged 40 to 49 years, five were aged 50 to 59 years, and one patient, aged 62 years, was in their 60s. Age and the initial posterior occlusal contact area showed a significant positive correlation (Fig 12). In contrast, a significant negative correlation was found between the initial posterior occlusal contact area and the posterior occlusal contact area changes (Fig 13) (Table VI).

Table VI. Initial maxillary posterior occlusal contacts: correlations with age and posterior occlusal contact area changes

	Initial posterior contact area (mm²)	
Variables	***r***	**P *value***
Age (y)	0.495	<0.01**
△ *Posterior contact area (mm²)*	-0.868	<0.001***

*Statistically significant (Pearson's Correlation coefficient: ***P*** <0.01, ****P*** <0.001).

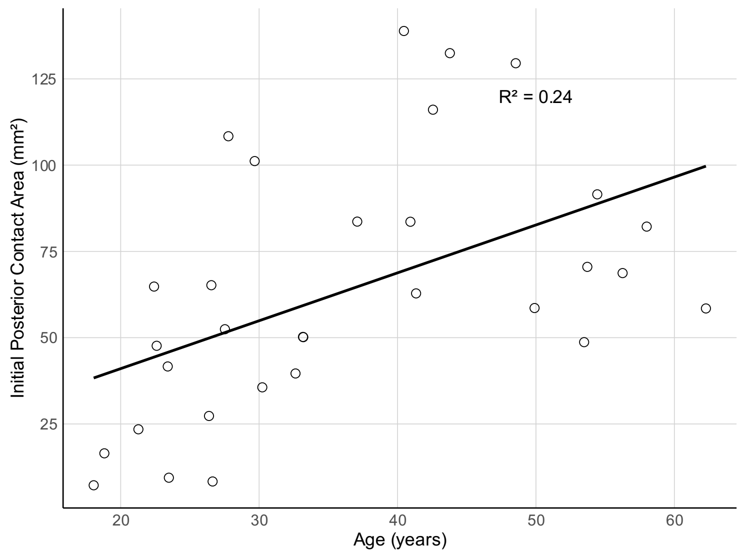

Fig 12. Correlation between age and initial occlusal contact area of posterior teeth

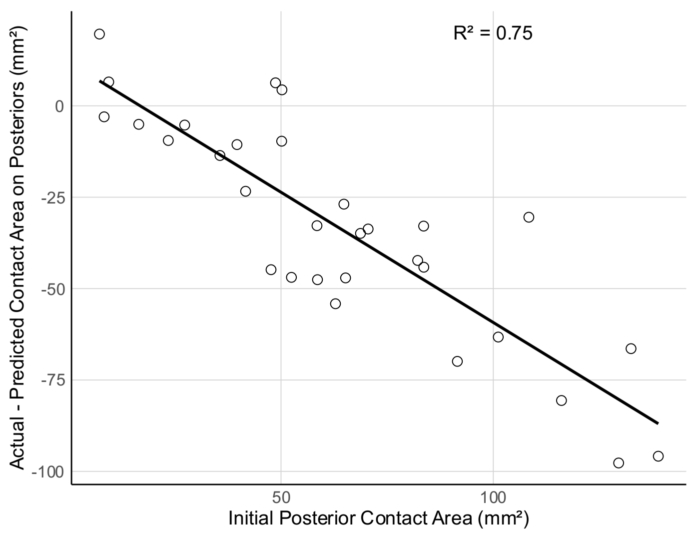

Fig 13. Correlation between initial occlusal contact area and occlusal contact area changes in the maxillary posterior teeth

IV. Discussion

The thickness of SmartTrack material, known to be 0.030 inches, decreases during the thermoforming process. In 2021, Mantovani et al. conducted a descriptive analysis of various regions of the aligner. Using micro-computed tomography, they found that the thickness of Invisalign aligners ranged from 0.582 mm to 0.639 mm in the incisor region, 0.569 mm to 0.644 mm in the canine region, and 0.566 mm to 0.634 mm in the molar region. They noted that the actual thickness of Invisalign aligners could be a factor in quantifying the extent of the 'bite-block' effect (Mantovani et al., 2021).

Digital dental models obtained with the iTero intraoral scanner have limitations in accurately representing occlusal contacts; however, the accuracy discrepancy is as low as 50 microns (Flügge et al., 2013). Therefore, several studies have used this method to evaluate occlusal contacts (Bowman et al., 2023; Frenkel et al., 2024), and the iTero intraoral scanner is clinically utilized to fabricate dental implant prosthetics (Revilla-Leon, Att, Ozcan, & Rubenstein, 2021). Three-dimensional digital scan data were used in this study because they are more sensitive and intuitive in detecting subtle bite-opening phenomena compared to cephalometric tracing, which primarily evaluates vertical positional changes in the teeth.

Kumagai et al. analyzed occlusal force distribution across the dental arch in the intercuspal position and evaluated its relationship with clenching strength. Their findings indicated occlusal force was most significant in the molar region, followed by the premolar and anterior teeth regions (Kumagai et al., 1999). A study using the T-scan II device to evaluate occlusal contacts and muscular balance in female adult patients treated with clear aligners for six months or less reported a statistically significant anterior shift in the center of occlusal force in the sagittal plane during centric occlusion (Tepedino et al., 2023). The findings of previous studies may help explain the decreasing trend in the posterior occlusal contact area observed in this study.

In this study, changes in the occlusal contact area in the maxillary posterior region exhibited no consistent pattern in the number of contact points, but the overall area tended to decrease. Following aligner treatment, the area of existing contact points either diminished or disappeared, while new contact points formed in different locations. Overall, occlusal contacts on the buccal cusps of the maxillary posterior teeth tended to decrease in size or disappear. In contrast, on the lingual cusps, the size of existing contact points decreased, or new contact points emerged. This tendency has been shown in other studies as well. In a study that analyzed the maxillary posterior region by comparing the predicted occlusal contact from digital simulation with the clinically achieved results after Invisalign treatment, the buccal and palatal cusps were separately evaluated for changes in area. The results showed that the reduction in the buccal cusp area was more significant than that of the palatal cusp for all posterior teeth (Bowman et al., 2023).

The correlation between anterior and posterior occlusal contact area discrepancies was not statistically significant. Therefore, in anterior segmental orthodontic treatment using aligners, the tendency for posterior occlusal contact areas to decrease follows this order, regardless of anterior occlusal contact area differences: second molars > first molars > second premolars > first premolars. Despite the orthodontic treatment not allowing for posterior tooth movement, unexpected intrusion occurred, and it was observed that the distribution of occlusal force shifted relatively anteriorly compared to before treatment.

In deep bite cases, the bite can be improved by intruding the anterior teeth, extruding the posterior teeth, or using a combination of both approaches. The Precision Bite Ramp feature, introduced in 2014 as part of the Invisalign G5 protocol, is manually applied by clinicians to the lingual surface of maxillary anterior aligners. An analysis of the effects of the Invisalign G5 with bite ramps and fixed appliances on the correction of skeletal deep bites in adult patients demonstrated that both appliances were effective in treating deep bites. However, the fixed appliances group exhibited more pronounced skeletal changes than the Invisalign group (Henick, Dayan, Dunford, Warunek, & Al-Jewair, 2021). A previous study showed that the intrusion movements of the maxillary and mandibular incisors with Invisalign G5 in patients with mild to moderate crowding (22 patients) or spacing (2 patients) were not significantly shown as predicted, as assessed using CBCT (Al-Balaa et al., 2021). A study evaluating the accuracy of Invisalign in correcting deep overbite by comparing the predicted outcomes from ClinCheck software to the actual posttreatment results found that, on average, only 43.4% of the prescribed overbite reduction was achieved in patients using Precision Bite Ramps (Blundell, Weir, & Byrne, 2022).

This study focused on patients undergoing short-term anterior segmental orthodontic treatment, and the anterior bite ramps were designed to reduce posterior occlusal pressure by disocclusion of the posterior teeth rather than address the skeletal deep overbites. The treatment plan included slight anterior intrusion movements to establish an ideal anterior overbite and prevent premature contact. The digital simulation at 14 stages intentionally set smaller anterior occlusal contact areas than the initial state. When the anterior bite ramps were used, the increase in the anterior occlusal contact area was reduced compared to the predicted values, and the decrease in the posterior occlusal contact area was less pronounced. However, these differences were not statistically significant. These findings align with previous studies suggesting that the anterior bite ramps have limited effectiveness in improving anterior overbite or achieving the predicted anterior intrusion.

In this study, two male patients were excluded from the 33 patients who met the inclusion criteria, as previous research reported a statistically significant difference in masticatory forces between males and females. The average occlusal force in the Korean male group was 480.8 ± 217.9 N, while the average in the Korean female group was 412.3 ± 233.6 N (P <0.05) (Yoon, Choi, Kim, & Chung, 2010).

This retrospective study was conducted on female patients aged between 18.05 and 62.28 years. The correlation analysis between age and the posterior occlusal contact area changes showed a weak negative relationship (P < 0.05). In a previous study, Palinkas et al. categorized the participants by age into children (7-12 years), adolescents (13-20 years), young adults (21-40 years), adults (41-60 years), and older people (61-80 years). They compared the means of maximal bite force across these five groups. Their findings indicated a decrease in average maximal bite force as the age groups progressed from adolescents to young adults, adults, and older people (Palinkas et al., 2010). Another study compared the bite force of healthy adults over 60 years of age with that of young adults. All participants had at least 20 teeth, and the Dental Prescale system (Occluzer, GC Corp., Tokyo, Japan) measured and evaluated bite force. Although the average bite force was higher in young adults, the difference was insignificant. These findings suggest that age does not affect bite force in adults with adequate dentition (Chong, Khoo, Goh, Rahman, & Shoji, 2016). In this study, all patients across all age groups had 28 dentitions, allowing the differences in bite force by age to be disregarded. Additionally, no significant correlation was found between the gonial angle, a parameter associated with bite force, and the posterior occlusal contact area reduction. Therefore, it can be concluded that bite force did not significantly impact changes in this study's posterior occlusal contact areas.

This study confirmed that, as age increased, the pretreatment posterior occlusal contact area tended to be larger, and a larger pretreatment posterior occlusal contact area was associated with a more significant reduction in posterior occlusal contact area following treatment. Tooth wear occurs due to masticatory activity, and with more substantial wear, the occlusal contact area tends to increase (Johansson, Kiliaridis, Haraldson, Omar, & Carlsson, 1993). Therefore, regardless of age, it is important to anticipate potential occlusal changes at the early stages of anterior segmental orthodontic treatment with clear aligners in patients with significant posterior occlusal wear. During treatment, active intervention for posterior bite seating can be implemented by incorporating attachments or vertical elastics that encourage posterior extrusion with the concept of overcorrection along with anterior bite ramps or by selecting a Hawley-type removable retainer posttreatment (Sauget, Covell Jr, Boero, & Lieber, 1997). Another approach is to trim and remove the aligner's posterior occlusal coverage during a short treatment period.

The increase in anterior occlusal contact area compared to the predicted values after wearing clear aligners showed a negative correlation with the initial overjet (OJ), indicating that smaller initial OJ was associated with greater increases in actual anterior contact area compared to the predicted values ($P < 0.05$). After treatment, anterior OJ decreased, and overbite increased, but neither change was statistically significant ($P > 0.05$). This negative correlation can be attributed to smaller initial OJ, which increases the likelihood of anterior premature contact due to less anterior intrusion than predicted during treatment.

This study has the following limitations: First, it evaluates the outcomes of wearing clear aligners for approximately 140 days, reflecting early treatment responses rather than completed results. Second, as the study included only female patients, future research should incorporate male participants to explore potential gender differences. Third, the accuracy of occlusal contact area measurements from STL files created via intraoral scans cannot be fully ensured, emphasizing trend analysis over absolute quantitative accuracy.

Nonetheless, this pilot study aimed to provide foundational evidence for reducing posterior occlusal contact during short-term anterior segmental orthodontic treatment with clear aligners and to explore its clinical implications. The findings from this study may offer valuable clinical insights that should be considered when prescribing digital treatment plans.

V. Conclusion

This study demonstrated significant changes in occlusal contact areas during short-term anterior segmental orthodontic treatment with clear aligners. Specifically:

1. Anterior region (except the canines): Actual occlusal contact areas increased significantly compared to predicted values.

2. Posterior region: Actual occlusal contact areas decreased significantly, with reductions being more pronounced toward the second molars.

3. Age effect: Older patients exhibited larger initial posterior contact areas and more significant reductions in posterior occlusal contact areas.

4. Other factors: Anterior bite ramps did not significantly influence these discrepancies, and no significant correlations were found with most skeletal or dental characteristics, except for initial overjet, which correlated with anterior occlusal contact discrepancies.

These findings highlight the need to account for posterior occlusal contact reductions when planning anterior segmental treatment using clear aligners.

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Abstract in Korean

성인 환자에서 투명 교정 장치를 이용한 전치부 부분 교정 치료 시 교합 접촉의 단기적 변화

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송 지 혜

본 연구에서는 투명 교정 장치를 이용한 전치부 부분 교정 치료를 받은 성인 환자를 대상으로 디지털 가상 모델에서 예측된 교합 면적과 실제 교합 면적 간의 차이를 평가하였다. 구치부에 의도적인 교정력이 가해지지 않은 환자를 대상으로 하였기에 구치부에서는 초진 상태와의 비교 분석도 가능하다는 추가적 의미가 있다. 이 후향적 연구는 14 개의 투명 교정 장치를 착용한 31 명의 여성 환자에서 치료 전후에 구강 스캐너를 이용하여 획득한 디지털 모델을 이용하였다. 열 네번째 단계의 삼차원 가상 모델 (예측된 결과)과 14 개의 장치를 착용한 후 구강 스캐너로 획득한 디지털 모델 (실제 결과)을 사용하여 교합 접촉 면적을 비교 분석하였다. 교합점이 표시된 상악 교합면 이미지를 ImageJ 프로그램을 이용해 교합점의 면적을 측정하였고 다음과 같은 결과를 도출하였다.

1. 예측 교합 면적에 비해 실제 교합 면적은 전치부에서는 유의하게 증가 (P < 0.05*), 구치부에서는 유의하게 감소했는데 (P <0.001***), 최후방 구치로 갈수록 더 많이 감소하였다. 중절치에서는 예측 값에 비해 실제 결과가 0.49mm^2 (P < 0.01**), 측절치에서는 0.18mm^2 더 컸다 (P <0.05*). 반면, 제 1 소구치에서는 3.09mm^2 (P <0.01**), 제 2 소구치에서는 5.44mm^2 (P <0.001***), 제 1 대구치에서는 11.46mm^2 (P <0.001***), 제 2 대구치에서는 13.42mm^2 더 작았다 (P <0.001***).
2. 전치 교합 면적의 차이 값과 구치 교합 면적 차이 값 사이에 유의미한 상관 관계를 보이지 않았다. 전치부 바이트 램프가 존재할 때와 존재하지 않을 때 이들의 상관 관계는 여전히 유의성이 없었다.
3. 전치 부위 그리고 구치 부위, 각 부위에서 예측 교합 면적과 실제 교합 면적 간 차이 값은 전치부 바이트 램프가 없을 때와 있을 때 유의미한 차이가 없었다.
4. 초진 수평 피개가 전치 예측 교합 면적과 실제 교합 면적의 차이 값에 유의미한 상관성 (r = -0.447, P <0.05*)을 보인 것 이외에는 전치 부위, 구치 부위에서의 예측 값과 실제 값의 차이는 모든 골격, 치성 항목과 유의미한 상관성이 없었다.
5. 나이가 증가할수록 초기 구치 교합 접촉 면적이 더 넓었으며 (r = 0.499, P <0.01**), 초기 구치 접촉 면적이 넓을 수록 구치 교합 면적 감소가 더 크게 나타났다 (r = -0.868, P <0.001***).

이상의 연구를 통하여 투명 교정 장치를 이용한 단기간의 전치부 부분 교정 시 구치 교합 면적이 유의미하게 감소하였으며, 그 감소 경향은 제 2 대구치 > 제 1 대구치 > 제 2 소구치 >

제 1 소구치 순서로 나타남을 확인하였다. 또한, 나이가 많을 수록 구치부 교합면적의 감소량은 더 증가함을 알 수 있었다.

핵심되는 말 : 투명 교정 장치, 단기적 전치 부분 교정, 예측과 실제 교합 면적