Treatment of anterior open bites using non-extraction clear aligner therapy in adult patients

Heeyeon Suh[a]; Bella Shen Garnett[b]; Kimberly Mahood[c]; Noor Mahjoub[d]; Robert L Boyd[e]; Heesoo Oh[f]

[a] Research Assistant Professor, Department of Orthodontics,
University of the Pacific, Arthur A. Dugoni School of Dentistry, San Francisco, CA

[b] Private Practice, San Francisco and Adjunct Clinical Assistant Professor,
Department of Orthodontics, University of the Pacific, Arthur A. Dugoni School of Dentistry, San Francisco, CA

[c] Assistant Professor, Department of Orthodontics,
University of the Pacific, Arthur A. Dugoni School of Dentistry, San Francisco, CA

[d] Private Practice, San Francisco, CA

[e] Professor Emeritus, Former Chair, Department of Orthodontics,
University of the Pacific, Arthur A. Dugoni School of Dentistry, San Francisco, CA

[f] Professor and Chair, Department of Orthodontics,
University of the Pacific, Arthur A. Dugoni School of Dentistry, San Francisco, CA

Corresponding author:
Dr. Heesoo Oh, Department of Orthodontics, University of the Pacific, Arthur A. Dugoni School of Dentistry, 155 Fifth Street, San Francisco, CA, 94103, USA
E-mail: hoh@pacific.edu

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Abstract

Objective: The purpose of this study was to examine the effectiveness and mechanism of clear aligner therapy in correcting adult anterior open bites.

Methods: In this retrospective study, the sample was drawn from a single clinician's practice. Sixty-nine adult anterior open bite patients (OB < -0.5 mm) were collected and classified into Class I, II, and III groups. Fifty patients presented with skeletal open bites (MPA ≥ 38°), and 19 patients presented with dental open bites. Fifteen cephalometric landmarks at pre (T1)- and post-treatment (T2) were identified. The magnitude of planned and actual movements of the incisors and molars were calculated.

Results: Positive overbite with mean final overbite of 1.1 ± 0.8 mm was achieved in 94% of adult patients. The mean overbite change was 3.3 ± 1.4 mm. With clear aligners alone, 0.36 ± 0.58 mm of upper molar intrusion was achieved. The Class II group showed greater intrusion of the upper molars and greater reduction of the mandibular plane angle than the Class I group. The Class III group showed greater lower incisor extrusion and no significant vertical skeletal changes.

Conclusions: Clear aligners can be effective in controlling vertical dimension and correcting mild to moderate anterior open bites in adult patients. Treatment mechanism for Class III group was significantly different from Class I and Class II groups. Upper incisor extrusionin the dental open bite and MPA reduction and lower incisor extrusion in the skeletal open bite were the most significant contributing factors for open bite closure.

Key words: Clear aligner, Orthodontic treatment, Tooth movement, Anterior open bite

INTRODUCTION

Open bites are among the most challenging malocclusions to treat as it is associated with skeletal, dental, functional, and habitual factors.[1-3] Open bite malocclusion has been classified into dental open bite and skeletal open bite. Skeletal open bite is characterized by increased mandibular plane angle and increased lower facial height. In contrast, dental open bite is characterized by proclined incisors, under-erupted anterior teeth, normal or slightly excessive molar height, and thumb or finger sucking habits.[4]

In adults, treatment options are limited.[5-8] Orthognathic surgery is indicated in adult patients with severe skeletal open bites and unaesthetic facial proportions.[9, 10] For less severe skeletal open bites and patients who elect to not pursue surgery, non-surgical fixed appliance therapy with intermaxillary vertical elastics and, sometimes, extraction has been a viable alternative. However, it often results in an unaesthetic facial outcome and significant side effects, such as root resorption.[11, 12] Therefore, the search continues for more effective and efficient treatment modalities. Over the past two decades, skeletal temporary anchorage devices (TADs) have significantly expanded the scope of orthodontic treatment beyond the traditional limits of tooth movement, making it possible to correct anterior open bites with orthodontic treatment alone.[13-15]

Adult orthodontic patients frequently seek less invasive treatment alternatives for open bite correction to avoid extractions, temporary skeletal anchorage devices (TADs), or surgery. Clear aligners have become popular when treating adult patients because of esthetics and comfort.[16-18] Previous literature indicated that clear aligners may be efficient in treating open bites, since occlusal coverage provides a mechanical advantage over fixed appliances in controlling the vertical dimension.[16-21] However, it remains controversial how clear aligners correct open bites. Most of the literature supporting the effectiveness of open bite treatment with clear aligners have been case reports, case series, or manufacturer's claims. Some of the previous studies reported both intrusion of molars and extrusion of incisors.[17, 21] On the other hand, others reported open bite was corrected mainly by extrusion of incisors.[22]

The purpose of this study was to examine 1) how clear aligners correct anterior open bite, and 2) how treatment mechanics differ in different vertical skeletal patterns and Angle class malocclusions.

MATERIAL AND METHODS

Subjects

This retrospective study was approved by the institutional review board of University of the Pacific (#16-77). The sample was drawn from the practice of a single clinician (B.G.) whois board-certified by the American Board of Orthodontics and is a top 1% Invisalign certified orthodontist. To minimize selection bias, the clinician was not involved in the sampling process. A list of all patients who started orthodontic treatment between 2011 and December of 2019 was generated. This period was chosen because algorithms for intrusion of posterior teeth were introduced in 2011. The total number of adult patients eligible for screening was 1,799. The primary inclusion criteria were: 1) adult patients older than eighteen years old; 2) received Invisalign treatment; 3) complete records (lateral cephalometric radiographs and study casts) at pre- and post- treatment; 4) presence of an anterior open bite (OB < -0.5 mm) on the lateral cephalometric radiographs. Patients who had craniofacial anomalies, fixed orthodontic treatment,limited treatment, extraction other than third molars, and surgeries were excluded. To identify anterior open bite patients, two research dentists visually examined initial lateral cephalometric radiographs and photographs of all eligible adult patients in Dolphin™ imaging. From 79 (4.5%) patients who were identified as having a clinically detectable anterior open bite, 10 patients were further excluded because one of the criteria (anterior open bite defined as OB < -0.5 mm on the radiograph) was not met.

The final sample consisted of 69 adult anterior open bite patients (Table 1). Skeletal and dental open bites were differentiated based on the initial mandibular plane angle (MPA) using SN-MPA. Patients with MPA ≥ 38° were classified as being in the skeletal open bite group, whereas patients with MPA < 38° were classified as being in the dental open bite group. Fifty out of 69 patients (72%) had skeletal open bites; the remaining 19 patients had dental open bites (Table 1). The sagittal relationship was divided into three groups according to Angle's classification. The Class II group included patients who had an equal or greater than end-on Class II molar relationship bilaterally. Patients who presented with a less than half cusp Class II to Class I molar relationship were identified as being in the Class I group. The Class III group was identified as an equal or greater than end-on Class III molar relationship bilaterally with a negative or edge-to-edge overjet. Since severe skeletal Class III open bites were predominantly treated with orthognathic surgery, only 9 Class III patients were included in the sample. The total sample consisted of 44 Class I, 16 Class II, and 9 Class III patients.

Treatment modality

No TADs were utilized, and crowding was resolved by interproximal reduction (IPR) and some arch expansion. Third molar extractions were recommended before clear aligner therapy when they occluded with the opposing teeth. Prior to treatment, myofunctional therapy was discussed when patients presented with anterior tongue thrusts. The patients were instructed to change aligners every 7 to 10 days. In general, clear aligner therapy exerts intrusive forces on the posterior teeth and extrusive forces on the anterior teeth by utilizing optimized attachments; the anterior teeth are extruded as a unit by leveraging the posterior teeth as anchorage to close the open bite (Invisalign's G4 protocol).

Class I patients with skeletal open bites are considered "masked Class III malocclusions." When the molars are intruded, the mandible often autorotates and a more Class III relationship develops that requires Class III elastics and additional incisor retraction. For Class II open bite patients, more molar intrusion was planned. The clinician planned to close open bite through molar intrusion and autorotation of the mandible. For half a cusp or less Class II molar relationships, Class II correction was achieved using Class II elastics, whereas full-cusp Class II molar relationships were treated with sequential distalization. Class II elastics were applied from precision cuts in the upper canine and buttons on the lower first molar. In Class III skeletalopen bite patients, molarintrusion was planned to maintain the vertical dimension while using Class III elastics. In contrast, Class III dental open bites were treated by extrusion of the upper molars and lower incisors using Class III elastics.

Cephalometric Analysis

Pre (T1)- and post-treatment (T2) lateral cephalometric radiographs were imported into Dolphin™ Imaging (version 11.8; Dolphin Imaging, Chatsworth, Calif). Cephalometric landmark location and superimpositions were performed independently in Dolphin Imaging by two orthodontic faculty. After performing anterior cranial base, maxillary, and mandibular structural superimpositions, three reference planes (S-N, ANS-PNS, and Go-Me) were transferred from the T1 tracing to the T2 tracing. Fifteen cephalometric measurements were generated by computer operations in Dolphin imaging (Figure 1). The average values of the two judges' estimates were used.

Evaluation of programmed tooth movement from ClinCheck®

The programmed vertical movements for each tooth were exported from the tooth movement table in the first ClinCheck plan approved by the clinician. The mean value of the right and left first molars was used for molar movement, and the average of the four incisors wasused for incisor movement. As an estimation of the percentage of accuracy, the following equation was calculated: Percentage of accuracy=100%-([|planned–achieved|/|planned|] × 100%).[23, 24]

Statistical Analysis

The Inter-rater reliability was assessed by Cronbach's alpha, a universal ICC measure. Chi-square tests were used to compare proportions between the groups. With regards to treatment changes, stepwise multiple regression was performed to investigate relationships among variables. Paired t-test was used to assess cephalometric changes. Two-way ANOVA andTukey post hoc test were used to evaluate the influences of Angle classification, vertical pattern, and their interaction on treatment change. Pearson's correlation was performed to investigate relationships among variables in dental and skeletal groups. *P*-values less than .05 were considered statistically significant. SPSS (version 24.0; IBM Corp) and the language R (version 3.6.1; R Foundation for Statistical Computing) were used to analyze the data.

RESULTS

Seventy-seven percent of the patients were female, and there was no statistical difference in sex proportions between the three Angle classification groups. There was a statistically significantly higher proportion of female patients in the skeletal open bite group than the dental open bite group, 86% vs 58%, respectively ($P = 0.005$). The mean age at T1 for all patients was 33.0 ± 8.4 years, and the mean treatment time was 1.4 ± 0.72 years. No statistical differences were found in treatment time or the number of refinements between the Class I, II, and III groups.

Cephalometric analysis

Inter-rater reliability was excellent with an ICC of greater than 0.9 for all cephalometric measurements. Table 1 shows the distribution for open bite severity. At T1, the mean overbite was -2.2 mm and the MPA was 41.07° (Table 2). The initial skeletal characteristics were similar in the Class I and II groups except overjet (Table 3). Class II patients presented with significantly higher MPAs than Class III patients. At T2, positive overbite was achieved in 94% of patients. Only 4 out of the 69 patients did not obtain a positive overbite. The mean overbite change for the total sample was 3.3 ± 1.4 mm (Table 2). There were no statistically significant differences in mean overbite changes and final mean overbite between the three Angle class groups (Table 3).

To evaluate how open bite correction was achieved with clear aligners, stepwise multiple regression was performed (n=69). A model including changes (Δ, T2-T1) of U1-PP, L1-MP, and MPA was selected: Δ OB (mm) = 0.57 + 1.01 [Δ U1-PP (mm)] + 0.83 [Δ L1-MP (mm)] – 0.92[Δ MPA (°)] (R^2 = 0.831, P < .0001) (Table 4). Another well-fitting model was built with vertical changes of molars instead of MPA change: Δ OB (mm) = 0.42 + 1.08 [Δ U1-PP (mm)] + 0.78 [Δ L1-MP (mm)] - 1.20 [Δ U6-PP (mm)] - 0.74 [Δ L6-MP (mm)] (R^2 = 0.836, P < .0001) (Table 4).

For cephalometric changes (T2-T1), two-way ANOVA found no statistically significant interaction between Angle classification and vertical pattern. Therefore, the results were interpreted separately. Regarding Angle classification, the treatment mechanism in Class III group was significantly different from Class I and Class II groups (Table 3, Figure 2). There were statistically significant differences in vertical dimension changes. The magnitude of upper molar intrusion in the Class I and Class II groups were similar at 0.39 mm and 0.56 mm, respectively. Upper molar intrusion contributed to autorotation of the mandible and a decrease inlower face height in both the Class I and II groups. In contrast, upper and lower molar vertical positions in the Class III group were maintained. However, a significantly greater amount of lower incisor extrusion and retroclination contributed to anterior open bite closure (Figure 2).

When comparing dental and skeletal open bites, there was no statistically significant difference in cephalometric measurements change. Overbite correction was slightly greater in the skeletal (3.47 ± 1.38 mm) than dental (2.84 ± 1.48 mm) open bite group, but no statistical significance was found. Changes in MPA, LFH, and L1-MP were moderately correlated with overbite change in the skeletal open bite group, but not for the dental open bite group (Table 5).

Comparison of planned and actual incisor and molar movements

Programmed tooth movements from ClinCheck (Table 6) showed that almost twice the amount of intrusion was programmed in the Class II group compared to the Class I and III groups. Only about 55% of the programmed upper molar intrusion was achieved in the Class I group and 38% in the Class II group. No upper molar intrusive movement was obtained in the Class III group (Table 3). No meaningful lower molar intrusion was achieved in spite of about 0.5-0.6 mm of programmed intrusion for all three groups.

DISCUSSION

Clear aligner therapy is a relatively new approach, and the studies regarding its biomechanics and effectiveness are still limited. The present study demonstrated that correction of mild to moderate anterior open bites in adults using clear aligners was effective. The mean overbite change was 3.3 ± 1.4 mm (ranging from 0.7 mm to 7.1 mm). A positive overbite was achieved in over 94% of all three malocclusion groups. The average treatment time was about 1.5 years.

One complicating feature of clear aligner research is that there are three tooth positions involved in treatment: desired tooth position, planned (programmed) tooth position in the ClinCheck, and actual tooth position. Programmed tooth movement and actual tooth movement can differ[25] as a result of anchorage loss or inter-arch elastics. Therefore, in certain cases, overcorrection or under-correction might be programmed to achieve the desired tooth position.[23] This study focused mainly on the actual vertical tooth movement achieved by clear aligners.

Model selected by stepwise regression included changes of U1-PP, L1-MP, and MPA. Vertical changes of molars instead of MPA change were included to investigate how vertical changes contribute to the overbite change: $\Delta OB\ (mm) = 0.42 + 1.08\ [\Delta U1 - PP\ (mm)] + 0.78\ [\Delta L1 - MP\ (mm)] - 1.20\ [\Delta U6 - PP\ (mm)] - 0.75\ [\Delta L6 - MP\ (mm)]$ (^{2} = 0.836, < .0001). According to the model built from the present study, about 0.4 mm of upper molar intrusion results in overbite increase of 0.5 mm. Hence, for overbite change of 3.3 mm (mean overbite change, n=69), 0.4 mm upper molar intrusion (mean upper molar intrusion, n=69) contributed 15% to total open bite correction. Increase in overbite of 1.2 mm per 1 mm upper molar intrusion in the present study was smaller than previous reports of 2-3 mm increase in overbite.[26-29] The discrepancy might come from the interpretation of the data, as simple ratios and linear regressions can be interpreted differently. The coefficient for upper molar intrusion in the present study was close to previous studies which presented overbite increase by 1.5 mm[26] and 1.2 mm,[28] per 1 mm additional upper molar intrusion. Although there is a limitation in the generalization, the model could adequately assess how molar intrusion contributed to open bite correction.

The study also showed that cephalometric changes were different between open bites in Class I, II, and III malocclusions. In Class II patients, the greatest changes were found in maxillary incisor retroclination, MPA reduction, and upper molar intrusion (Table 3). Even with Class II elastics and distalization mechanics, good vertical control was achieved with slight MPA reduction. In the current study, mild to moderate Class III patients with less severe skeletal open bites obtained bite closure through good vertical control and retroclination and extrusion of the lower incisors. The clinician programmed intrusive movement on the upper molars and the lower incisors to negate significant extrusive movements from Class III elastics (Table 6).

There was no statistically significant difference in treatment change between dental and skeletal groups. This can be attributed to the fact that most of the patients in this study were hyperdivergent although 19 patients were classified into dental open bite group (MPA < 38). The results of the correlation analysis (Table 5) indicated that upper incisor extrusion (U1-PP) was highly correlated with overbite change in the dental open bite group, while MPA reduction, thus LFH reduction, and lower incisor extrusion (L1-MP) were moderately correlated with open bite closure in the skeletal group.

There was a significant difference between programmed and actual incisor extrusive movements (Tables 6 and 3, respectively). The actual upper incisor vertical position change (U1-PP) is composed of three components: programmed absolute extrusion of U1, relative extrusion from U1 retroclination, and the reciprocal extrusive force on the incisor from molar intrusion anchorage loss. Celebi et al.[30] reported that 0.4-0.5 mm of relative extrusion/intrusion occurred at each 5° change of inclination when U1SNA ranges from 93-115°.

Vertical control tends to be challenging in adult patients. Extrusion of molars resulting in clockwise rotation of the mandible is generally observed with fixed appliance treatment.[14, 31] On the other hand, maxillary molar intrusion from skeletal anchorage has been reported in the range of 1.45-4 mm with a mean intrusion of about 2 mm.[11, 14, 32, 33] The present study showed that clear aligners alone achieved relatively small molar intrusion yet reliable vertical control. Consistent upper molar intrusion, though small, was achieved in 55 of the 69 cases. For the Class I and II groups in this study, about 1 mm of upper molar intrusion was planned and less than 1 mm of upper molar intrusion was achieved (0.4 mm and 0.6 mm for Class I and Class II groups, respectively) with clear aligners alone. Upper molar intrusion of 0.4 mm was reported in a previous study.[17] While the present study showed statistically significant but clinically small amount of intrusion can be achieved, whether more intrusion is possible as programmed intrusion increases remains a question. Currently, some clinicians consider greater than 1 mm of intrusion as less predictable.[34] In addition, molar intrusion anchorage loss could result in greater upper incisor extrusion.[34] It is also important to consider the fact that skeletal open bite patients with high MPAs, who comprised the majority of the sample in the current study, tend to have weak musculature and low occlusal bite forces.[35, 36] Lower molar intrusion by 0.8 mm was reported in the prior study.[17] In the present study, lower molar intrusion was achieved in half of the total cases, while lower molar vertical positions were maintained in the other half.

The present study has some limitations besides being a retrospective study. The study would have benefitted from a larger sample size, especially since the Class III group was small. According to the result of this study, however, open bite treatment mechanism in Class III patients is significantly different from mechanism in Class I and Class II patients. It would be reasonable to consider Cl III group separately for future studies. Also, to compare differences between the programmed and actual tooth movements and to quantify the predictability of tooth movement using clear aligners, actual tooth movements were measured from lateral cephalometric radiographs to use global references, since no teeth or structures in the dental arch could be used for superimposition. Thus, only a general pattern for each tooth movement could be evaluated. Digital scans integrated with a CBCT study in the future should resolve this issue. Lastly, generalization of this study's results should be limited since the sample was derived from a single clinician's practice. However, by including patients from a single clinician, the present study reduced heterogeneity and variability of clinical skills.

CONCLUSIONS

1. Using clear aligner therapy, open bite correction (positive overbite) was achieved in 94% of adult anterior open bite patients.
2. Clear aligners alone provided limited but consistent upper molar intrusion with maintained lower molar vertical position, which in turn, offered reasonable vertical control.
3. Treatment mechanism for Class III group was significantly different from Class I and Class II groups.
4. Upper incisor extrusion in the dental open bite group and MPA reduction and lower incisor extrusion in the skeletal open bite group are among the most significant contributing factors for open bite closure.

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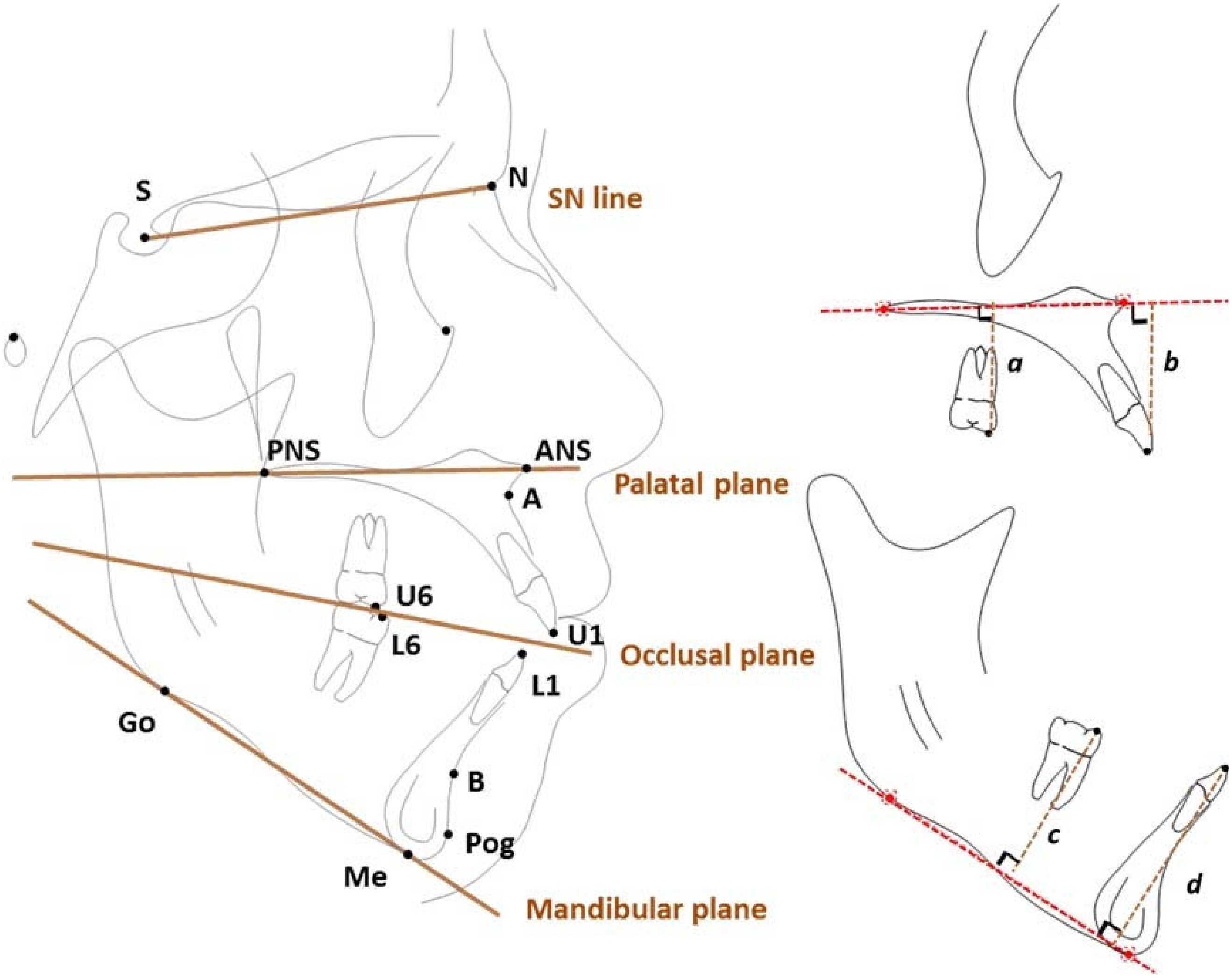
FIGURE LEGENDS

Figure 1. Cephalometric landmarks, reference planes, and dentoalveolar linear measurements used in this study. Measurements were measured using the same reference planes at T1 and T2 tracings. a (U6-PP), perpendicular distance between mesiobuccal cusp of maxillary 1st molar andpalatal plane (ANS-PNS) (mm); b (U1-PP), perpendicular distance between incisal edge of maxillary central incisor and palatal plane (mm); c (L6-MP), perpendicular distance between mesiobuccal cusp of mandibular 1st molar and mandibular plane (Go-Me) (mm); d (L1-MP), perpendicular distance between incisal edge of mandibular central incisor and mandibular plane (mm).

Figure 2. Vertical changes by Angle class groups. A, U6-PP change; B, L6-MP change; C, LFHchange; D, L1-MP change. Dental intrusion presented as negative value; dental extrusion presented as positive value. * represents significant difference between the groups. Statistical significance set at $P < .05$.



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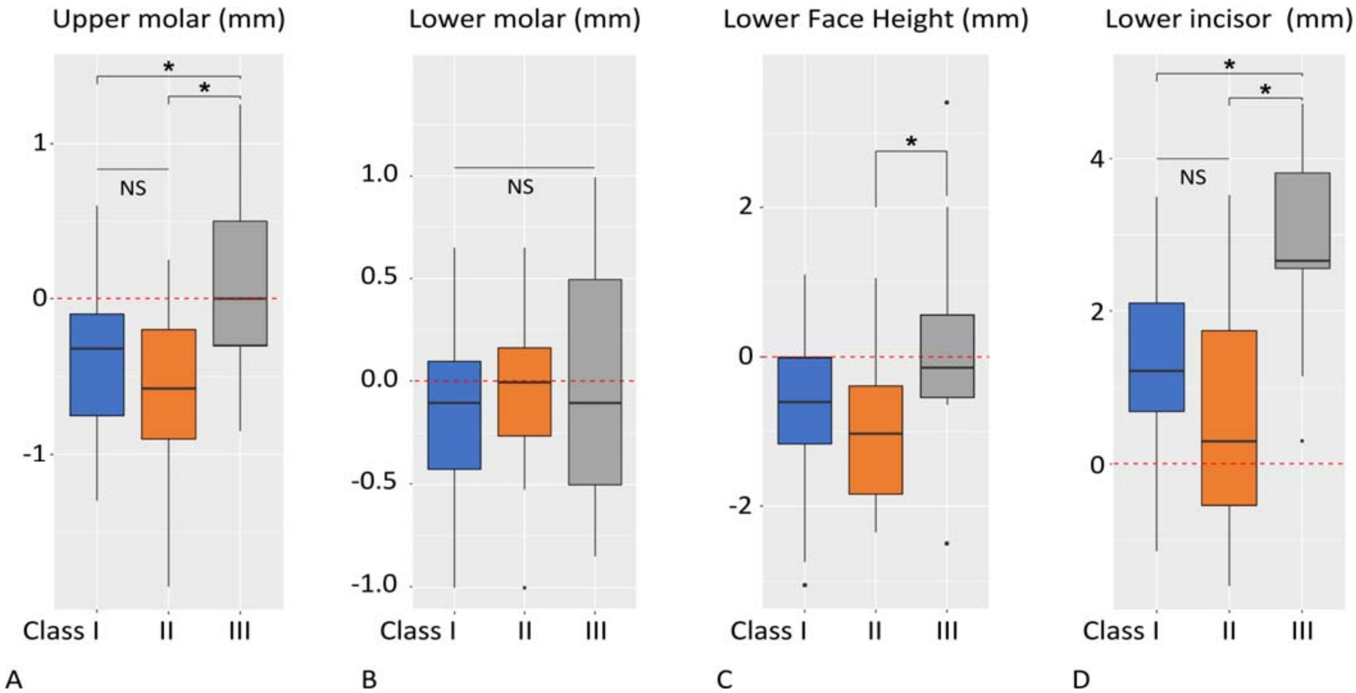

Fig. 2. Vertical changes by Angle class groups. A, U6-PP change; B, L6-MP change; C, LFH change; D, L1-MP change. Dental intrusion presented as negative value; dental extrusion presented as positive value. * represents significant difference between the groups. Statistical significance set at P < .05.

Table 1. Sample characteristics for anterior open bite patients

category	n	%
Sex		
Male	15	23
Female	54	77
Age (years)		
18 - 25	6	9
25 - 35	44	64
≥ 35	19	27
Initial overbite (mm)		
< -5	3	4
-5 - -4	7	10
-4 - -3	9	13
-3 - -2	10	14
-2 - -1	30	44
-1 - -0.5	10	14
Vertical pattern (M:F)		
Dental open bite	19 (8:11)	28
Skeletal open bite	50 (7:43)	72
Angle Classification (M:F; Dental open bite:Skeletal open bite)		
Class I	44 (9:35; 13:31)	64
Class II	16 (2:14; 2:14)	23
Class III	9 (4:5; 4:5)	13
Previous Orthodontic treatment		
Yes (Ext vs Non-Ext)	13 (6 vs 7)	19
None	56	81
Third molar present at T1	18	
Extraction during treatment	9	50
remained in arch	9	50

standard deviation, minimum, and maximum values and comparison of cephalometric measurements at T1 and T

	T1				T2				Changes (T2-T1)				
	Mean	SD	min	max	Mean	SD	min	max	Mean	SD	min	max	*P*
ANB (°)	4.21	2.65	-1.60	9.90	4.10	2.66	-1.95	9.40	-0.11	0.46	-2.00	0.80	0.0
SNA (°)	79.47	4.05	71.70	90.30	79.51	4.13	71.70	90.65	0.04	0.20	-0.75	0.65	0.0
SNB (°)	75.26	4.67	65.70	88.65	75.42	4.63	66.90	88.50	0.16	0.44	-1.00	1.40	0.00
OPA (°)	20.68	5.42	5.00	34.40	21.23	5.88	3.45	32.65	0.54	2.21	-3.35	8.05	0.0
MPA (°)	41.07	7.41	22.75	57.75	40.64	7.41	23.20	57.65	-0.42	0.95	-2.35	3.40	0.00
LFH (mm)	72.64	5.41	59.30	87.15	72.04	5.64	59.30	86.50	-0.60	1.10	-3.05	3.40	<.00
A (°)	122.78	9.13	100.95	143.35	132.80	8.42	112.90	152.80	10.02	6.40	-5.55	30.25	<.00
SNA (°)	102.04	6.81	89.30	120.40	96.35	7.30	83.00	116.95	-5.69	4.38	-21.75	3.95	<.00
MPA (°)	94.11	7.11	75.60	109.10	90.22	7.67	67.40	104.20	-3.89	4.55	-16.00	13.55	<.00
OB (mm)	-2.21	1.39	-6.55	-0.55	1.09	0.80	-0.85	2.85	3.30	1.43	0.70	7.05	<.00
OJ (mm)	3.22	2.05	-2.75	10.75	2.64	0.69	0.80	5.75	-0.59	1.94	-8.85	4.65	0.0
6-PP (mm)	24.99	2.38	20.35	31.30	24.63	2.44	19.70	31.80	-0.36	0.58	-1.85	1.25	<.00
1-PP (mm)	29.80	2.83	23.65	38.35	31.01	2.92	24.40	38.40	1.20	0.93	-0.45	3.90	<.00
6-MP (mm)	33.85	2.78	28.90	42.80	33.73	2.82	28.80	42.05	-0.12	0.47	-1.00	1.35	0.0
-MP (mm)	37.39	3.37	30.50	43.85	38.75	3.85	32.15	47.70	1.36	1.30	-1.60	4.70	<.00

of T2-T1 difference (paired-sample t-test; significance at P < .05).

ephalometric measurements between Angle Class I, II, and III malocclusions.

Class I (n=44)			Class II (n=16)				Class III (n=9)		
T2	T2-T1	$P^{\S}$	T1	T2	T2-T1	$P^{\S}$	T1	T2	T2-T1
.17 ± 2.47	-0.14 ± 0.39	*	5.51 ± 2.75	5.32 ± 2.75	-0.20 ± 0.65	NS	1.43 ± 1.78	1.58 ± 1.74	0.15 ± 0.35
9.24 ± 3.85	0.04 ± 0.13	NS	78.72 ± 4.06	78.75 ± 4.17	0.03 ± 0.33	NS	82.08 ± 4.72	82.17 ± 4.8	0.09 ± 0.16
5.08 ± 4.02	0.18 ± 0.41	**	73.22 ± 4.04	73.44 ± 4.02	0.22 ± 0.57	NS	80.64 ± 5.2	80.58 ± 5.14	-0.06 ± 0.27
.36 ± 4.86	0.40 ± 1.57[a]	NS	22.11 ± 4.94	24.50 ± 5.52	2.40 ± 2.51[b]	**	16.83 ± 6.58	14.76 ± 6.41	-2.07 ± 1.28
0.42 ± 7.53	-0.45 ± 0.67[ac]	**	44.63 ± 6.35	43.84 ± 6.60	-0.80 ± 0.91[a]	**	35.91 ± 6.61	36.07 ± 5.93	0.16 ± 1.46[c]
.87 ± 5.80	-0.65 ± 0.93[ac]	***	71.90 ± 4.93	70.95 ± 5.10	-0.95 ± 1.00[a]	**	74.57 ± 5.09	74.8 ± 5.44	0.23 ± 1.67[c]
0.70 ± 8.14	9.38 ± 4.88	***	121.19 ± 10.61	132.95 ± 8.73	11.77 ± 9.73	***	127.81 ± 9.87	137.84 ± 8.26	10.04 ± 5.85
5.70 ± 6.23	-5.24 ± 3.36[a]	***	100.79 ± 6.49	92.02 ± 6.91	-8.76 ± 5.71[b]	***	104.75 ± 9.88	102.31 ± 8.74	-2.44 ± 2.99
91.19 ± 7.80	-3.72 ± 3.29[a]	***	93.38 ± 7.55	91.20 ± 6.04	-2.18 ± 6.39[a]	NS	91.53 ± 6.56	83.78 ± 7.09	-7.75 ± 4.31
10 ± 0.71	3.30 ± 1.46	***	-2.55 ± 1.36	1.08 ± 0.96	3.63 ± 1.43	***	-1.66 ± 0.56	1.06 ± 0.98	2.72 ± 1.17
.71 ± 0.70	-0.57 ± 1.41[a]	*	4.63 ± 2.26	2.63 ± 0.64	-2.00 ± 2.22[b]	**	0.43 ± 1.34	2.26 ± 0.7	1.83 ± 1.29[c]
4.49 ± 2.23	-0.39 ± 0.51[a]	***	24.35 ± 2.50	23.79 ± 2.55	-0.56 ± 0.51[a]	***	26.66 ± 2.35	26.81 ± 2.22	0.14 ± 0.74[c]
0.89 ± 2.91	1.16 ± 0.86[ac]	***	29.44 ± 2.65	31.20 ± 2.97	1.76 ± 1.00[a]	***	30.85 ± 3.16	31.27 ± 3.2	0.42 ± 0.48[c]
3.82 ± 2.92	-0.16 ± 0.47	*	33.12 ± 2.47	33.07 ± 2.58	-0.05 ± 0.39	NS	34.49 ± 2.47	34.47 ± 2.8	-0.03 ± 0.62
3.81 ± 3.43	1.35 ± 0.94[a]	***	35.67 ± 3.15	36.28 ± 3.23	0.61 ± 1.53[a]	NS	40.07 ± 2.62	42.84 ± 3.47	2.77 ± 1.37[c]

D.

f T2-T1 difference (paired-sample t- test; significance at $P < .05$); *, $P < .05$; **, $P < .01$; ***, $P < .001$; NS, not s

Class II, and Class III groups for cephalometric changes; the values with different superscript letters are significantl

Table 4. Selected regression models presenting relationships between overbite change and predictor variables.

		ΔOverbite (mm)		
	Predictors	Estimates	CI	*P*
Model 1	Intercept	0.57	0.22 – 0.91	0.002
	ΔU1-PP (mm)	1.01	0.84 – 1.17	<.001
	ΔL1-MP (mm)	0.83	0.71 – 0.95	<.001
	ΔMPA (□)	-0.92	-1.08 – -0.75	<.001
	R^2	0.831		
Model 2	Intercept	0.42	0.05 – 0.79	0.028
	ΔU1-PP (mm)	1.08	0.91 – 1.24	<.001
	ΔL1-MP (mm)	0.78	0.66 – 0.91	<.001
	ΔU6-PP (mm)	-1.2	-1.49 – -0.91	<.001
	ΔL6-MP (mm)	-0.74	-1.07 – -0.42	<.001
	R^2	0.836		

CI, 95% confidence interval

Table 5. The relationship between overbite changes and changes of cephalometric variables during treatment (T2-T1) by vertical skeletal pattern.

	Dental open bite group (n=19)		Skeletal open bite group (n=50)	
Changes (T1-T2)	Correlation coefficient (r)	*P*	Correlation coefficient (r)	*P*
ANB	-0.49	0.03	-0.32	0.01
SNA	-0.05	NS	0.21	NS
SNB	0.51	0.03	0.44**	0.001
OPA	-0.11	NS	-0.14	NS
MPA	-0.29	NS	-0.53***	<.0001
LFH	-0.36	NS	-0.52***	<.0001
IIA	0.15	NS	0.35**	0.007
U1SNA	-0.24	NS	-0.16	NS
IMPA	0.10	NS	-0.25	0.04
OJ	-0.31	NS	0.01	NS
U6-PP	0.00	NS	-0.33	0.010
U1-PP	0.76***	<.0001	0.32	0.011
L6-MP	-0.53	0.02	-0.35**	0.007
L1-MP	0.37	NS	0.45**	0.001

, *P* < .01; *, *P* < .001; NS, not significant.

Table 6. Comparison of programmed vertical tooth movements between Angle Class I, II, and III malocclusions from the ClinCheck[a].

	Class I (n=44)	Class II (n=16)	Class III (n=9)	*P* ‡	Dental open bite group (n=19)	Skeletal open bite group (n=50)	*P* ‡
U6 (mm)	-0.71 ± 0.52[a]	-1.45 ± 0.78[bc]	-0.79 ± 0.66[ac]	<.001	-0.77 ± 0.53	-0.93 ± 0.72	0.34
L6 (mm)	-0.63 ± 0.56	-0.48 ± 0.63	-0.60 ± 0.54	0.54	-0.42 ± 0.45	-0.66 ± 0.6	0.13
U1 (mm)*	0.69 ± 1	0.49 ± 1.05	0.31 ± 0.37	0.48	0.80 ± 1.16	0.52 ± 0.86	0.29
L1 (mm)*	0.11 ± 0.86	0.13 ± 0.58	-0.42 ± 0.99	0.19	0.08 ± 1.15	0.02 ± 0.69	0.79

Data presented Mean ± SD.

[a], Data collected from the first ClinCheck.

Minus sign indicates intrusion; plus sign indicates extrusion; ‡ANOVA

*, incisor's vertical movement includes only absolute extrusion/intrusion movement.

The values with different superscript letters are significantly different (p<0.05).