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Management of Overbite with the Invisalign[®] Appliance

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Abstract

Management of Overbite with the Invisalign® Appliance

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Studies on the management of overbite with the Invisalign® appliance are limited to case reports or case-series, hence the success and mechanism of action to manage overbite with this appliance is poorly documented. Therefore, this retrospective study sought to assess the nature of overbite changes with the Invisalign® appliance. The study sample included 68 normal overbites, 40 deepbites, and 12 openbites. Cephalometric analyses suggested that the Invisalign® appliance opened deepbites a median 1.5 mm, while the openbite patients had a median deepening of 1.5 mm closing. The median change for the normal overbite patients was 0.3 mm. Changes in incisor position were responsible for most of the improvement in deepbite and openbite groups. Minimal changes in molar vertical position and mandibular plane angle were noted. The Invisalign®

appliance appears to manage the vertical dimension relatively well, and the primary mechanism is via incisor movements.

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1 INTRODUCTION

The Invisalign® appliance uses a series of computer designed clear plastic shells that closely fit over the teeth and incrementally move the teeth to their correct position (Align Technology, Inc., 1998; Joffe, 2014). Orthodontic treatment by the Invisalign® appliance may be more aesthetically appealing to some patients when compared to conventional fixed appliances, which partly explains the increasing demand for this treatment method (Lingenbrink et al., 2002).

The Invisalign® technique was initially proposed to treat mild orthodontic cases (Bollen et al., 2003; Joffe, 2014; Phan and Ling, 2007; Vlaskalic and Boyd, 2001). Nonetheless, reports of complex orthodontic cases treated with the Invisalign® appliance have been emerging in the literature (Boyd, 2007; Castroflorio et al., 2013; Guarneri et al., 2013). For example, a recent study demonstrated the successful closure of 4 mm openbite by extrusion of the anterior teeth using a series of 35 Invisalign® aligners (Guarneri et al., 2013).

Soon after the introduction of the Invisalign® system in the late 1990s, practitioners noticed that the appliance commonly induces deepening of the overbite (Boyd et al., 2000). It was suggested that aligners covering all the posterior teeth could function as a bite block, thereby intruding the posterior teeth. This would result in a reduction of posterior vertical dimension, and consequently deepening of the overbite (Kuster and Ingervall, 1992).

The Invisalign® system has evolved over the last 16 years and now incorporates treatment options to better manage the vertical dimension. Additionally, the Invisalign® system has developed new treatment features, which have been recommended to correct both deepbites and openbites. Examples of these new treatment options are attachments, virtual bite ramps, and the reduction of occlusal coverage by the aligners. Attachments are composite buttons built on tooth

surfaces and they come in various shapes in order to assist with the movement of the teeth. Specifically, these attachments (i) increase retention, (ii) transmit desirable force to the teeth, and (iii) support auxiliary function such as placement of elastics (Tuncay, 2006). Virtual bite ramps function similar to bite plates or bite turbos. These bite ramps, which are fabricated on the upper aligner, contact the mandibular incisors to dis-occlude the posterior teeth when individuals bring their teeth together.

Despite these advancements in the Invisalign® appliance, evidence supporting the effectiveness of these treatment modalities is limited to case-reports and case series. Studies with larger samples and better designs are required to understand the mechanism by which the Invisalign® appliance manages the vertical dimension. To this end, this retrospective cohort study sought to investigate the vertical dimension changes in patients with various pre-treatment overbites who were treated with the Invisalign® appliance. Moreover, we aimed to identify the dental and skeletal changes associated with bite closing or opening.

2 STUDY DESIGN

This study was approved by the Institutional Review Board (IRB) of the Human Subjects Division at the University of Washington.

2.1 SAMPLE POPULATION

The study sample was collected from adult patients consecutively treated adult patients with the Invisalign® appliance in three private orthodontic offices. Two practices were located in the State of Washington, and one in the providence of British Columbia. A total of 313 patient records were screened, of which 193 patients (62%) were excluded. The most common reason for

exclusion was the lack of final lateral cephalometric radiographs. The second common reason was that the dentition was not in complete occlusion while the radiograph was taken.

The study sample was stratified into groups of normal overbite, deepbite and openbite based on the pre-treatment overbite measured on cephalometric radiographs. Normal overbite was defined as pre-treatment overbite ranging from 0 mm to less than 4 mm. Patients with 4 mm or greater pre-treatment overbite were classified in the deepbite group (Huang et al., 2012). The openbite group included patients with negative pre-treatment overbite.

2.2 INCLUSION CRITERIA

Inclusion criteria were (1) the patient was 18 or older at the beginning of the treatment, (2) the treatment was completed between Jan 1, 2010 and Jan 1, 2014, (3) 11-40 aligners were used for each arch, (4) a maximum of three revision sets of aligners were used, (5) the treatment plan was non-extraction, (6) molar anterior-posterior occlusal relationship was not changed (e.g., no Class II to Class I occlusion change), (7) posterior-transverse relationships were not changed significantly (e.g., no correction of posterior crossbite), (8) fixed appliances were not used, (9) patient had good-quality pre and post-treatment cephalometric radiographs. Two investigators (RK and WL) screened the records at the orthodontic offices. Each subject eligible for the study was then assigned to an anonymous study ID number and the records were de-identified using these ID numbers.

2.3 RECORD COLLECTION

The collected records included (i) initial and final lateral cephalometric radiographs, (ii) age of the patient at the start of the treatment, (iii) gender, (iv) questionnaires filled out by the clinicians regarding their treatment strategies.

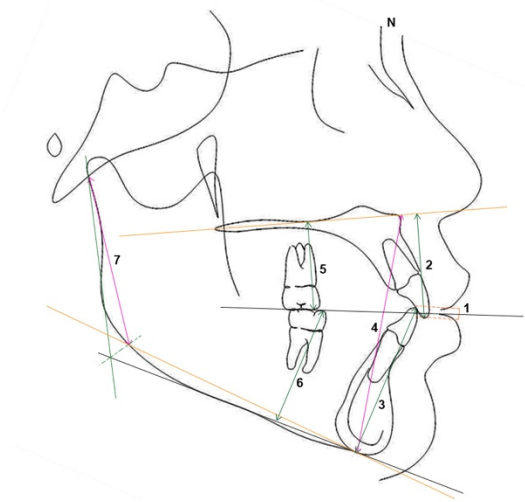
2.4 MEASUREMENTS

De-identified lateral cephalometric radiographs were imported to Dolphin Imaging software to perform cephalometric analyses. Seventeen landmarks were marked on the initial and final lateral cephalometric radiographs consecutively. We opted to mark the landmarks for both the pre and post-treatment radiographs of each patient sequentially to reduce potential landmark identification error. Dolphin software then calculated the linear and angular measurements, which were used in our statistical analyses.

To assess the changes that occurred during the treatment, nine linear and three angular measurements were examined (Figure 1). Palatal, occlusal and mandibular planes were used as the reference lines. Palatal plane was defined as a straight line passing through the anterior and posterior nasal spine points (A Jacobson and RL Jacobson, 2006). Occlusal plane was defined as a straight line drawn through the bisection of the mesiobuccal cusp tips of first molars and the bisection of the incisal edge of the most anterior central incisors (Downs, 1956). Mandibular plane was defined as a straight line connecting menton to constructed gonion (The American Board of Orthodontics, 2016).

Figure 1. Cephalometric Measurements

A. Linear Cephalometric Measurements



B. Angular Cephalometric Measurements

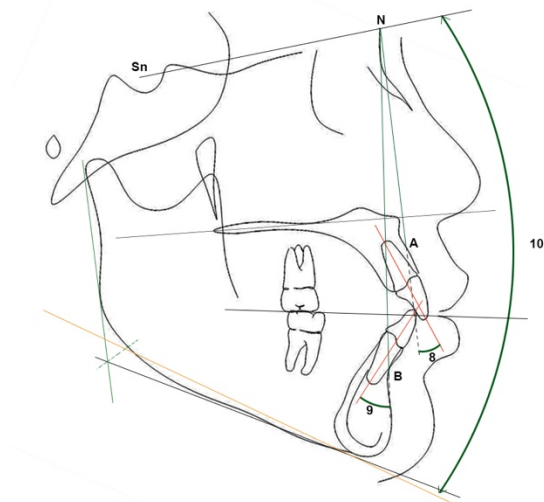


Figure 1 Legend: Linear and angular cephalometric measurements used to assess the anterior and posterior vertical dimension changes in patients underwent orthodontic treatment with the Invisalign® appliance. A) Linear measurements: (1) overbite, (2) maxillary incisor tooth tip to palatal plane, (3) mandibular incisor tooth tip to mandibular plane, (4) anterior facial height, (5) maxillary molar mesial cusp tip to palatal plane, (6) mandibular molar mesial cusp tip to mandibular plane, (7) posterior facial height. B) Angular measurement: (8) maxillary incisor axis to Nasion-A-point, (9) mandibular incisor axis to Nasion-B-point, (10) mandibular plane angle.

2.4.1 Changes in the Anterior Vertical Dimension

The linear measurements were (i) overbite defined as the shortest vertical distance between the tip of maxillary incisor and the tip of mandibular incisor perpendicular to the occlusal plane and (ii) vertical position of the incisors defined as the shortest distance between the maxillary and mandibular incisors to the palatal and mandibular planes, respectively (reference lines) (Burke and A Jacobson, 1992). Additionally, the anterior facial linear height was measured. The anterior facial height was defined as the shortest distance between anterior nasal spine and menton (Bishara et al., 1984).

The angular measurements were (i) the angle between the maxillary incisor long axis and the Nasion-A point line as well as (ii) the angle between the mandibular incisor long axis and the Nasion-B point line (Steiner, 1953).

2.4.2 Changes in the Posterior Vertical Dimension

To assess the changes in the posterior vertical dimension, several linear and angular measurements were measured. The vertical dimension changes of maxillary and mandibular molars were determined using linear measurements. Specifically, the shortest distance between the palatal plane and maxillary first and second molar mesiobuccal cusp tips were measured. Similarly, the shortest distance between the mandibular first and second molar mesiobuccal cusp tips to mandibular plane were measured (Burke and A Jacobson, 1992). The posterior facial height was measured as the shortest distance between constructed gonion and articulare (Bishara et al., 1984). Lastly, the angle between mandibular plane and the Sella-Nasion reference line was measured (McNamara, 1984).

2.5 INTRA-EXAMINER ERROR ANALYSIS

Approximately two weeks after the initial measurements were completed, ten cephalometric radiographs were randomly selected by the R statistical package for the measurement error analysis. Landmarks on these lateral cephalometric radiographs were re-identified, and the measurements were re-calculated using the Dolphin Imaging software. The reliability error was reported as the mean difference between the initial and re-traced cephalometric values (Erkan et al., 2012).

2.6 STATISTICAL ANALYSIS

Statistical analyses were conducted in two phases. Initially, descriptive analyses were performed to examine the cephalometric measurements of pre and post-treatment radiographs in all the three groups. Detailed descriptive analyses are presented in the Appendix.

To examine the difference between cephalometric measurements pre and post-treatment, we used non-parametric Wilcoxon signed-rank test with a 0.5 levels of significance. We opted to use this analysis because the majority of our variables were not normally distributed. Additionally, Kruskal-Wallis analysis with a 0.5 levels of significance was used in order to investigate overbite changes in the three groups.

The statistical analyses were conducted using the R statistical package (Version 2.11.1) through R-Studio (Version 0.99.491).

3 RESULTS

A total of 120 patients (normal overbite group=68, deepbite group=40, and openbite group=12) were included in this study. The median age of patients was 33 years (IQR=17) and 70% of the patients were female.

The intra-examiner error analysis indicated a 0.03 ± 0.08 mm measurement error for the overbite, which was the primary outcome in this study. Other linear measurement errors were less than 1 mm. The error in the angular measurements assessing the incisors position was about 1 degree. The measurement error for the mandibular plane angle was 0.3 ± 1.16 degrees. The details of intra-examiner analysis are reported in Table 1.

Table 2 represents a summary of the pre-treatment cephalometric measurements. A detailed summary of cephalometric values is presented in the Appendix (Appendix Table 1-3).

Table 1. Intra-Examiner Reliability Cephalometric Analysis (N=10)

	Mean	SD
Incisors position (Linear Measurement)		
Overbite	0.03	0.08
U1 to Palatal Plane	0.35	0.73
L1 to Mandibular Plane	0.14	1.16
Anterior Facial Height	0.13	1.24
Incisors Position (Angular Measurement)		
U1 - Nasion-A-point	1.12	2.19
L1 - Nasion-B-point	0.94	2.03
Molar position (Linear Measurement)		
U6 to Palatal Plane	0	0.54
L6 to Mandibular Plane	0.56	0.96
U7 to Palatal Plane	0.2	0.83
L7 to Mandibular Plane	0.18	0.74
Posterior Facial Height	0.43	1.28
Mandibular Plane (Angular Measurement)		
SN - Mandibular plane	0.31	1.16

Table 1 Legend. 10 lateral cephalometric radiographs were randomly selected. Landmarks were re-identified, and linear and angular measurements were re-calculated using the Dolphin Imaging software. The table presents mean differences between the first and second rounds of measurements.

Table 2. Pretreatment Cephalometric Measurements

	Normal Overbite (N=68)			Deepbite (N=40)			Openbite (N=12)		
	Median	Mean	SD	Median	Mean	SD	Median	Mean	SD
Incisors position (Linear Measurement)									
Overbite	2.3	2.3	1.1	5.1	5.3	1.0	-0.8	-1.1	0.9
U1 to Palatal Plane	27.7	27.9	2.8	29.5	29.0	3.4	28.9	29.6	3.6
L1 to Mandibular Plane	41.3	41.0	3.3	40.6	41.1	4.3	43.5	43.2	4.1
Anterior Facial Height	65.9	65.4	5.0	64.2	65.0	6.9	69.8	72.1	7.3
Incisors Position (Angular Measurement)									
U1 - Nasion-A-point	19.1	19.9	5.9	12.7	12.8	6.2	25.2	23.0	8.2
L1 - Nasion-B-point	25.4	25.9	5.9	20.1	21.7	8.8	27.6	30.4	6.2
Molar position (Linear Measurement)									
U6 to Palatal Plane	22.4	22.3	2.3	21.8	21.9	3.2	22.9	23.7	3.7
L6 to Mandibular Plane	32.5	32.4	2.8	31.5	32.3	3.3	31.8	33.3	3.8
U7 to Palatal Plane	19.9	19.7	2.7	17.9	18.0	3.9	19.6	19.9	3.8
L7 to Mandibular Plane	30.3	29.9	2.9	28.8	29.3	3.1	29.2	30.3	3.7
Posterior Facial Height	87.6	86.9	7.2	85.1	86.6	8.1	84.8	85.6	9.0
Mandibular Plane (Angular Measurement)									
SN - Mandibular plane	29.2	29.6	7.1	29.9	28.9	7.1	34.3	35.6	8.7

Table 2 Legend. Linear and angular measurements were analyzed to assess the pre-treatment anterior and posterior vertical dimensions in the study sample (N=120).

3.1 THE INVISALIGN[®] APPLIANCE MAINTAINS OVERBITE IN PATIENTS WITH PRE-TREATMENT NORMAL OVERBITE

The anterior vertical dimension in patients with pre-treatment normal overbite showed minimal change (Figure 2). The median overbite change was -0.3 mm in this group. Moreover, our results suggested a minor proclination of maxillary and mandibular incisors, which was only statistically significant for the maxillary incisors ($\Delta U1-NA = -0.7^\circ$ and $\Delta L1-NB = 0.6^\circ$). The anterior facial height increased 0.7 mm, which was a statistically significant change. However, this change was within the intra-examiner error.

Posterior vertical dimension similar to the anterior vertical dimension was largely maintained in the normal overbite group. The median mandibular plane angle change was 0.4° , which was within the range of intra-examiner error.

Collectively, the magnitude of the statistically significant changes was within the intra-examiner error rate.

Figure 2. Vertical Dimension Changes in Normal Overbite Patients Treated with the Invisalign® appliance (N=68)

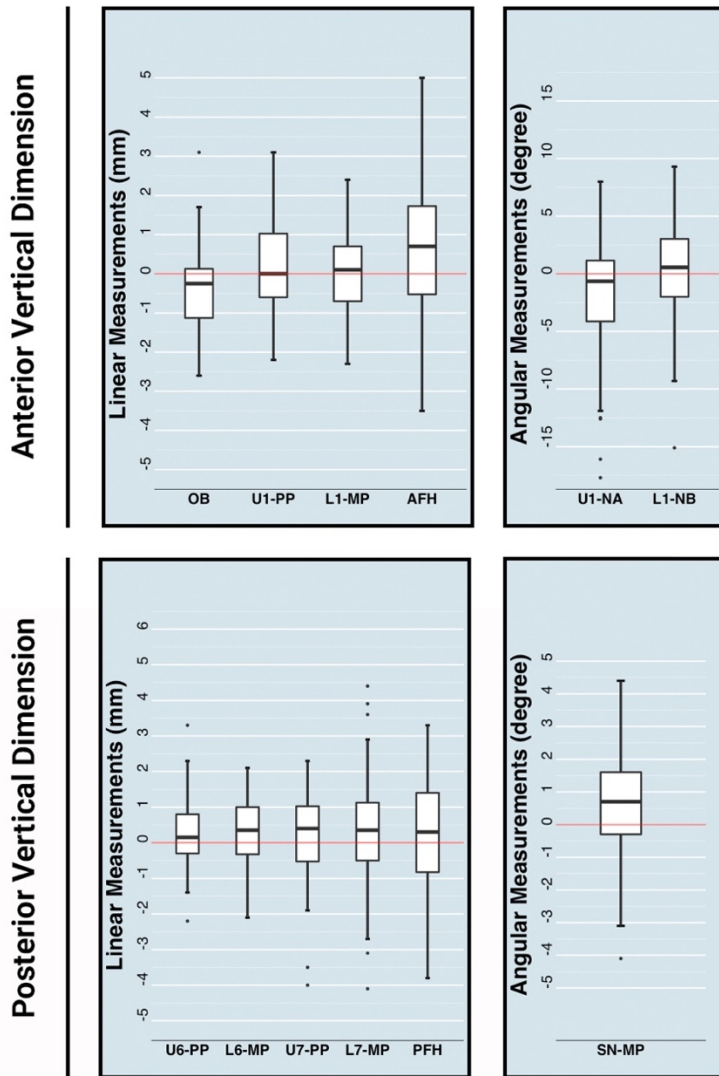


Figure 2 Legend. Lateral cephalometric radiographs of adult patients with pre-treatment normal overbite were analyzed. The boxplots represent the changes between initial and final cephalometric measurements, which examine anterior and posterior vertical dimension changes. Details of these measurements are presented in the appendix. The sample size was 68 patients. The Invisalign® appliance appeared to minimally affect the anterior and posterior vertical dimensions.

3.2 THE INVISALIGN[®] APPLIANCE REDUCES THE OVERBITE IN PATIENTS WITH PRE-TREATMENT DEEPBITE

We detected a 1.5 mm median opening of the overbite in deepbite patients. The primary mechanism responsible for reducing overbite in this group seemed to be proclination of the mandibular incisors and intrusion of the maxillary incisor teeth (Figure 3). Our results suggested that both first and second mandibular molars were extruded 0.5 mm on average, which was within the range of intra-examiner error. Similar changes were detected in the mandibular plane angle (Appendix Table 2). Taken together, it appears that the overbite improves in individuals with pre-treatment deepbite. Proclination of the mandibular incisors was the main mechanism of opening the bite.

3.3 THE INVISALIGN[®] APPLIANCE DEEPENS THE VERTICAL DIMENSION IN PATIENTS WITH PRE-TREATMENT OPENBITE

Overbite improved in all the patients with pre-treatment openbite (Figure 4). We found a median deepening of 1.5 mm in the openbite group (Appendix Table 3). Overbite correction in openbite patients was primarily by extrusion of maxillary and mandibular incisors ($\Delta U1-PP = 0.9$ mm, $\Delta L1-MP = 0.8$ mm).

No significant changes were detected in linear measurements of the posterior vertical dimension in patients with pre-treatment openbite (Appendix Table 3). Moreover, the mandibular plane angle changes were insignificant ($\Delta SN-MP = 0.3$ °).

Figure 3. Vertical Dimension Changes in Deepbite Patients Treated with the Invisalign® appliance (N=40)

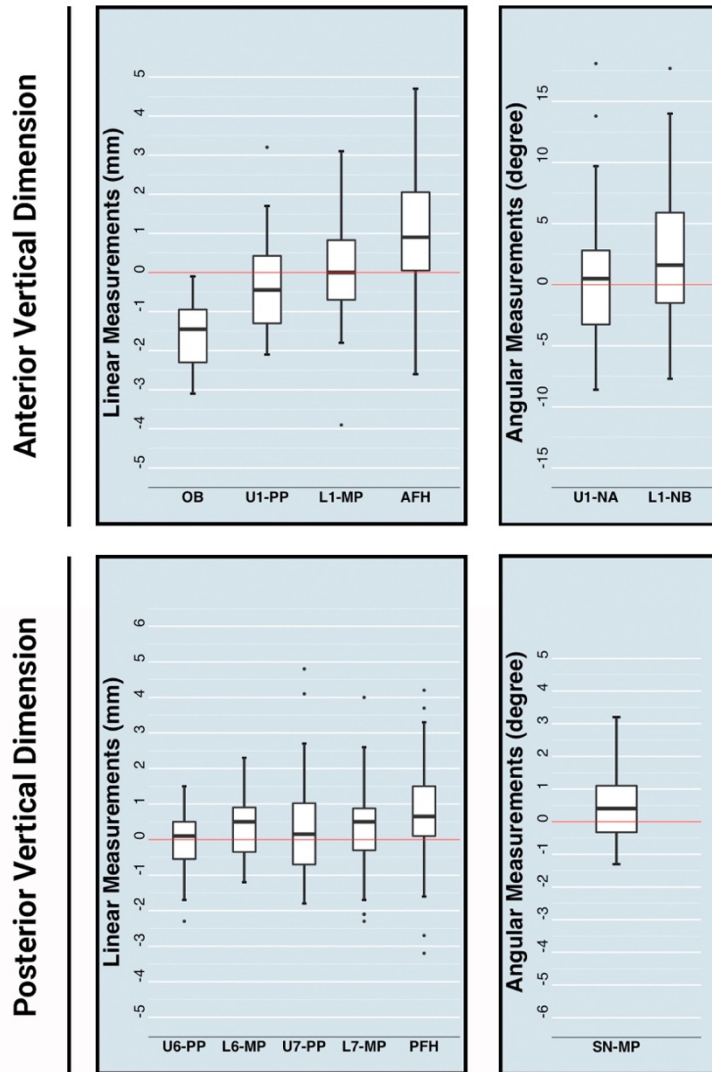


Figure 3 Legend. Lateral cephalometric radiographs of adult patients with pre-treatment deep bite were analyzed. Changes in initial and final cephalometric measurements, which examine anterior and posterior vertical dimension, were reported in the boxplots. Details of cephalometric measurements are presented in the supplementary data. The sample in this group was 40 patients. The Invisalign® appliance appeared to normalize the overbite primarily through proclination of mandibular incisors and intrusion of upper incisors. Mandibular molars were also slightly extruded.

Figure 4. Vertical Dimension Changes in Openbite Patients Treated with the Invisalign® appliance (N=12)

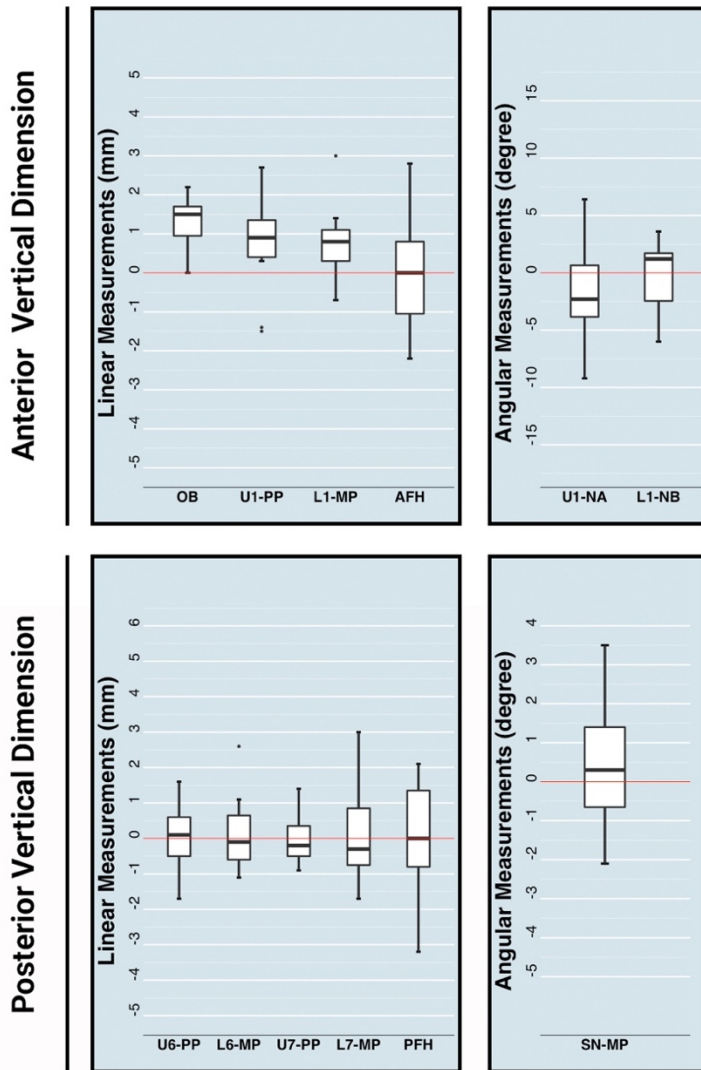


Figure 4 Legend. Lateral cephalometric radiographs of 12 adult patients with pre-treatment open bite were analyzed. To examine changes in the anterior and posterior vertical dimension, differences between initial and final cephalometric measurements were analyzed and are presented in the boxplots. Details of cephalometric measurements are reported in the supplementary data. The Invisalign® appliance reduced anterior overbite by extrusion of maxillary and mandibular incisors.

3.4 SIMILAR TREATMENT STRATEGIES ARE REPORTED TO MANAGE OVERBITE WITH THE INVISALIGN[®] APPLIANCE

The summary of extracted data from questionnaires filled out by the three practitioners is presented in Table 2. The two common approaches that these clinicians took to maintain the overbite in patient with pre-treatment normal overbite were trimming distal ends of the aligners covering second molars and maintaining the curve of Spee.

In order to correct deepbite, the studied orthodontists used (i) overbite over-correction, (ii) leveling the curve of Spee, and (iii) virtual bite ramps.

Utilizing attachments to extrude incisors was a common strategy among the three orthodontists to manage anterior openbite.

Table 3. Treatment Strategies to Manage Overbite

	Normal Overbite	Deepbite	Openbite
Practitioner A	<ul style="list-style-type: none"> • Virtual bite ramp • Cut off terminal molars or premolars • Cut distal to the canine in treatment-induced post openbite, sometimes along with vertical elastics 	<ul style="list-style-type: none"> • Virtual bite ramp • Vertical posterior elastics • No contacts on incisors • Over-correction of overbite • Level Curve of Spee 	<ul style="list-style-type: none"> • Attachments for extrusion of anterior teeth • Attachments for intrusion of posterior teeth
Practitioner B	<ul style="list-style-type: none"> • Trim distal of second molars • Do not use virtual bite ramps 	<ul style="list-style-type: none"> • Virtual bite ramps • Sometime no contacts on incisors • Over-correction of overbite • Use overcorrecting aligners 	<ul style="list-style-type: none"> • Attachment for extrusion of incisors • Extra thickness of plastics covering the posterior teeth • Over-correction of overbite • Clenching exercise to intrude posterior teeth
Practitioner C	<ul style="list-style-type: none"> • Maintain Curve of Spee • Maintain positive occlusal contacts on the posterior teeth 	<ul style="list-style-type: none"> • Level Curve of Spee by extruding mandibular premolars and intruding mandibular incisors • Level curve of Wilson 	<ul style="list-style-type: none"> • Attachment for extrusion of incisors (1 to 1.5 mm maximum) • Intrusion of posterior maxillary and mandibular teeth

Table 2 Legend. A questionnaire was used to determine treatment plan strategies for maintaining or correcting the overbite. This table summarizes the strategies used by each practitioner.

4 DISCUSSION

The idea to incrementally move teeth with removable clear appliances was introduced in the 1970s (Ponitz, 1971). In 1999, Align Technology introduced the Invisalign® technique, which was a modification to available clear aligners at the time. The Invisalign® technique utilized virtual digital technology to sequentially reposition the teeth to their correct locations (Align Technology, Inc., 1998). Plastic shells are then manufactured based on the sequential models.

The Invisalign® appliance has been greatly improved over the last 16 years. Nonetheless, our understanding of the appliance is largely limited to marketing claims released by Align Technology and some case reports, published in the orthodontic literature (Rossini et al., 2015). A recent systematic review on the efficiency of clear aligners in controlling orthodontic tooth movement identified 11 publications from 2000 to 2014. Six of these studies had a moderate risk of bias while the risk of bias in the other studies was unclear (Rossini et al., 2015). Therefore, one could reason that studies with large sample sizes and stringent research designs are required to better understand how the Invisalign® appliance corrects malocclusions. To this end, this study reports on management of overbite with the Invisalign® appliance using the records of consecutively treated patients from three private practices.

The first aim of this study was to investigate the control of overbite with the Invisalign® appliance in patients with pre-treatment normal overbite. Our results suggested that the Invisalign® appliance is typically successful in maintaining the anterior and posterior vertical dimension in these patients (Figure 5). This finding contradicts the common notion among clinicians that the Invisalign appliance deepens the bite. The assumption that the Invisalign® appliance deepens the overbite is often supported anecdotally by a practitioner's daily experience

as well as by a single early study that suggested that the Invisalign® appliance intrudes the posterior teeth during treatment, thereby increasing the overbite (Boyd et al., 2000). Our results indicate a trend of minor extrusion, up to 0.6 mm, of posterior teeth in patients with normal overbite. Improvements in the Invisalign technique, such as the virtual bite ramps, could be partly responsible for maintaining posterior vertical dimension despite the potential bite block effect of this appliance. An alternative explanation could be the employment of treatment strategies by orthodontists to avoid deepening of the overbite.

Figure 5. Overbite Changes in Patients with Pre-treatment Normal, Deep, and Open bites (N=120).

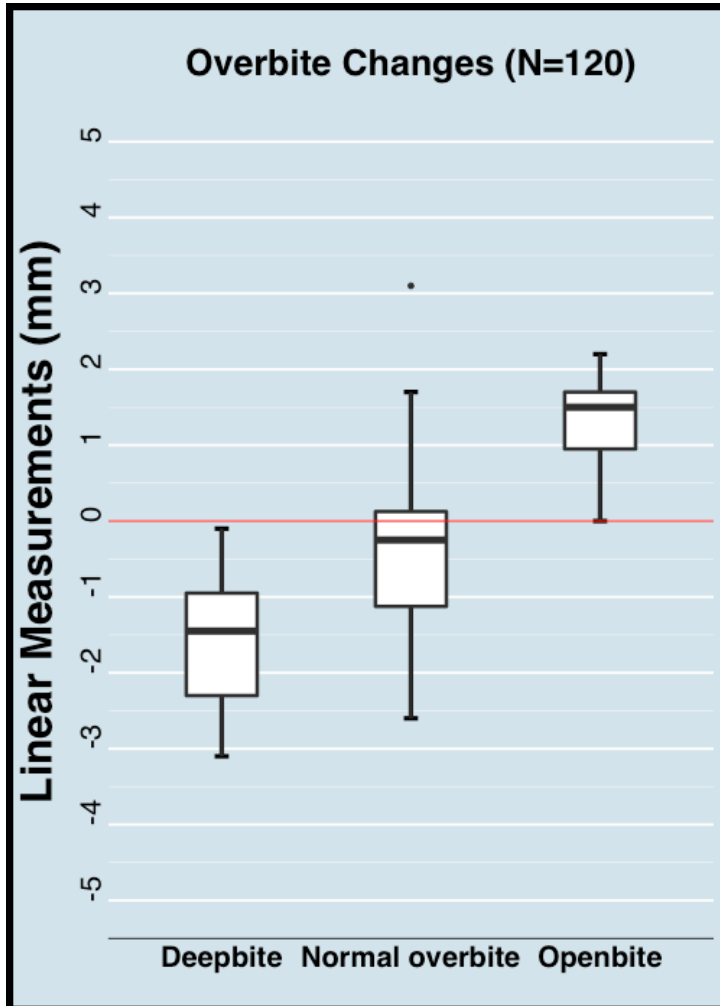


Figure 5 Legend. Cephalometric analyses were used to determine the overbite changes in patients treated with the Invisalign® appliance. The boxplot represents overbite changes among patients with normal, deep and open bites. Kruskal-Wallis analysis indicated that overbite changes among the three group of patients were statistically significant (p-value = 0.0001).

The second aim of this study was to determine the effectiveness of the Invisalign® appliance in correcting deepbites as well as openbites. Our findings from studying deepbite patients indicate that the anterior vertical dimension was improved in the majority of these patients (Figure 5). To our knowledge, this is the first report of a large consecutively treated sample of patients providing evidence that the Invisalign® appliance is effective for correcting overbite in patients with deepbite. Nonetheless, some of the more severe deepbites in our study were not corrected to normal overbite values. Moreover, the studied subjects were all treated prior to the introduction of Invisalign® G5 technology – specifically designed to treat patients with deepbite (Align Technology, Inc., 1998). Our cephalometric analyses to determine the mechanism by which the Invisalign® appliance corrects the deepbite suggests that proclination of mandibular incisors, along with intrusion of maxillary incisors and extrusion of the mandibular molars, were the primary sources of deepbite correction with the Invisalign® appliance. These findings contradict the recommendation by a recent systematic review suggesting that the Invisalign® appliance could only be used to treat mild deepbites (Rossini et al., 2015).

Part of the second aim of this study concentrated on patients with pre-treatment openbites. We found that the Invisalign® appliance appeared to be successful in improving the overbite in patients with moderate anterior openbite (Figure 5). Additionally, these corrections were mainly linked to extrusion of the incisors. Our results contradict the recommendation by a systematic review not to use the Invisalign® appliance to treat patients with openbite (Rossini et al., 2015). This recommendation was based on a study reported a partial success in extrusion of anterior teeth with the Invisalign® appliance (Kravitz et al., 2009).

Collectively, the results of our second aim indicated that overbite improved in all of the studied patients with openbites and deepbites. Moreover, the overbite was corrected to the normal

overbite range in the majority of these patients (Figure 6). Note that the overbite in patients with pre-treatment normal overbite remained in the normal overbite range (Figure 6).

Figure 6. Scatterplot Representing Post-treatment Overbite as a Function of Pre-treatment Overbite (N=120)

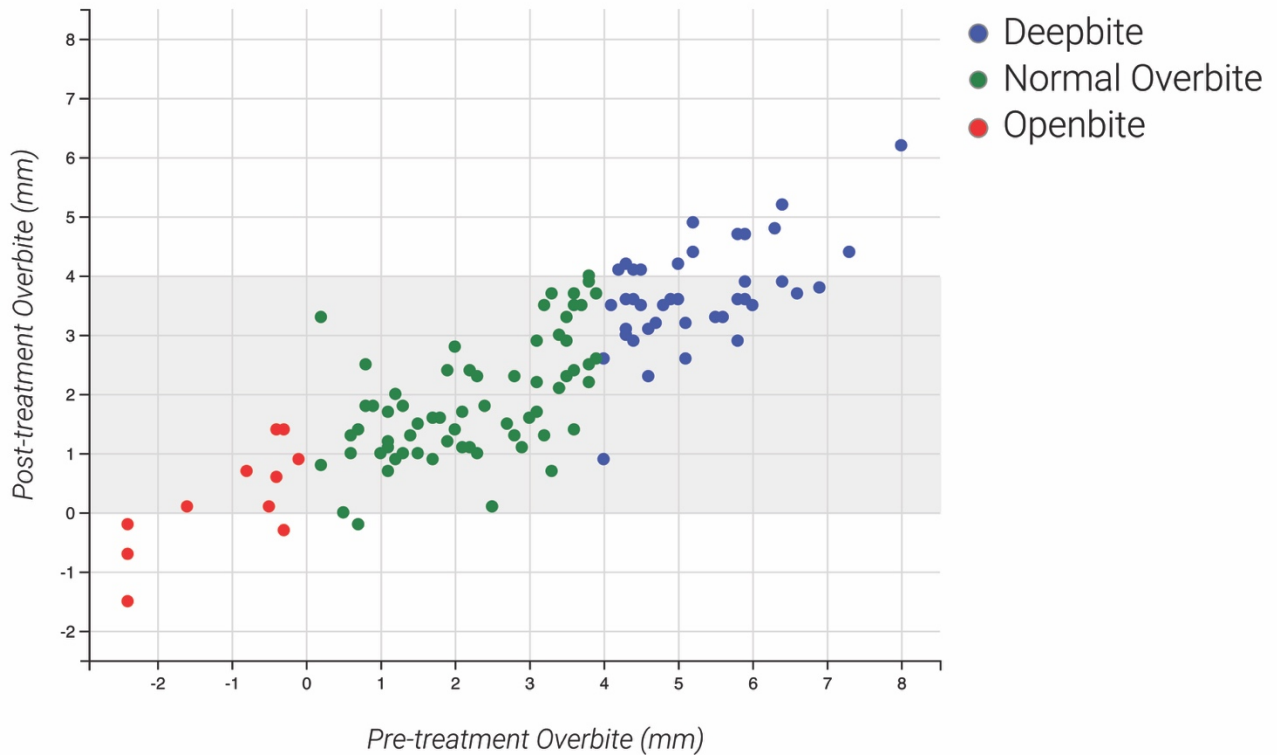


Figure 6 Legend. Overbite measured in pre and post-treatment cephalometric radiographs were plotted to examine the post-treatment overbite association with pre-treatment overbite. This plot delineates that patients with normal overbite (green dots) stay in the normal overbite range (gray zone). Additionally, our results indicate that overbite improves in all patients with deepbites (blue dots) and openbites (red dots), and that the majority of these patients achieved an overbite range between 0 to 4 mm, which could be considered to be within the range of normal overbite.

The third aim of the study wished to identify the effectiveness of treatment strategies often used to maintain or correct overbite with the Invisalign® appliance. We could not collect complete patient specific information used to correct or control the overbite in our studied sample. We learned that the practitioners have routine strategies, which are often not documented in the patient records. Nonetheless, it would seem that these strategies (Table 3) are usually effective in maintaining or achieving normal anterior vertical dimensions.

Despite the growing use of the Invisalign® appliance and the evolving improvement of the appliance, most of our knowledge about the Invisalign® system is limited to case reports and non-peer reviewed published data by Align Technology. A recent systematic review on the effectiveness of the Invisalign® appliance recommended that randomized clinical trials with rigorous methodology should be conducted to determine the effectiveness of the Invisalign® appliance (Rossini et al., 2015). While we agree with the authors, one of the essential barriers to conduct randomized clinical trials to evaluate the effectiveness of the Invisalign® appliance is the lack of available funding. Therefore, one can reason that at this time well-designed retrospective studies might improve our knowledge until randomized trials can be performed.

Our results suggested that 1.5 mm of overbite improvement is achieved with the Invisalign® appliance in deepbite patients can be expected. A previous systematic review on the stability of deepbite correction reported an average of 3 mm overbite correction with the fixed appliances (Huang et al., 2012). We also found that the Invisalign® appliance was associated with a median correction of 1.5 mm in openbite patients, which is half of the reported average openbite correction with a non-surgical fixed appliance approach (Greenlee et al., 2011). These comparisons may indicate that aligners can usually improve deepbites and openbites yet the aligners may not be able to produce as much correction as fixed appliances.

5 LIMITATIONS

Challenges in lateral cephalometric analysis were the primary limitation of this study (Houston et al., 1986). Inconsistent head positioning, movement during the exposure, inconsistent exposures, magnification error, and landmark identification are all potential challenges in studies utilizing lateral cephalometric radiographs. To reduce the potential errors, we opted to use Dolphin Imaging software for our cephalometric analyses. This allowed us to reduce the potential error to only landmark identification since the software automatically calculate the linear and angular measurements (Erkan et al., 2012). This also lessened the chance for investigator bias. Second, all the pre and post-treatment cephalometric radiographs were taken using the same cephalometric x-ray machines in all three practices. Additionally, the landmark identification on pre and post-treatment radiographs was sequentially performed to reduce the error.

The second limitation of this study was the fact that almost 50% of screened patients were not included because of the absence of post-treatment cephalometric radiographs. It is unknown whether this might have introduced selection bias to this study.

The small sample size for the openbite group is the third limitation of this study. Most of the screened patients were treated with a surgical approach, which eliminated them from inclusion in this study. Further studies with larger samples of openbite patients are needed to verify our findings.

Finally, it should be noted that all three practitioners have considerable experience with the Invisalign® appliance. This is not necessarily a limitation, but it is possible that the results they achieved in these patients may be better than those achieved by less experienced clinicians.

6 CONCLUSION

We conclude that the Invisalign[®] appliance is relatively successful in managing overbite. Specifically, the Invisalign[®] appliance maintains the overbite in patients with normal overbite. Additionally, our results did not support the alleged intrusion of posterior teeth during treatment with the Invisalign[®] appliance. We also found that the Invisalign[®] appliance could improve overbite in deepbite patients primarily by proclination of the mandibular incisor teeth. Finally, we found that the Invisalign[®] appliance could reduce mild to moderate anterior openbite mainly through extrusion of the incisor teeth.

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APPENDIX A

Appendix Table 1. Cephalometric Analysis of Patients with Pre-treatment Normal Overbite Treated with the Invisalign® Appliance (N=68)

	Mean			Median			SD			Min			Max			Wilcoxon Signed-Rank
	T0	T1	Δ	T0	T1	Δ	T0	T1	Δ	T0	T1	Δ	T0	T1	Δ	P-Value
Incisors position (Linear Measurement)																
Overbite	2.3	1.9	-0.4	2.3	1.7	-0.3	1.1	1.0	1.0	0.2	-0.2	-2.6	3.9	4.0	3.1	0.0012*
U1 to Palatal Plane	27.9	28.0	0.1	27.7	27.8	0.0	2.8	2.9	1.1	20.3	20.9	-2.2	34.5	35.0	3.1	0.4824
L1 to Mandibular Plane	41.0	41.1	0.1	41.3	41.1	0.1	3.3	3.3	1.0	34.0	34.2	-2.3	49.0	49.2	2.4	0.6554
Anterior Facial Height	65.4	66.1	0.7	65.9	66.1	0.7	5.0	5.3	1.8	51.4	53.2	-3.5	75.6	76.9	5.0	0.0032*
Incisors Position (Angular Measurement)																
U1 - Nasion-A-point	19.9	18.2	-1.7	19.1	18.8	-0.7	5.9	5.3	5.4	5.9	2.7	-17.7	35.6	30.4	8.0	0.0454*
L1 - Nasion-B-point	25.9	26.0	0.1	25.4	25.7	0.6	5.9	4.6	4.8	11.4	8.7	-15.1	51.6	42.3	9.3	0.5311
Molar position (Linear Measurement)																
U6 to Palatal Plane	22.3	22.5	0.2	22.4	22.1	0.2	2.3	2.4	0.9	15.8	16.5	-2.2	30.4	30.4	3.3	0.0651
L6 to Mandibular Plane	32.4	32.7	0.3	32.5	32.3	0.4	2.8	2.9	1.0	25.7	26.8	-2.1	38.2	38.4	2.1	0.0228*
U7 to Palatal Plane	19.7	19.7	0.1	19.9	19.6	0.1	2.7	2.8	0.8	13.2	11.6	-2.4	29.5	29.4	1.6	0.3552
L7 to Mandibular Plane	29.9	30.1	0.2	30.3	29.9	0.4	2.9	2.9	1.2	23.1	22.8	-4.0	36.4	36.6	2.3	0.0406*
Posterior Facial Height	86.9	87.2	0.3	87.6	88.0	0.3	7.2	7.0	1.6	72.4	70.5	-3.8	103.3	102.1	3.3	0.1228
Mandibular Plane (Angular Measurement)																
SN - Mandibular plane	29.6	29.9	0.3	29.2	29.5	0.4	7.1	7.0	1.6	13.2	15.4	-4.1	53.1	50.4	4.4	0.0935

Appendix Table 1 Legend. Summary of linear and angular cephalometric measurements for patients with normal overbite. P-value and 95% confidence interval were calculated using the Wilcoxon signed-rank at 0.5 levels of significance. T0 = Pre-treatment; T1= Post-treatment; Δ = Pre to post-treatment changes, * = Statistically significant at the $\alpha=0.5$ significance levels.

Appendix Table 2. Cephalometric Analysis of Patients with Pre-treatment Deepbite Treated the Invisalign® Appliance (N=40)

	Mean			Median			SD			Min			Max			Wilcoxon Signed-Rank
	T0	T1	Δ	T0	T1	Δ	T0	T1	Δ	T0	T1	Δ	T0	T1	Δ	P-Value
Incisors position (Linear Measurement)																
Overbite	5.3	3.7	-1.6	5.1	3.6	-1.5	1.0	0.9	0.9	4.0	0.9	-3.1	8.0	6.2	-0.1	0.0001*
U1 to Palatal Plane	29.0	28.6	-0.4	29.5	28.4	-0.5	3.4	3.3	1.1	22.4	22.7	-2.1	35.6	37.9	3.2	0.0259
L1 to Mandibular Plane	41.1	41.2	0.0	40.6	41.4	0.0	4.3	4.4	1.3	32.9	33.7	-3.9	53.4	53.0	3.1	0.8718
Anterior Facial Height	65.0	66.0	1.0	64.2	64.9	0.9	6.9	6.8	1.7	53.5	55.3	-2.6	81.0	80.9	4.7	0.0009*
Incisors Position (Angular Measurement)																
U1 - Nasion-A-point	12.8	13.3	0.4	12.7	12.9	0.5	6.2	7.4	5.5	-0.1	0.3	-8.6	30.1	28.1	18.1	0.8350
L1 - Nasion-B-point	21.7	24.2	2.5	20.1	23.4	1.6	8.8	7.9	5.8	4.6	7.3	-7.7	42.8	42.3	17.7	0.0201*
Molar position (Linear Measurement)																
U6 to Palatal Plane	21.9	21.8	-0.1	21.8	21.3	0.1	3.2	3.2	0.9	15.6	16.3	-2.3	29.1	29.1	1.5	0.9458
L6 to Mandibular Plane	32.3	32.7	0.4	31.5	32.6	0.5	3.3	3.3	1.0	26.5	26.9	-1.2	39.2	39.5	2.3	0.0164*
U7 to Palatal Plane	18.0	18.4	0.4	17.9	17.9	0.2	3.9	3.3	1.4	7.7	11.8	-1.8	26.0	26.6	4.8	0.2136
L7 to Mandibular Plane	29.3	29.7	0.4	28.8	29.1	0.5	3.1	3.1	1.3	24.1	24.5	-2.3	36.3	37.6	4.0	0.0489*
Posterior Facial Height	86.6	87.2	0.7	85.1	86.2	0.7	8.1	8.5	1.5	74.1	74.1	-3.2	107.4	108.9	4.2	0.0652
Mandibular Plane (Angular Measurement)																
SN - Mandibular plane	28.9	29.4	0.5	29.9	30.6	0.4	7.1	7.0	1.0	10.7	12.2	-1.3	44.7	44.6	3.2	0.0104*

Appendix Table 2 Legend. Summary of linear and angular cephalometric measurements for patients with deepbite. P-value and 95% confidence interval were calculated using the Wilcoxon signed-rank at 0.5 levels of significance. T0 = Pre-treatment; T1= Post-treatment; Δ = Pre to post-treatment changes, * = Statistically significant at the $\alpha=0.5$ significance levels.

Appendix Table 3. Cephalometric Analysis of Patients with Pre-treatment Openbite Treated the Invisalign® Appliance (N=12)

	Mean			Median			SD			Min			Max			Wilcoxon Signed-Rank
	T0	T1	Δ	T0	T1	Δ	T0	T1	Δ	T0	T1	Δ	T0	T1	Δ	P-Value
Incisors position (Linear Measurement)																
Overbite	-1.1	0.2	1.3	-0.5	0.1	1.5	1.0	0.9	0.6	-2.4	-1.5	0.0	-0.1	1.4	2.2	0.005*
U1 to Palatal Plane	29.6	30.3	0.7	28.9	28.7	0.9	3.7	3.8	1.2	24.9	25.4	-1.5	35.9	36.5	2.7	0.129
L1 to Mandibular Plane	42.8	43.5	0.8	43.5	43.5	0.8	3.6	4.1	1.0	38.0	37.3	-0.7	49.4	52.4	3.0	0.029*
Anterior Facial Height	71.6	71.6	0.0	69.8	69.4	0.0	6.9	7.4	1.5	61.8	61.1	-2.2	82.1	82.8	2.8	0.878
Incisors Position (Angular Measurement)																
U1 - Nasion-A-point	22.3	20.9	-1.4	25.1	22.7	-2.3	7.6	6.6	4.7	11.0	6.5	-9.2	34.3	30.2	6.4	0.248
L1 - Nasion-B-point	30.2	30.1	-0.1	27.6	30.0	1.2	6.0	5.7	2.9	22.7	20.2	-6.0	37.4	37.6	3.6	1
Molar position (Linear Measurement)																
U6 to Palatal Plane	23.5	23.6	0.1	22.9	22.8	0.1	3.4	3.6	1.0	19.2	18.4	-1.7	28.8	29.0	1.6	0.799
L6 to Mandibular Plane	33.1	33.3	0.2	33.6	32.8	-0.1	2.9	3.7	1.1	29.4	29.2	-1.1	40.0	42.6	2.6	0.929
U7 to Palatal Plane	19.9	19.9	0.0	19.6	19.6	-0.2	3.5	3.6	0.8	15.7	15.4	-0.9	25.8	25.6	1.4	0.790
L7 to Mandibular Plane	30.0	30.2	0.2	29.8	29.6	-0.3	2.8	3.9	1.4	27.0	25.3	-1.7	37.4	40.4	3.0	0.965
Posterior Facial Height	84.2	84.2	0.1	84.8	84.2	0.0	7.2	7.5	1.6	75.6	75.0	-3.2	101.8	102.1	2.1	0.799
Mandibular Plane (Angular Measurement)																
SN - Mandibular plane	36.5	36.9	0.4	36.1	36.2	0.3	8.0	7.0	1.7	25.7	26.6	-2.1	51.5	51.5	3.5	0.445

Appendix Table 3 Legend. Summary of linear and angular cephalometric measurements for patients with openbite. P-value and 95% confidence interval were calculated using the Wilcoxon signed-rank at 0.5 levels of significance. T0 = Pre-treatment; T1= Post-treatment; Δ = Pre to post-treatment changes, * = Statistically significant at the $\alpha=0.5$ significance levels.