2021

Efficacy Of Lower Incisor Intrusion Using Clear Aligners

Cason Roberson
University of Alabama at Birmingham

EFFICACY OF LOWER INCISOR INTRUSION USING CLEAR ALIGNERS

by

CASON J ROBERSON

NADA SOUCCAR, COMMITTEE CHAIR
ANDRE FERREIRA
CHIN-CHUAN FU
AMJAD JAVED
CHRISTOS VLACHOS

A THESIS

Submitted to the graduate faculty of The University of Alabama at Birmingham,
in partial fulfillment of the requirements for the degree of
master of science

BIRMINGHAM, ALABAMA

2021

EFFICACY OF LOWER INCISOR INTRUSION USING CLEAR ALIGNERS

CASON J ROBERSON

ORTHODONTICS

ABSTRACT

Objective: The primary objective of this study is to evaluate pre and posttreatment lateral cephalometric radiographs on patients treated with Invisalign by the same orthodontist where lower incisor intrusion was prescribed and to determine the amount of true lower incisor intrusion achieved during treatment.

Methods: This retrospective case series study included 48 patients with an overbite exceeding 2mm, who were treated with Invisalign clear aligner therapy, and whose Clincheck treatment plan included lower incisor intrusion. The mean age of the study group was 27 years with 14 (29%) of the subjects being male and 35 (71%) being female. The mean treatment time was 13.77 months. Patients were consecutively treated by the same private practice orthodontist using the same treatment protocols. Pretreatment and posttreatment lateral cephalograms were analyzed to determine changes due to orthodontic treatment and were compared to the predicted Clincheck movements.

Results: A statistically significant change ($P<0.05$) was seen in 6 of the 15 cephalometric measurements. OB was decreased an average of 0.7mm (±1.0mm), OJ was decreased 0.6mm (±1.5mm), ANB decreased 0.2mm (±1.1mm) the upper molars (U6-PP) were extruded 0.6mm (±1.0mm), the lower molars (L6-MP) were extruded 0.3mm (±0.9mm), and the anterior facial height (AFH) was increased 0.4mm (±1.4mm). No significant difference was found in the distance from the center of resistance of the lower incisor to the mandibular plane (Midpoint Root), which showed an average change of 0.1mm (±1.2mm).

Conclusions: The amount of lower incisor intrusion seen in this study did not reflect the efficacy that has been presented in previous studies. Our study did show that Invisalign was predictably able to reduce overbite in patients with a pretreatment deep bite and that this correction occurs primarily due to posterior extrusion, secondarily due to relative intrusion, or a change lower incisor proclination, and tertiarily due to lower incisor intrusion.

Keywords: Invisalign, clear aligner, deep bite, lower incisor, mandibular incisor, intrusion

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

LITERATURE REVIEW

Overbite is determined by the amount of vertical overlap of the maxillary and mandibular incisors, measured as either the distance between the incisal edges or the percentage overlap of the mandibular incisors. Ideal overbite is defined to be from 0 to 2 mm or 5-40% overlap and excessive overbite, or deep bite, as measuring greater than 2mm or 40%.[1–4] In his review of the Third National Health and Nutrition Examination Survey (NHANES III), Proffit noted an overbite of 3mm or greater was reported in approximately 50% of the United States population. This number was slightly higher for those in the mixed dentition at 56%.[5] In a 2018 systematic review of studies on the prevalence of various malocclusions, Alhammadi et al. reported the global incidence of a deep bite greater than 2.5 mm to be 22% in adults and 24% in the mixed dentition.[6] Deep bites can be a product of either skeletal growth or dental compensation and can occur in any anteroposterior malocclusion (Class I, II and III) or vertical growth pattern (hypodivergent and hyperdivergent), but it is most commonly associated with skeletal hypodivergent Class II division 2 patients.[2,7]

Prior to Viken Sassouni, the popular cephalometric analyses were the Downs and Steiner analysis. And though the Steiner analysis did include one vertical measurement (mandibular plane to SN), these two analyses primarily evaluated the skeletal contributions to a malocclusion from an anteroposterior perspective.[1] Sassouni hypothesized that there was a constant in the architecture of the head that results in a vertically well-proportioned facial profile. He defined four horizontal bony planes which consisted of the anterior cranial base (supraorbital) plane, the palatal plane, the occlusal plane, and the mandibular plane and evaluated their relationship to each other. It was the convergence of these planes posteriorly at a common point, defined as O, that Sassouni considered an important contribution to a well-proportioned face. He noted that in vertical disproportions, as in the case of skeletal deep bites, these planes would carry the center of convergence (point O) far from the posterior aspect of the skull.[8,9]

The cause of a deep bite is multifactorial and results from reduced lower face height, flat mandibular plane angle, more acute gonial angle, insufficient eruption of the posterior teeth or over eruption of the anterior teeth, and an increased curve of Spee.[2] Factors affecting treatment approach depend on the patient's growth status, mandibular plane angle, and incisal display on rest and smile.[10] Nonsurgical treatment of a deep bite can be accomplished by extrusion of the posterior teeth, relative intrusion of the incisors, true intrusion of the maxillary or mandibular incisors or a combination of these.[11–13] Relative intrusion can involve holding the incisors in their current position while the posterior teeth erupt, or are extruded, or by proclining or flaring of the incisors. Any eruption of the posterior teeth in the absence of growth can result in the downward and backward rotation of the mandible and an increase in facial convexity.[14,15] Additionally, Varlik et al. notes "Extrusion of the posterior dentition, although an effective method of bite opening in growing patients, is not indicated in patients with normal incisor display or normal or longer lower facial height [and] its stability is questionable in nongrowing patients with average to low mandibular plane angles."[13] True intrusion of the maxillary incisors is indicated in patients with excessive incisal display at rest or excessive incisal and gingival display on smiling, while true intrusion of mandibular incisors requires a favorable maxillary incisal and gingival display.[12,13] If our objective is to reduce or hold the vertical dimension, correction of the deep bite requires true intrusion of the anterior teeth. Relative intrusion as the sole method of correcting a deep bite has a very limited application because it requires that the incisors' pretreatment position be upright, or retroclined, to allow for the proclination required for correction. However, Shudy does note that in cases where orthodontic treatment is initiated around age 11 it results in a cessation of vertical growth of the mandibular incisor, resulting relative intrusion.[7]

Treatment Approaches

Burstone states that "The decision to intrude [anterior teeth] or extrude [posterior teeth] is based on at least 3 factors: skeletal convexity, vertical dimension, and the interocclusal (freeway) space. The estimated amount of growth during treatment helps to determine the amount that posterior teeth can be extruded."[15] Tweed advocated for leveling the mandibular arch through the use of a continuous arch wire with a reverse curve of Spee and class III elastics. This technique allowed for the extrusion of the molars and premolars while allowing for minimal proclination and intrusion of the lower incisors .[16,17] Ricketts' utility arch allowed for leveling of the curve of Spee and deep bite correction through intrusion of the lower incisors to the level of the premolars, rather than by extrusion of the posterior segments, and thereby limiting any backward rotation of the mandible.[18] In their 1989 study, Dake and Sinclair looked at the results of these two arch leveling techniques in patients treated by Dr. Robert Ricketts and Dr. Fred Schudy. They found that both methods effectively corrected the deep bite. The group treated by Dr. Ricketts showed more incisor intrusion but also showed more proclination and protrusion of the lower incisors than the group treated by Dr. Schudy. Both groups showed a similar amount extrusion of the lower first molar with minimal change to the mandibular plane angle and anterior facial height.[16]

With the advent of temporary anchorage devices (TADs) came the ability to perform some orthodontic movements with less difficulty and eliminating or minimizing counteracting side effects of certain treatment mechanics.[19,20] One approach to leveling the mandibular arch through lower incisor intrusion is with a segmental arch wire and two TADs placed between the lower lateral incisors and the canines.[10] This allows for the application of an intrusive force that does not have the potential for distal tipping and extrusion of the mandibular first molar that can result with the use of a utility arch. In comparison of intrusion of the lower incisors using temporary anchorage devises with that of a utility arch, Aydogdu and Ozsoy found that both methods were equally effective in achieving incisor intrusion with the only difference between the two techniques being distal tipping of the lower first molar in the utility arch group.[10]

In his 1945 paper titled "The philosophy of the tooth positioning appliance," Harold Kesling laid the foundation of what would become a multibillion dollar industry focused on the manufacturing of series of removable polyurethane aligners individualized for each orthodontic patient, prescribed by their orthodontist as an alternative to fixed appliances for the correction of their malocclusion.[21,22] In 1999, Align Technology (Santa Clara, California) introduced the Invisalign system and over the last twenty years they have utilized digital scanning technology, continued product development, and algorithmic improvements to carve out an increasing percentage of the orthodontic market; their website reports its use in the treatment of over 8 million orthodontic cases.[23] The earliest versions of the Invisalign system, similar to the Kesling's positioner, was primarily used in cases with minor crowding or spacing, slight rotations, changes in axial position, or minor changes to the arch form. It wasn't until the second generation of aligners, and the addition of bonded attachments, bonded buttons, and intermaxillary elastics that the Invisalign system was able to predictably correct moderate malocclusion.[22,24] As the system has continued to evolve, more complex treatment has become possible however it still lacks the efficacy in consistently achieving the proposed treatment plan, or Clincheck, without need for refinement scans and additional Clinchecks. Additionally, there are some clinicians that remain uncertain about the types of movements that a clear aligner system can predictably accomplish. Several studies have been conducted to evaluate the accuracy of the proposed movements planned by the Invisalign software. In 2009, Kravitz et al. reported a mean accuracy in predicted tooth movements of the anterior teeth of 41% and the accuracy of mandibular lateral and central incisor intrusion found to be 40% and 46.6.%, respectively.[21] Drake et al. evaluated the achieved proposed movement of incisors needing "minor alignment" over an 8 week period and found 55% of the prescription was achieved.[25] In a very similar study, Chisari et al. looked at the efficacy of moving a single maxillary incisor 1mm labially and reported an average of 57% achieved movement.[26] Krieger et al. noted a high level of agreement between the planned and achieved movements of anterior teeth in the sagittal and transverse planes, however, movements in the vertical plane resulted in larger deviations.[27] In a 2017 study, Khosravi et al. looked at management of overbite using Invisalign by comparing pre and posttreatment cephalograms and reported a 1.5mm improvement in deep bite correction. This improvement they noted came primarily from proclination of the lower incisors with extrusion of mandibular first and second molars as an additional factor. This study, however, did not evaluate the efficacy of the proposed movements prescribed by the Invisalign Clincheck.[28] In an evaluation of treatment in the maxillary arch, an overall efficiency in molar distalization, premolar derotation, and incisor torquing movements of 59.3% was reported in a 2014 study by Simon et al..[29] Most recently, Al-Balaa et al. in a 2021 article evaluated the predicted and actual outcome of anterior intrusion with Invisalign using cone-beam computed tomography. They reported an overall anterior intrusion efficacy of 51.19% and a mandibular incisor efficacy of 44.71%.[30]

Evaluation of Treatment

Posttreatment evaluation of orthodontic intrusion of incisors is difficult to determine due to the inevitable labio-lingual change in tooth angulation during treatment.[31] This change in angulation will alter the position of the incisal edge leading to what is termed "pseudo-intrusion/extrusion" or "relative intrusion/extrusion."[14] This relative intrusion is difficult to separate from true bodily intrusion of a tooth without determining the vertical change in the center of resistance of the tooth due to treatment. Several methods have been described in past studies to evaluate orthodontic intrusion. Many of these same methods have been applied to studies evaluating Invisalign treatment, sometimes combining them with methods to evaluate how those changes compare to what was predicted by the Clincheck software. Kravitz et al., Drake et al., and Krieger et al. superimposed digitized pretreatment and posttreatment models to evaluate Invisalign treatment outcomes using a software called ToothMeasure (Align Technology, Santa Clara, California). Both studies looked at what movements resulted in the correction of the malocclusion while Kravitz et al. looked additionally at how these movements correlated with the predicted movements of the associated Clincheck.[21,27] Simon et al. used a similar technique involving laser scanning of pre and posttreatment models to compare with the Clincheck proposed model using Surfacer 10.0 software (Imageware/Siemens PLM Software, Pano, Texas, USA).[29] These methods of model superimposition use the incisal edge in reference to the occlusal plane to determine incisor intrusion or extrusion, both of which are highly variable during treatment and make it very difficult to separate true intrusion from relative intrusion. In the discussion of his study's results Kravitz wrote, "Future studies should incorporate lateral cephalometric or volumetric 3-dimensional cone-beam imaging to assess tooth movement with Invisalign, as an alternative to superimposing on stationary posterior teeth. Such studies will allow for the evaluation of posterior teeth movement and address questions regarding root movement with Invisalign."[21] Otto et al. focused on the vertical change in the root apex position on pre and posttreatment lateral cephalograms stating, "It is inaccurate to measure intrusion at the incisal edges of labially tipped teeth, without accounting for the changes in axial inclination."[32] This method, however, has its own limitations in that it does not account for any apical root resorption that may occur during treatment, and that the root apex position is also changes during any uncontrolled tipping movements. In 2021, Al-Balaa et al. used cone-beam computed tomography to evaluate true intrusion, however, the incisal edge was still used as the reference point to evaluate the vertical change in the lower incisor to mandibular plane.[30]

Burstone advocated for evaluation of true intrusion by measuring the apical movement of the geometric center of the root, or the centroid.[14] Centroid is a geometric term that describes the center of mass of an object. This concept applied to orthodontics has been termed the center of resistance and is defined in single-rooted teeth as being between one third and one half of the root length from the alveolar crest.[33] It is the reference point of choice when determining true intrusion because it is independent of any change in inclination.[34] The centroid point is identified on a pretreatment lateral cephalogram and compared to a defined horizontal plane (the palatal plane for the upper incisor and the mandibular plane for the lower incisor). This point is then transferred to the posttreatment cephalogram and the vertical change between the two points is the true intrusion achieved during treatment. Previous studies have set their center of resistance, or centroid point, at 30 to 40% the length of the root from the alveolar crest. [13,31]

Aim

The primary objective of this study is to evaluate pre and posttreatment lateral cephalometric radiographs on patients treated with Invisalign by Dr. Andre Ferreira where lower incisor intrusion was prescribed and to determine the amount of true lower incisor intrusion achieved during treatment. A secondary objective will be to compare the amount of tooth movement achieved to that which was predicted by the Clincheck software to determine the efficacy of the prescribed movements. Previous studies evaluating the efficacy of various tooth movements using Invisalign have found the overall accuracy of the Clincheck predictions to be less than 60%.[25,26,29] Furthermore, the lower incisor intrusion achieved during treatment was noted to be as low as 40% of that which Clincheck predicted.[21] With the continued evolution of aligner technology and treatment techniques, it is very likely that the efficacy of lower incisor intrusion has increased in kind.

Our hypothesis is that intrusion of lower incisors using clear aligners shows greater than 50% accuracy when clinical outcome, evaluated through pre and posttreatment cephalometric radiographs, is compared to the amount of intrusion predicted by the Clincheck software.

Specific Aim: To assess the amount of lower incisor intrusion that can predictably be achieved with clear aligners by comparing pre and posttreatment lateral cephalograms.

CHAPTER 2

MATERIALS AND METHODS

Samples

Pretreatment (T1) and posttreatment (T2) lateral cephalograms of 48 patients who were treated with Invisalign and whose Clincheck (Align Technology, Santa Clara, California) treatment plan prescribed mandibular incisor intrusion for correction of a deep bite. All patients were treated by Dr. Andre Ferreira (A.F.) in his private practice in Anniston, Alabama. This sample consisted of subjects ranging in age from 11-61.

The inclusion criteria for this study were the following: (1) Permanent dentition with an overbite exceeding 2mm, (2) No dental or congenital abnormalities, (3) No reported habits, to include finger sucking or tongue thrust, (4) Non-extraction and non-surgical treatment approach, (5) Clincheck treatment plan that prescribes mandibular incisor intrusion, (6) No other appliances or auxiliaries used during treatment. Exclusion criteria: (1) Inadequate pretreatment or posttreatment lateral cephalograms (2) Inadequate pretreatment Invisalign scans with corresponding Clincheck representations.

Treatment Protocol

The treatment began with an intraoral digital scan of the patient's maxillary and mandibular dentition as well as their bite in maximum intercuspation, using an Itero digital scanner. All scans were then sent to Invisalign to be added to a prescription for submission and generation of a Clincheck treatment plan. Attachments were placed on the teeth according to the final accepted treatment plan and aligners were given to the patient with instructions to change at prescribed intervals. At the completion of treatment, attachments were removed and a lower fixed retainer bonded on both lower canines and all lower incisors and overlay essix retainers were fabricated for the maxillary and mandibular arches and delivered to the patient.

Data Collection and Cephalometric Analysis

Lateral cephalometric head films were taken at two different time points: the beginning of orthodontic treatment (T1) and the completion of orthodontic treatment (T2). Each lateral cephalometric head film was imported into Dolphin Imaging software (Patterson, Chatsworth, California) and was digitally traced by a third-year orthodontic resident (C.R.) at the University of Alabama at Birmingham. A total of 15 landmarks were identified on each cephalometric head film. These landmarks included 6 angular measurements and 9 linear measurements. The center of resistance of the lower incisor was established as the midpoint of the length of the root measured from the alveolar crest to root apex.

Table 1. Summary of Cephalometric Measurements

Measurement	Definition
SKELETAL	
SNA (º)	Anteroposterior position of maxillary base to the anterior cranial base
SNB (º)	Anteroposterior position of mandibular base to the anterior cranial base
ANB (º)	Anteroposterior relationship of maxillary base to mandibular base
MP-SN (º)	Mandibular plane angle, angle between mandibular plane, gonion (Go) – menton (Me), and anterior cranial base plane (Sella-Nasion)
Posterior Face Height (PFH) (mm)	Posterior facial height, linear measurement from sella (S) to gonion (Go)
Anterior Face Height (ANS-Me / AFH) (mm)	Lower anterior facial height, linear measurement from anterior nasial spine (ANS) to menton (Me)
DENTAL	
U1-PP (º)	Angle between the long axis of the most anterior maxillary central incisor and palatal plane (PP)
L1-MP (º)	Angle between the long axis of the most anterior mandibular central incisor and mandibular plane (MP)
U1-NA (mm)	Linear measurement from NA line to labial surface of most anterior maxillary central incisor
L1-NB (mm)	Linear measurement from NB line to labial surface of most anterior mandibular central incisor
U6-PP (mm)	Maxillary posterior dentoalveloar height, perpendicular distance between the mesial cusp of the maxillary first molar and the palatal plane (PP)
L6-MP (mm)	Mandibular posterior dentoalveolar height. perpendicular distance between mesial cusp of the mandibular first molar and the mandibular plane (MP)
Midpoint Root (mm)	Center of resistance to mandibular plane, perpendicular distance from the midpoint of the mandibular central incisor root, from alveolar crest to root apex, to the mandibular plane (MP)
Overbite (OB) (mm)	Vertical distance between the incisal edges of the maxillary and mandibular central incisors
Overjet (OJ) (mm)	Horizontal distance between the incisal edges of the maxillary and mandibular central incisors

Intraoral scans producing digital models were also taken at the beginning of orthodontic treatment (T1) and submitted to Invisalign for generation of a proposed orthodontic treatment plan. Linear measurements were taken from the scanned models and the final predicted treatment outcome from the approved Clincheck simulation for comparison with cephalometric measurements. The following measurements were acquired using the Clincheck software: Initial overjet and overbite, predicted final OB, as well as individual tooth movements such as tipping, intrusion and extrusion of incisors, canines, premolars and molars.

The aim of this study is to assess the amount of lower incisor intrusion that can predictably be achieved with clear aligners by comparing pre and posttreatment lateral cephalograms. Our hypothesis is that intrusion of lower incisors using clear aligners shows greater than 50% accuracy when clinical outcome, evaluated through pre and posttreatment cephalometric radiographs, is compared to the amount of intrusion predicted by the Clincheck software.

Statistical Analysis

For each variable measured, a mean, median, maximum, minimum, and standard deviation was calculated. The nonparametric Wilcoxon signed-rank test was used to examine the difference between the cephalometric measurements before and after treatment. Statistical tests were two-sided and were performed using a significance level of 0.05. Statistical analyses were conducted using SAS software (version 9.4; SAS Institute, Cary, NC).

CHAPTER 3

RESULTS

To verify intra-examiner reliability, five cephalometric radiographs were selected and retraced two weeks apart. Each measurement was checked for a significant difference between the two tracing timepoints. None of the measurements were found to be statistically significant ($P<0.05$), indicating that the precision of the cephalometric landmark identification and associated measurements was high enough to consider them consistent and reliable between timepoints and patients.

Table 2. Intra-reliability Analysis for Cephalometric Measurement

Variable	**Mean Difference**	**SD**	**P-Value**
OB (mm)	-0.28	0.75	0.63
U1-PP (^{o})	1.78	2.86	0.31
L1-MP (^{o})	-1.54	2.38	0.25
AFH (mm)	-0.66	1.05	0.31
U1-NA (mm)	0.54	0.3	0.063
L1-NB (mm)	-0.1	0.25	0.50
U6-PP (mm)	-0.14	0.38	0.75
L6-MP (mm)	0.2	0.95	0.63
PHF (mm)	-0.32	1.5	0.69
MP-SN (^{o})	0.12	0.67	1.00
SNA (^{o})	-0.46	0.86	0.38
SNB (^{o})	-0.28	0.75	0.44
ANB (^{o})	-0.34	0.11	0.063
OJ (mm)	0.2	0.07	0.063
Midpoint Root (mm)	-0.18	0.56	0.50

A total of 48 consecutively treated patients were included in this study with an average pretreatment overbite measuring 3.4mm (±1.3mm) cephalometrically. The mean age of the study group was 27 years with 14 (29%) of the subjects being male and 34 (71%) being female. The mean treatment time was 13.77 months (Figure 1). Of the pretreatment (T1) and posttreatment (T2) cephalometric measurements compared, 6 were found to have a statistically significant difference (Table 3). These measurements were overbite (OB), anterior facial height (AFH), upper first molar to palatal plane (U6-PP), lower first molar to mandibular plane (L6-MP), A point – Nasion – B point (ANB), and overjet (OJ). During treatment, OB was decreased an average of 0.7mm (±1.0mm) (Figure 2), OJ was decreased 0.6mm (±1.5mm), ANB decreased 0.2mm (±1.1mm) the upper molars (U6-PP) were extruded 0.6mm (±1.0mm), the lower molars (L6-MP) were extruded 0.3mm (±0.9mm), and the anterior facial height (AFH) was increased 0.4mm (±1.4mm).

Figure 1. Total Treatment Time (N=48)

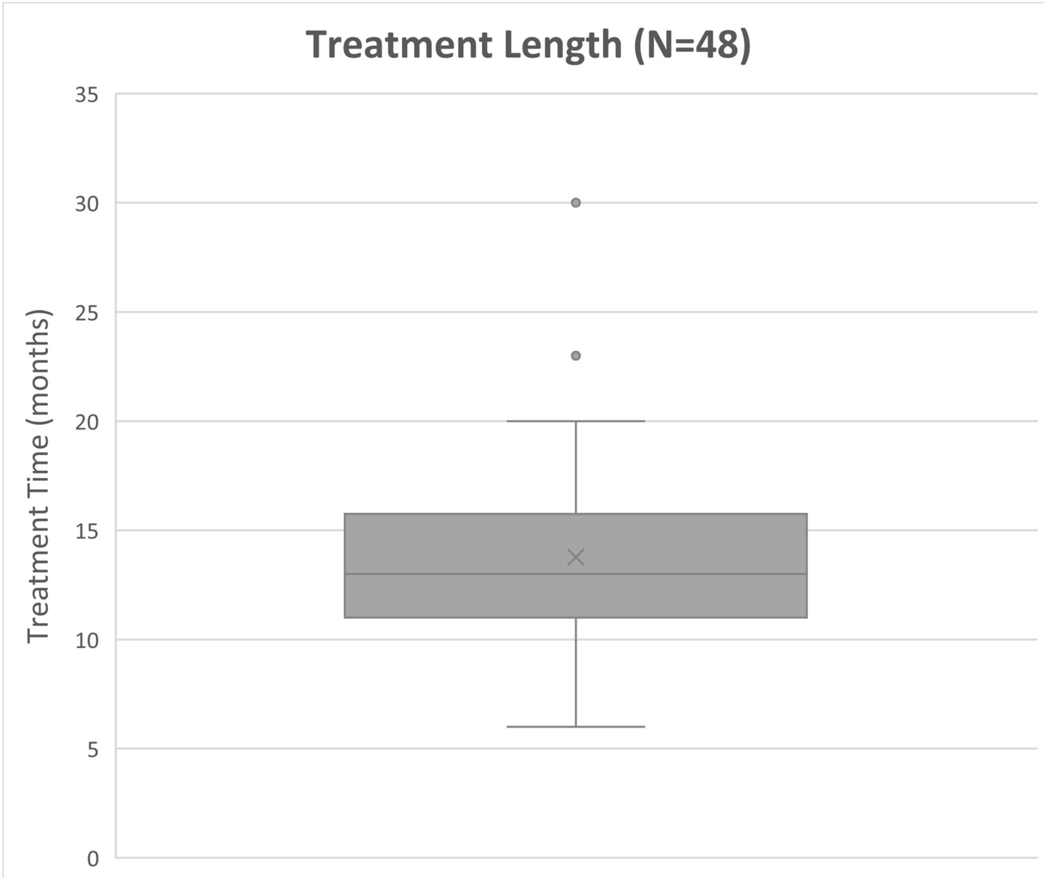
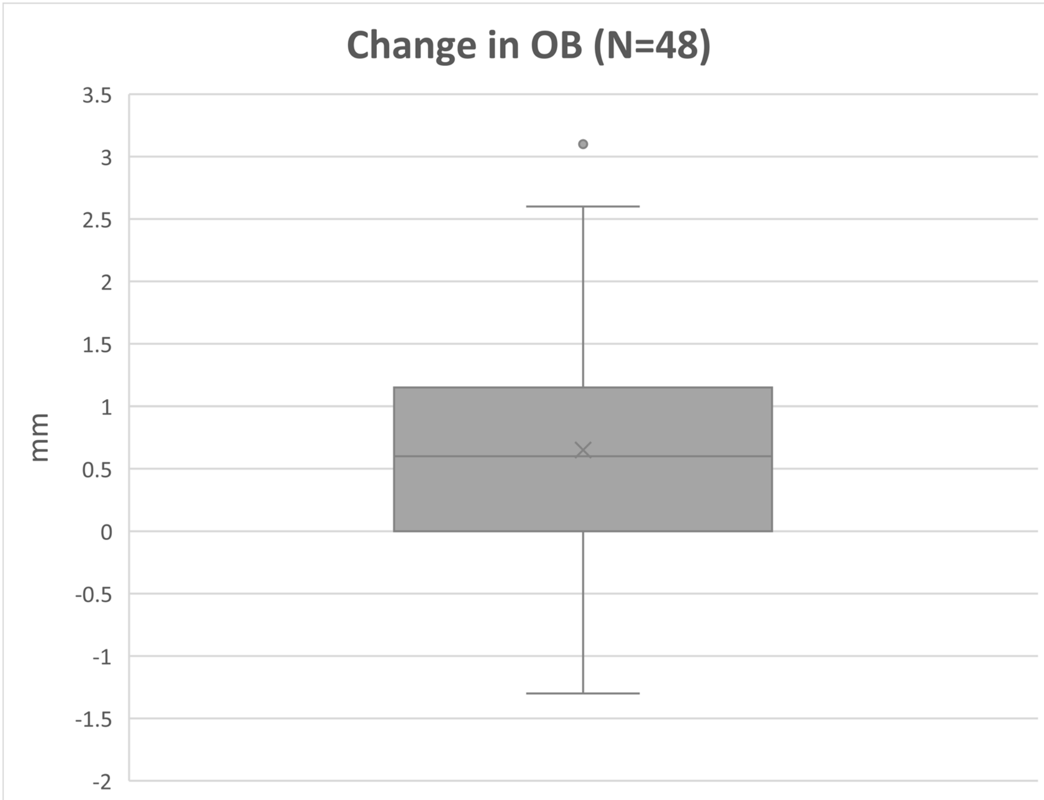


Figure 2. Change in Overbite with Treatment (N=48)



No significant difference was found in the distance from the center of resistance of the lower incisor to the mandibular plane (Midpoint Root), which showed an average change of 0.1mm (±1.2mm). Nor was a significant difference found in the lower incisor to mandibular plane (L1-MP) which changed 0.8º (±7º) on average during treatment.

Table 3. Cephalometric Analysis of Patients Treated with Lower Incisor Intrusion (N=48)

Variable	T1 Mean	T2 Mean	Mean Change	SD	P-Value
OB (mm)	3.4	2.7	-0.7	1.0	0.0001*
U1-PP (⁰)	110.2	109.1	-1.1	16.6	0.5140
L1-MP (⁰)	96.1	96.8	0.8	7.0	0.0855
AFH (mm)	62.9	63.3	0.4	1.4	0.0051*
U1-NA (mm)	3.6	3.5	0.0	2.4	0.9646
L1-NB (mm)	4.5	4.8	0.3	1.5	0.1985
U6-PP (mm)	21.6	22.2	0.6	1.0	0.0001*
L6-MP (mm)	30.5	30.8	0.3	0.9	0.0280*
PHF (mm)	46.6	47.1	0.5	2.0	0.0601
MP-SN (⁰)	28.8	28.8	0.0	1.5	0.9709
SNA (⁰)	83.1	82.8	-0.3	1.6	0.2048
SNB (⁰)	79.9	79.8	0.0	1.4	0.8633
ANB (⁰)	3.2	3.0	-0.2	1.1	0.0476*
OJ (mm)	3.7	3.1	-0.6	1.5	0.0001*
Midpoint Root (mm)	-25.3	-25.2	0.1	1.2	0.5157

CHAPTER 4

DISCUSSION

The aim of this study was to assess the amount of lower incisor intrusion that can predictably be achieved with clear aligners by comparing pre and posttreatment lateral cephalometric head films. This study greatly benefited from the fact that each participant was consecutively treated by the same orthodontist (A.F.) in his private practice using the same treatment philosophy and Invisalign protocols, as well as the same imaging methods and machines used for patient records. This study also benefited from the largest sample size of those reviewed in this paper with 48 participants. Comparable studies ranged had sample sizes that ranged from 22 to 40 participants.[21,25,26,28–30]

Our results were not what we hypothesized nor were they consistent with those found in previous studies involving clear aligners and lower incisor intrusion. Previous studies found lower incisor intrusion efficacy to be between 40-60%, however, we found no significant difference in the reduction of the distance from the mandibular plane to lower incisor centroid point (Midpoint Root), a measurement that we attest most accurately evaluates true intrusion, and this measured difference also did not approach the 50% accuracy that we hypothesized.[21,25,26,29,30] Though the average true intrusion seen in this study (0.1mm ±1.2mm) did not reflect the execution of the average prescribed amount by Clincheck (3.1mm), the patients selected for this study were those that had a pretreatment deep overbite exceeding 2mm and our results do reflect an ability of Invisalign to predictably reduce overbite.

Rather than seeing a significant decrease in overbite through intrusion of the lower incisor, significant differences were found in the distance of the upper molar to palatal plane (U6-PP) and the lower molar to mandibular plane (L6-MP). Additionally, though there was no significant difference found in the lower incisor's proclination to mandibular plane, it did approach statistical significance ($P=0.0855$) with a mean increase of 0.8 ± 7^{o}. This would lead us to conclude that the change in overbite was primarily due to posterior extrusion, secondarily due to relative intrusion, or a change lower incisor proclination, and tertiarily due to lower incisor intrusion. Nanda described the method of posterior extrusion to resolve a deep overbite as "the most common and easiest" and reported that "1-mm of molar extrusion results in 2 to 2.5mm of bite opening in the incisor region."[12] Though our results did not show posterior extrusion to have as significant an effect on overbite as Nanda reported, our data did show that 1mm of molar extrusion equated to 0.78mm in overbite reduction on average.

The assumption has been made that clear aligners are an inherently intrusive appliance due to what is called "the bite-block effect." The bite-block effect stems from a 1992 article by Kuster et al. that evaluated two different bite-blocks and their resultant effect of intrusion of posterior teeth to aid in the correction of skeletal anterior open bites.[35] A correlation has been suggested between traditional bite-block appliances and the thickness of plastic that exists between the maxillary and mandibular occlusal surfaces during clear aligner therapy, an increased bite force, and the approximate prescribed wear time of 23+ hours per day. This intrusive effect, however, was not seen in the data that was collected in this study. The average predicted movement of the upper first molar in the Clincheck software was 0.175mm of extrusion, but the resultant change seen was 0.6±1.0mm of extrusion. Likewise, the average predicted movement of the lower first molar in the Clincheck software was 0.267mm of intrusion, but the resultant change seen was 0.3±0.9mm of extrusion (Table 4). This extrusive effect on the posterior teeth during clear aligner therapy is consistent with what is expected with the use of fixed orthodontic appliances and a continuous straight archwire, which is a combination of extrusion of posterior teeth and intrusion of anterior teeth in the leveling of the curve of Spee. Proffit et al. notes that, "It is necessary to avoid pitting intrusion of one tooth against extrusion of its neighbor because in that circumstance extrusion will dominate,"[1] and this is exactly what we are doing when placing attachments on teeth adjacent to those we are planning to move vertically. Even if the full wrap of plastic on the posterior teeth and an increased bite force does have an intrusive effect on the molars, the extrusive potential of posterior teeth in attempting to level the curve of Spee through incisor intrusion seems to overcome this effect.

Table 4. Prescribed vs. Actual Movement of the Upper and Lower First Molar

Tooth	**Prescribed Extrusion**	**Actual Extrusion**
U6 (mm)	0.175	0.6±1.0
L6 (mm)	-0.267	0.3±0.9

In a similarly conducted study, Khosravi et al. cephalometrically evaluated the vertical dimension changes in 40 patients with deep overbite (OB ≥ 4mm) treated with Invisalign. Their conclusions were that Invisalign's primary means of correcting deep bites was through mandibular incisor proclination, however, they also reported a significant statistical change in vertical position of the lower molars. The maxillary and mandibular second molars both showed a similar amount of extrusion to the molars measured in our study (L7-MP = 0.4±1.3mm; U7-PP = 0.4mm ±1.4mm). Though Khosravi et al. used the incisal edge as a reference point rather than the centroid, they also recorded a similar amount of lower incisor intrusion (L1-MP = 0.0±1.3mm) as well as a statistically significant difference in anterior facial height (AFH = 1.0±1.7mm) (Table 5).[28] With a similar amount of lower incisor intrusion, the greater amount of overbite correction seen in Khosravi et al.'s study is likely due to a greater amount of lower incisor proclination or that the similar amount of molar extrusion recorded was in the second molars. A similar amount of extrusion seen in the second molar versus the first molar may have a greater effect on overbite due to the mesial distal position of the second molars in the arch, and its proximity to the point of articulation of the maxillomandibular complex at the temporomandibular joint.

Table 5. Comparison of Results – Roberson et al. vs. Khosravi et al.

Variable	Roberson et al.	Khosravi et al.
OB (mm)	-0.7±1.0mm	-1.6±0.9mm
U6-PP (mm) (U7-PP)	0.6±1.0mm	0.4±1.4mm
L6-MP (mm) (L7-MP)	0.3±0.9mm	0.4±1.3mm
L1-MP (º) (L1-NB)	0.8±7.0º	2.5±5.8º
AFH (mm)	0.4±1.4mm	1.0±1.7mm
Midpoint Root (mm) (L1-MP)	0.1±1.2mm	0.0±1.3mm

Additionally, we found a statistically significant change in overjet (OJ), ANB, and anterior facial height (AFH). This reduction in OJ (0.6±1.5mm) was found to be due to uprighting of the upper incisor (-1.1±16.6º) and proclination of the lower incisor (0.8±7º). The change seen in ANB (-0.2±1.1º) also reflects a change in incisor inclination as well as correction of the sagittal component of the associated malocclusion. Since we did not see a corresponding significant difference in mandibular plane angle (MP-SN = 0.0±1.5mm), the significant change found in AFH (0.4±1.4mm) seems to be due to 46% (N=22) of the sample group being comprised of growing patients.

Limitations

Though all pretreatment and posttreatment lateral cephalometric head films were taken on the same cephalometric radiograph machine, potential for error in capturing and analyzing cephalometric films were still present. These areas include patient positioning, patient movement, magnification, inconsistent exposure, and landmark identification. Additionally, with the continued improvement in radiograph technology and the advent of cone-beam computed tomography, a reduction in tracing errors would be expected with improved resolution. Inclusion of additional participants in this study would have led to an increase in power, precision, and confidence interval of the study.

Future directions for additional studies

- Intraoral scans that correspond to each cephalogram
- Intraoral scans that include palatal rugae for superimposition
- Superimpose intraoral scans that correspond to cephalogram timepoints

- Use of CBCT to evaluate 3-dementional changes
- Superimpose intraoral scans that correspond to CBCT timepoints
- Evaluate the effect vertical movement of second molars has on the change in overbite

CHAPTER 5

CONCLUSIONS

- Correction of deep overbites with Invisalign occurs primarily due to posterior extrusion, secondarily due to relative intrusion, or a change lower incisor proclination, and tertiarily due to lower incisor intrusion.
- Our results did not show that posterior intrusion occurs with the use of the Invisalign appliance.

REFERENCES

1. Proffit WR, Fields HW, Larson B, Sarver DM. *Contemporary Orthodontics*. 6th ed. Philadelphia, IL: Mosby; 2018:744.
2. Ghafari JG, Macari AT, Haddad RV. Deep bite: Treatment options and challenges. *Semin Orthod*. 2013;19(4):253-266.
3. Nanda R. The Differential Diagnosis and Treatment of Excessive Overbite. *Dent Clin North Am*. 1981;25(1):69-84.
4. Moorrees CFA, Gren A-M, Lebret LML, Yen PKJ, Frohlich FJ. Growth studies of the dentition: A review. *Am J Orthod*. 1969;55(6):600-616.
5. Proffit WR. Prevalence of malocclusion and orthodontic treatment need in the United States: estimates from the NHANES III survey. *Int J Adult Orthodon Orthognath Surg*. 1997;13(2):97-106.
6. Alhammadi MS, Halboub E, Fayed MS, Labib A, El-Saaidi C. Global distribution of malocclusion traits: A systematic review. *Dental Press J Orthod*. 2018;23(6):40.e1-40.e10. doi:10.1590/2177-6709.23.6.40.e1-10.onl
7. Schudy FF. Vertical Growth Versus Anteroposterior Growth As Related To Function And Treatment. *Angle Orthod*. 1964;34(2):75-93.
8. Sassouni V. A Roentgenographic Cephalometric Analysis of Cephalo-Facio-Dental Relationships. *American Journal of Or*. 1955;41:735-764.
9. Sassouni V. A classification of skeletal facial types. *Am J Orthod*. 1969;55(2):109-123.
10. Aydoğdu E, Özsoy ÖP. Effects of mandibular incisor intrusion obtained using a conventional utility arch vs bone anchorage. *Angle Orthod*. 2011;81(5):767-775. doi:10.2319/120610-703.1
11. Engle G. Treatment of deep-bite cases. *Am J Orthod*. 1980;77(1):1-13.
12. Nanda R. Correction of Deep Overbite in Adults. *Dent Clin North Am*. 1997;41(1):67-87.
13. Kale Varlık S, Onur Alpakan Ö, Türköz Ç. Deepbite correction with incisor intrusion in adults: a long-term cephalometric study. *Am J Orthod Dentofacial Orthop*. 2013;144(3):414-419. doi:10.1016/j.ajodo.2013.04.014
14. Burstone CR. Deep overbite correction by intrusion. *Am J Orthod*. 1977;72(1):1-22. doi:10.1016/0002-9416(77)90121-X
15. Burstone CJ. Biomechanics of deep overbite correction. *Semin Orthod*. 2001;7(1):26-33. doi:10.1053/sodo.2001.21059
16. Dake ML, Sinclair PM. A comparison of the Ricketts and Tweed-type arch leveling techniques. *Am J Orthod Dentofacial Orthop*. 1989;95(1):72-78. doi:10.1016/0889-5406(89)90138-8
17. Tweed CH. A philosophy of orthodontic treatment. *Am J Orthod*. 1945;31:74-113.
18. Ricketts RM. Bioprogressive therapy as an answer to orthodontic needs. Part II. *Am J Orthod*. 1976;70(4):359-397. doi:10.1016/0002-9416(76)90111-1
19. Papadopoulos MA, Tarawneh F. The use of miniscrew implants for temporary skeletal anchorage in orthodontics: a comprehensive review. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2007;103(5):e6-15. doi:10.1016/j.tripleo.2006.11.022
20. Kim T-W, Kim H. *Clinical Application of Orthodontic Mini-implant*. 2nd ed. Seoul, Korea: Myung Mun Publishing; 2010.

21. Kravitz ND, Kusnoto B, BeGole E, Obrez A, Agran B. How well does Invisalign work? A prospective clinical study evaluating the efficacy of tooth movement with Invisalign. *Am J Orthod Dentofacial Orthop*. 2009;135(1):27-35. doi:10.1016/j.ajodo.2007.05.018
22. Kesling HD. The philosophy of the tooth positioning appliance. *Am J Orthod Oral Surg*. 1945;31(6):297-304.
23. The Company Behind The Smile. Align Technology Inc. https://www.aligntech.com/about. Accessed April 12, 2020.
24. Hennessy J, Al-Awadhi EA. Clear aligners generations and orthodontic tooth movement. *J Orthod*. January 2016:1-9. doi:10.1080/14653125.2015.1108725
25. Drake CT, McGorray SP, Dolce C, Nair M, Wheeler TT. Orthodontic tooth movement with clear aligners. *ISRN Dent*. 2012;2012:657973. doi:10.5402/2012/657973
26. Chisari JR, McGorray SP, Nair M, Wheeler TT. Variables affecting orthodontic tooth movement with clear aligners. A*m J Orthod Dentofacial Orthop.* 2014;145(4 Suppl):S82-91. doi:10.1016/j.ajodo.2013.10.022
27. Krieger E, Seiferth J, Marinello I, et al. Invisalign® treatment in the anterior region: were the predicted tooth movements achieved? *J Orofac Orthop*. 2012;73(5):365-376. doi:10.1007/s00056-012-0097-9
28. Khosravi R, Cohanim B, Hujoel P, et al. Management of overbite with the Invisalign appliance. *Am J Orthod Dentofacial Orthop*. 2017;151(4):691-699.e2. doi:10.1016/j.ajodo.2016.09.022
29. Simon M, Keilig L, Schwarze J, Jung BA, Bourauel C. Treatment outcome and efficacy of an aligner technique - regarding incisor torque, premolar derotation and molar distalization. *BMC Oral Health*. 2014;14:68. doi:10.1186/1472-6831-14-68
30. Al-Balaa M, Li H, Ma Mohamed A, et al. Predicted and actual outcome of anterior intrusion with Invisalign assessed with cone-beam computed tomography. *Am J Orthod Dentofacial Orthop*. 2021;159(3):e275-e280. doi:10.1016/j.ajodo.2020.10.018
31. Hans MG. Cephalometric evaluation of two treatment strategies for deep overbite correction. *Angle Orthod*. 1994;64(4):265-276.
32. Otto RL. A comparative analysis of intrusion of incisor teeth achieved in adults and children according to facial type . *Am J Orthod*. 1980;77(4):437-446.
33. Smith RJ. Mechanics of tooth movement. *Am J Orthod*. 1984;85(4):294-307.
34. Ng J, Major PW, Heo G, Flores-Mir C. True incisor intrusion attained during orthodontic treatment: a systematic review and meta-analysis. *Am J Orthod Dentofacial Orthop*. 2005;128(2):212-219. doi:10.1016/j.ajodo.2004.04.025
35. Kuster R, Ingervall B. The effect of treatment of skeletal open bite with two types of bite-blocks. *Eur J Orthod*. 1992;14(6):489-499. doi:10.1093/ejo/14.6.489