Predictability of deep overbite correction using Invisalign®

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Abstract

OBJECTIVES: To investigate the predictability of deep bite correction with Invisalign® (Align Technology, Santa Clara, CA, USA).

MATERIALS AND METHODS: This retrospective study included 60 adult patients who had undergone dual-arch orthodontic treatment exclusively with Invisalign®. Pre- and post-treatment digital models acquired from an iTero® scan were obtained from a single orthodontic practitioner. The ClinCheck® digital models of the final predicted outcome were obtained from Align Technology®. Linear values of pre-treatment, prediction and post-treatment overbite were measured using OrthoAnalyzer® (3Shape®, Copenhagen, Denmark) software. Overbite changes planned by ClinCheck® and overbite corrections obtained clinically were compared using a paired t-test ($P < 0.05$). A Spearman correlation coefficient was used to determine if larger overbite corrections predicted were correlated with poorer prediction accuracies. One-way analysis of variance (ANOVA) ($P < 0.05$) were used to determine if the severity of pre-treatment overbite, the number of active aligners, the number and type of bite opening mechanisms programmed in the ClinCheck®, and the number and type of mandibular premolars attachments significantly affected the prediction accuracy.

RESULTS: A statistically significant difference was found between the ClinCheck® prediction and the clinical final result regardless of the pre-treatment deep bite severity ($P < 0.05$). Requesting more overbite correction in the ClinCheck® did not significantly affect the accuracy ($\rho = 0.049$). Variance ratio tests were not significant ($P > 0.05$), except for cases programmed with mandibular incisor proclination in ClinCheck® ($P < 0.05$).

CONCLUSION: The mean prediction accuracy of deep overbite correction using Invisalign® was 37.67%. Lower incisor proclination seems to improve the prediction accuracy. Since the ClinCheck software significantly overestimates vertical changes, overcorrection of the finished occlusion is indicated.

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CHAPTER 1

Introduction

1.1 Preamble

With the introduction of clear aligner therapy, orthodontic treatment has gained significant popularity amongst adult patients (Melsen 2011). Over the past few years, we have witnessed a distinct shift toward an appliance that is more esthetic, more comfortable and more hygienic (Tai, 2018). The Invisalign® appliance (Align Technology Inc, Santa Clara, Calif) has been an esthetic alternative to fixed multibracket appliances in treating minor to complex malocclusions for almost two decades (Boyd, 2007). To date, the Invisalign® system is accessible in 103 countries and has been used to treat 5.8 million patients worldwide, including 1.3 million teens (Align Technology, Q2 financial report 2018). Align Technology® also stated that there are now more than 136,000 Invisalign® trained doctors across the globe (Align Technology, Align Investor Day 2018 Joe Hogan 2018).

Although the Invisalign® system was released to the market in the late 1990s by Align Technology®, the concept of using a series of clear, vacuum-formed tooth-positioning appliance to move teeth in increments was first suggested by Dr. H. D. Kesling in 1945 (Kesling 1946). Teeth were manually repositioned in wax and a clear retainer was fabricated for each stage of treatment until achieving desired alignment. Although it was capable of minor tooth movement, this technique was undoubtedly time-consuming (Phan & Ling, 2007). Sheridan and colleagues later proposed the use of Essix retainers with interproximal reduction to achieve progressive alignment (Sheridan, LeDoux & McMinn, 1993). It was only in 1997 that two MBA students of Stanford University came up with the idea of combining CAD-CAM (computer-aided design and computer-aided manufacturing) technology with orthodontics, in order to create what would soon become the world's first mass-produced, custom-made clear aligner system (Tai 2018).

The Invisalign® system is a series of customized removable clear plastic aligners that move the teeth incrementally according to computer algorithms developed in a virtual three-dimensional software program. Their trays are made of polyurethane. In January 2013, Align Technology®

introduced the SmartTrack® material, a plastic made of multiple layers of thermoplastic polyurethane sheets (Align Technology, Santa Clara, Calif). Each layer has different properties; the inner layers are softer and more formable, allowing a more precise fit of the plastic on the attachments and teeth (Align Technology, 2018). Align Technology states that the SmartTrack® material exhibits higher flexibility, elasticity and delivers more constant force compared to their previous single-layer material (Exceed-30). As a result, these properties make the tooth movement 75% more predictable (https://www.invisalign.com/the-invisalign-difference/smarttrack-aligner-material_).

Each aligner can generate 0.25 to 0.33mm of tooth movement (Malik et al. 2013). The patient's compliance is a key factor for treatment success since the appliance has to be worn for a minimum of 22 hours a day to be effective (Malik et al. 2013). Since 2016, the company has recommended to wear each aligner for a 1-week period before progressing to the next one, which would speed up treatment time by 50% (Align Technology, Santa Clara, CA, USA).

The stereolithographic technology is used to manufacture the aligners (Krieger et al. 2011, Proffit 2013, Tai 2018). A three-dimensional intraoral digital scan of the dental arches and surrounding gingival contours is taken and converted into a stereolithographic (.stl) file. A bite registration is also obtained digitally. A virtual 3D treatment simulation is then generated into the ClinCheck® software and the anticipated correction of the malocclusion is segmented in multiples stages (Proffit, 2013). The software program arranges the stages in a specific sequence and a simulation of the tooth movements using various treatment mechanics is built into the final occlusion. Any interaction between the orthodontist and Invisalign® takes place via ClinCheck®; the treatment plan is reviewed and modified by the practitioner, and finally approved. A stereolithographic model is fabricated for each stage of treatment using CAD/CAM laboratory techniques (Phan & Ling 2007, Tai 2018). A sequence of clear plastic aligners is shaped over the models and directly shipped to the doctor (Proffit, 2013). The final ClinCheck® stage shows a virtual image of the predicted treatment result. The actual clinical treatment outcome should be consistent with the final stage of ClinCheck® (Krieger et al. 2011).

At the time when the appliance was still relatively new, most clinicians were using it to treat mild crowding resolved by interproximal reduction (Tai, 2018). Since then, its usage has expanded significantly and several improvements in terms of material, attachments and design have been brought to the system (Khosravi 2017, Tai 2018). Several studies reported that Invisalign® presented important limitations in treatment of complex malocclusions (Phan & Ling 2007, Joffe 2003, Bollen et al. 2003, Vlaskalic & Boyd 2001), whereas more recent studies suggested that it was suitable for the treatment of moderate to complex malocclusions (Khosravi et al. 2017, Castroflorio et al. 2013, Guarneri et al. 2013, Boyd 2007). When complex malocclusions are treated solely with Invisalign®, refinements or midcourse corrections are often required (Proffit, 2013).

Deep overbite is one of the most common malocclusions encountered in the general population. Overall, it is estimated that deep bite represents about 95.2% of vertical occlusal problems (Proffit 2013). Deep bite is also probably the most challenging malocclusion to treat and maintain (Nanda, 2015). If left untreated, an excessive overbite has the potential to cause harmful effects on the dentition, the surrounding periodontium and the TMJ (Van't Spijker et al. 2015, Riolo et al. 1987). Function such as mastication, chewing and speaking, as well as the smile and facial profile esthetics may also be deleteriously affected (Amarnath et al. 2010, Cobourne 2016, Tai 2018). It is well known that fixed multibracket appliances have a natural tendency to open the bite (Nanda 2015 and Tai 2018). Conversely, several practitioners anecdotally noticed that clear aligners tend to induce deepening of the bite (Khosravi et al. 2017). It was suggested that the layer of plastic covering the posterior teeth could act as a posterior bite-block, resulting in a reduction of the posterior vertical dimension and increase in overbite (Kuster and Ingervall 1992, Boyd et al. 2000); however, Khosravi and colleagues (2017) didn't support this idea. Their cephalometric retrospective study reported that the Invisalign® appliance was successful at improving deep overbite (Khosravi et al. 2017). Boyd and Vlaskalic (2001) also reported that deep overbite correction is highly predictable with Invisalign®. Since the demand for esthetic orthodontic treatment is increasing in adults and that correcting deep overbite is an almost routine part of orthodontic treatment in this population, it is in the clinician's best interest to better understand the predictability of its correction with clear aligners. A poor prediction accuracy can adversely require midcourse corrections and more refinements, leading to longer treatment time than expected (Houle et al. 2016).

As Invisalign® continues to grow and gain popularity, questions regarding its prediction accuracy still remain (Kravitz et al. 2008, Kravitz et al. 2009, Krieger et al. 2012). There is limited data to assess the degree of discrepancy between the predicted and the clinical overbite obtained using Invisalign®. Kravitz and colleagues (2009) found a mean accuracy of 41% for tooth movement in the anterior region with Invisalign®. Parameters such as expansion, constriction, intrusion, extrusion, mesiodistal tip, labiolingual tip and rotated were evaluated. The authors also concluded that intrusion movements (41.3%) were more accurate than extrusion movements in the anterior region (29.6%) (Kravitz et al. 2009). Nguyen & Chen (2006) and Clements et al. (2003) were also unable to achieve a 100% accurate intrusion either; nonetheless, their prediction accuracy for vertical tooth movements was higher (between 79% and 84%). Retrospective studies conducted by Krieger and colleagues (2011 & 2012) concluded that tooth corrections in the vertical plane were the most difficult to achieve with Invisalign®. Overbite was the least accurate parameter and showed the highest deviations between the planned and the actual treatment outcome, with a prediction accuracy of 14.3% (Krieger et al. 2011). In their extended study using a larger study cohort, the mean difference between the overbite achieved and the predicted overbite was 0.71mm (Krieger et al. 2012). The authors warned that refinements should be expected toward the end of treatment when treating patients requiring major vertical tooth movements. They also recommended the use of supportive measures (horizontally bevelled attachments or elastics) to achieve optimal result.

Align Technology reported in 2011 that midcourse corrections or refinements might be needed in 20 to 30% of patients treated with Invisalign®. However, many orthodontists have reported that 70% to 80% of their patients require midcourse correction or refinements to achieve the pre-treatment goals (Boyd 2005, Sheridan 2004). Malik and colleagues (2013) also reported that most cases need refinements for optimal finish. The company also states that their SmartTrack® material is able to move teeth more precisely than their previous material (Align Technology 2018). Despite this, in a recent study by Gu et al. (2017) evaluating the effectiveness and efficacy of Invisalign compared to fixed appliances, 37.5% of their subjects needed refinements.

As of September 2018, no studies have focused on the predictability of deep overbite correction using Invisalign®. The present study analyzes the extent to which the final overbite predicted by ClinCheck® corresponds to the actual clinical overbite achieved at the end of treatment in deep bite subjects. The influence of pre-treatment deep bite severity, number of active aligners, presence of mandibular premolars attachments and bite opening mechanisms programmed in ClinCheck® will be examined. Evaluation of the accuracy of tooth movement is of particular importance because it will influence the final treatment result and overall treatment time. If tracking does not occur as planned, the aligners will not fit properly and therefore treatment time will be longer than what it was anticipated. A better understanding of the prediction accuracy of deep overbite correction could help the orthodontist to better plan the need and extent of overcorrection and auxiliary treatments, thereby reducing the number of midcourse corrections and refinements.

CHAPTER 2

Literature Review

A complex topic such as deep bite correction with the Invisalign® appliance requires a thorough review of quite a few important concepts. Initially, literature related to vertical growth of the jaws, vertical dental changes overtime, deep overbite definition and correction will first be covered in this section. Furthermore, this literature review will explore the reasons explaining the growing consumer demand for Invisalign® treatment. The clinical and technological process behind the Invisalign® treatment, from the stage of digital impression to the 3D model storage, will be discussed. Former methodologies of assessing overbite changes will be described. Previous and recent studies investigating the limitations and prediction accuracy of the Invisalign® system will also be reviewed. Although the orthodontic literature related to these topics is extensive and heterogenic, this paper will put emphasis on deep overbite correction using the Invisalign® appliance.

2.1 Normal vertical growth of jaws and growth patterns

2.1.1 Mechanism of vertical growth

Vertical elongation of the maxilla and mandible results from a combination of three distinct growth processes: primary displacement, secondary displacement and remodelling of bone surfaces and alveolar processes (Proffit 2013, Cobourne 2016).

<u>Upper face (Nasomaxillary complex)</u>

Primary displacement occurs through apposition of bone at the sutures connecting the maxilla to the cranium at the zygomatic and frontal articulations (Proffit 2013), leading to lowering of the maxilla as a whole (Björk and Skieller 1977). Secondary displacement of the maxilla occurs in response to the growth of the cranial base until the age of 7 (Proffit 2013). After the age of 7, sutural growth is the only mechanism contributing to the downward displacement of the maxilla. In terms of surface remodelling, bone is being removed from most of the anterior surface of the maxilla as it grows downward and forward (drift). As the maxilla moves downward, the nasal cavity space increases by nasal floor resorption concomitant to intra-oral bone deposition on the palate (Proffit 2013). The orbital floor also undergoes resorption (Cobourne 2016). The height of the nasomaxillary complex related to facial height is constant (44%) without any kind of rotation from 5 to 31 years in individuals with normal occlusion (Thilander et al. 2005). The maxillary height also increases through bone deposition at the alveolar processes. The alveolar processes may continue to grow in height beyond the age of 16 (Moorrees 1959). Their growth is particularly rapid during tooth eruption, exceeding the lowering of the palate (Thilander 2008).

Lower face (Mandible)

Like the nasomaxillary complex, the mandible grows in a forward and downward direction by displacement (primary and secondary) and remodelling. Moreover, implant and cephalometric studies indicate the presence of rotational changes in the mandible (Björk and Skieller 1977). Rotation can be either in an anterior (upward) or posterior (backward) direction, and is accompanied by remodelling along the inferior border of the mandible (Björk and Skieller 1977). Forward rotation is characteristic of a reduced lower facial height, whereas backward rotation is associated with an increased lower facial height (Proffit 2013). These rotations represent an imbalance in growth between anterior and posterior facial heights (Cobourne 2016). The presence and direction of mandibular rotation can be predicted using the seven structural signs developed by Björk (1969).

The mandible does not enlarge symmetrically; instead, the condyle and ramus elongate in a posterior and superior direction, and the mandibular body lengthens antero-posteriorly (Proffit 2013). These dimensional changes accelerate significantly during the growth spurt (Cobourne 2016). The cartilaginous growth at the condyle also contributes to mandibular growth. According to Enlow and Petrovic (1990), displacement is the primary phenomenon contributing to growth, whereas condylar growth is secondary and more adaptive in nature (Cobourne 2016).

2.1.2 Vertical growth in adults

Throughout normal growth, the increase in size of the jaws and dental arches occurs on a specific chronology for the three planes of space (Proffit 2013). The transverse usually stops to grow before the adolescent growth spurt. Then the antero-posterior facial growth continues through the period of puberty until late adolescence, usually the mid-teen years and until the late teens in some males. The last dimension to stop to growth is the height. Vertical growth has been detected into the third decade of life in both males and females. Longitudinal studies have demonstrated that a small amount of craniofacial growth continues during adulthood, especially in the vertical dimension (Behrents, 1985). It was also found that rotational changes of the jaws occur during adulthood and that they slightly differ between both sexes. In general, males tend to grow antero-posteriorly with a greater tendency towards counter-clockwise rotation of the mandible, resulting in a slight decrease of the mandibular plane angle. Conversely, in females, facial growth tends to follow a vertical pattern with a clockwise rotation of the mandible and a concomitant increase in the mandibular plane angle. Mandibular rotation during adulthood is also associated with a concomitant eruption of teeth. A slight increase in facial height should then be expected throughout adulthood after the adolescence period with dental compensation, especially in long-face and female patients.

A recent study conducted by Barbosa et al (2017) showed that hypodivergence starts early and becomes more severe with age.

2.1.3 Vertical dental changes over time

Eruption of permanent teeth is a dynamic long-term process beginning from early childhood and continuing passively through adulthood. After the permanent teeth reach the occlusal level, their eruption continues at a slower rate and their extent of eruption equals the vertical growth of the ramus. Vertical growth increases the space between the maxilla and mandible, allowing the upper and lower teeth to erupt further (Proffit 2013). After the growth spurt and during adult life, teeth continue to erupt at an extremely slow rate. Despite tooth wear becoming more pronounced with age, the lower facial height usually remains constant or even increases slightly because of compensating additional tooth eruption. The face height would decrease only in case of extremely severe wear where the eruption may not compensate.

In the primary dentition stage, the primary incisors are usually upright and associated with a positive overbite, varying between 10 and 40% (Cobourne 2016), unless a prolonged digit or dummy sucking-habit is present. According to Dermaut and Pauw (1997), at 5 to 6 years of age, the percentage of overbite ranges between 36.5% and 39.2%. As the mandible grows forward and occlusal wear increases, a transient edge-to-edge incisor relationship might develop. During the period of mixed dentition and prior to the early permanent dentition establishment, a transient anterior open bite might be present as the permanent incisors are erupting to reach the occlusal plane. Although the overbite usually increases between the age of 9 to 12, it then decreases between 12 years and adulthood (Fleming 1961). Afterwards it remains relatively unchanged and varies between 37.9% to 40.7% unless there is a reduced vertical dimension caused by missing teeth or extensive wear (Nanda, 2015).

A recent retrospective study conducted by Massaro and colleagues (2018) evaluating dental changes in subjects with normal occlusion over a 40-year period reported that overbite tends to slightly decrease with age. From 13 to 17 years of age, an overbite reduction of 0.79mm was observed. According to the authors, this could be attributed to mandibular growth, eruption of second and third molars and reduction in curve of Spee depth. From 17 to 60 years of age, a decrease of 0.69mm was noted, which could be related to wear of incisors occurring with aging and residual mandibular growth.

The occlusion does not remain static throughout life and should be regarded as a dynamic process (Thilander 2007). Several longitudinal cephalometric studies have investigated changes in incisor position, inclination and overbite in growing subjects from childhood to adulthood. However, these studies have shown inconsistent results and numerous differences between genders. It has been reported that the upper incisors tend to procline with age (Bishara 1981, Watanabe 1999) especially in females (Bishara et al, 1989), whereas other studies have shown that they tend to progressively upright in both sexes (Forsberg 1989, Behrents 1985, Ceylan 2002), especially in males (Bishara et al, 1989). In terms of lower incisor axial inclination, previous studies found an increase in lower inclination with age (Bishara 1981, Forsberg 1989, Watanabe 1999). In contrast, Ceylan study (2002) reported that the lower incisors remained very stable from 10 to 14 years of age. The interincisal angle was found to decrease from childhood to adulthood (Bishara 1981, Behrents 1985, Watanabe 1999), but to increase significantly between 10 to 14 years of age in both males and females (Ceylan et al. 2002) or tend to remain stable (Forsberg 1979). Two studies reported no significant changes in the overbite with age (Forsberg 1989, Behrents 1985). Conversely, Ceylan study (2002) has refuted this statement and reported a significant increase in overbite in both boys and girls. Sinclair and Little (1983) found significant increases in overbite and overjet from 9 to 13 years of age, whereas significant decreases were reported between 13 to 20 years of age. Bishara et al (1994) studied dental changes between 25 and 46 years of age. During this period, significant dental changes were found in females, such as a decrease in the U1:SN angle, along with an increase in overbite and interincisal angle. In males, however, only the interincisal angle showed a significant increase.

In Class II division 2 subjects, Barbosa and colleagues (2017) reported that most retroclination of the maxillary incisors occurs during the early mixed dentition stage while the permanent incisors are erupting because of the pressure of the lower lip.

2.1.4 Development of the curve of Spee

According to Andrews (1972), a flat to mild curve of Spee allows the best static maximal intercuspation. Flattening the occlusal plane should be part of the orthodontic treatment goals. The depth of the curve of Spee has a direct influence on the overbite (Cobourne 2016). The deeper the curve, the deeper the overbite will be. An increased curve of Spee is a common feature of brachycephalic subjects (Wylie 1944, Bjork 1953) and is often associated with short mandibular bodies (Salem et al. 2003).

The development of the curve of Spee is multifactorial, resulting in a wide individual variation in its presentation (Feralla et al. 2002, Shannon and Nanda 2004, Salem et al. 2003, Baydas et al. 2004). In the deciduous dentition, the curve of Spee is usually minimal or flat. Afterwards, with the eruption of the mandibular permanent first molars, incisors and second molars above the pre-existing occlusal plane, the curve deepens significantly. Following that, in the adolescent dentition stage, the curve flattens slightly and remains fairly stable into early adulthood (Marshall et al. 2008). These findings are in agreement with the previous litterature (Bishara et al. 1989, Ash 1993, Carter & McNamara, 1998) which was lately confirmed in a recent retrospective study conducted by Massaro and colleagues (2018). The authors reported a decrease of 0.49mm in the curve of Spee depth during the adolescence period. This could be related to the end of eruption of the mandibular second molars after 13 years of age (Massaro et al. 2018). The curve of Spee was also found to be stable from adolescence to adulthood.

2.1.5 Growth pattern: Hypodivergent vs. Hyperdivergent

Growth pattern is greatly influenced by genetic predisposition and environmental factors such as habits, breathing and masticatory muscle strength (Proffit 2013, Nanda 2015). Also, each growth pattern has specific morphological characteristics. Hypodivergence has been associated with deep bite malocclusion (Nanda 2015). Typical features of hypodivergent pattern include excessive forward rotation of the mandible during growth, decreased incisor show, excessive lip compression, shorter lower facial height, deep mentolabial sulcus, deep bite tendency, heavy bite force and strong musculature (Proffit 2013, Cobourne 2016). It is well known that growth pattern is established early in life and is unlikely to change or improve over time (Barbosa et al. 2017). Most hypodivergent patterns (58%) persist through the growth spurt and 36% shift to normodivergence (Buschang et al. 2002). On the other hand, hyperdivergent subjects typically present the following: overeruption of the posterior teeth causing a downward and backward rotation of the mandible, anterior open bite tendency, narrow palate, short posterior to anterior facial height ratio, increased lower facial height, steep mandibular plane angle, and weak bite force and musculature. Several investigations have found an association between high mandibular plane angle and backward rotation of the mandible and its influence on the anterior vertical facial proportions (Schendel et al. 1976, Opdebeeck and Bell 1978, DeCoster 1936, Siriwat and Jarabak 1985). However, according to Baumrind et al (1984) and Skieller and Björk (1984), the mandibular plane angle cannot be considered a good facial growth predictor because subjects with high mandibular plane angles can present with either a backward or forward rotation of the mandible.

2.2 Deep overbite

The earliest definition of overbite was first developed by Strang (1950) and was described as “the overlapping of the upper anterior teeth over the lowers in the vertical plane”. A deep overbite is defined as an excessive vertical overlapping of the lower incisors by the upper incisors in centric occlusion (Proffit, 2013). Severe cases can be associated with an impinging contact with the opposing palatal mucosa. Deep bite associated with Class II Division 2 malocclusion, also referred as “cover bite”, is one of the most severe manifestations of the condition (Peck et al. 1998).

Another severe form of deep overbite is the "closed bite" caused by the loss of posterior teeth (Moyers 1998).

The definition of normal overbite varies in the literature depending on the source. Overbite can be described in terms of millimeters or percentage. According to Nanda (2015), the overbite should be quantified in percentage given the fact that the crown length of the upper and lower incisors varies from one individual to another. A normal overbite usually ranges from 1 to 3 mm, with the incisal edges of the mandibular incisors contacting slightly at or above the cingulum of the maxillary incisors (Fattahi et al. 2014, ABO Discrepancy Index 2017). According to Nanda (2015), an ideal overbite should range between 2 and 4 mm vertically or between 5% and 25% of incisor coverage. In terms of percentage, other authors stated that a normal overbite should be 30% or one third of the clinical crown height of the mandibular incisors (Sreedhar C, Baratam S. 2009, Cobourne 2016). A vertical coverage of 30-40% is considered excessive (Moorrees et al. 1963, Nanda 2015).

Deep bite is one of the most common malocclusions in both children and adults (Grieve 1928, Mershon 1937, Callaway 1940, Goldstein & Stanton 1936). The prevalence of deep bite in the general population has been reported to be from 11.8% (Jonsson et al. 2007) to 36.7% (Borzabadi et al. 2009). It was estimated that 15%-20% of the population in the United States had an overbite of or more than 5 mm (Brunelle et al. 1996). Another cross-sectional study conducted by Tausche (2004) focusing on children aged between 6 and 8 years reported that deep overbite affected 46.2% of them. Proffit (2013) stated that severe deep bite (overbite > 5 mm) is found in 20% of children and 13% of adults. Overall, it is estimated that deep bite represents about 95.2% of vertical occlusal problems (Proffit 2013).

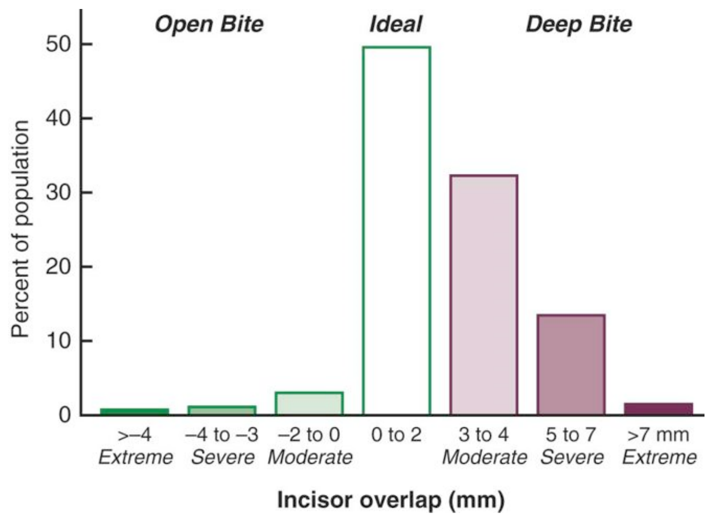

Figure 2.1 *Open bite/deep bite relationships in the U.S. population, 1989-1994*
(Proffit, 2013)

Deep overbites can be dentoalveolar, skeletal or environmental in origin, or a combination of any of them (Richardson 1969, Wylie 1946, Bjork 1969, Nielsen 1991, Fatahi et al. 2014, Nanda 2015). Development of deep bite is associated with numerous causative factors (Parker et al. 1995). Table 2.1 summarizes those factors with the citing authors.

Table 2.1 *Factors causing deep bite malocclusion*

Related causative factors		Authors
Dental	Upright or retroclined maxillary and/or mandibular incisors	Popovich (1955) Steadman (1947) Fleming (1961) Ludwig (1967) Herness (1979) Sangchareарn and Christopher (2007) Fattahi et al. (2014)
	Incisor overeruption	Strang (1950) Prakash & Margolis (1952) Popovich (1955) Ceylan and Eroz (2001)

		El-Dawlatly et al (2012) Fattahi et al. (2014)
	Deep curve of Spee	Ghafari and Street (1998) Baydas et al (2004) Marshall et al (2008) El-Dawlatly et al. (2012)
	Undereruption of the maxillary and posterior segments	Faerovig and Zachrisson (1999)
	Excessive overjet	Goldstein and Stanton (1936)
	M-D width of anterior teeth	Steadman (1947) Neff (1949) Fleming (1961)
	Canine position	Steadman (1947)
	Molar infraocclusion / undereruption	Strang (1950) Prakash & Margolis (1952) Fleming (1961) Wylie (1946)
	Molar cusp height	Fleming (1961) Bolton (1958)
	Premature loss of permanent teeth	Moyers (1998)
Skeletal	Mandibular ramus height	Fleming (1961)
	Decreased gonial angle	Ceylan and Eroz (2001)
	Vertical facial type, shortened anterior lower face height	Wylie (1946) Bjork (1953 and 1969) Nanda (1990) Beckmann et al (1998) Ghafari and Street (1998) Naumann et al (2000) Fattahi et al. (2014)
	Class II division 1 and 2 malocclusion	Feldmann et al (1999)

Environ-ment	Lateral tongue thrust or abnormal tongue posture causing posterior infraocclusion	Nanda (2015)
	Extensive posterior tooth wear	
Age-related natural opening of deep bite		Nanda (1973) Bresonis and Grieve (1974) Ceylan and Baydas (2002)

The highest contributing factors in deep bite development are listed below (Tai 2018):

- Deep curve of Spee
    - The most important dental factor according to El-Dawlatly et al. 2012
- Upright or retroclined maxillary and/or mandibular incisors
- Hypererupted maxillary incisors
- Brachyfacial skeletal pattern

Skeletal and dental features of deep bite malocclusion have been widely investigated by numerous studies. Increased overbite is often associated with reduced vertical proportions (Beckmann et al. 1998, Bjork 1953 and 1969, Wylie 1946, Nanda 1990, Naumann et al. 2000). Furthermore, skeletal characteristics include a hypodivergent growth pattern, a reduced lower anterior facial height, a flat mandibular plane angle, a more acute gonial angle (Ceylan and Eroz 2001), a decreased posterior maxillary dimension, a downward rotation of the palatal plane and a more anterior position of the ramus (Trouten et al. 1983). When a skeletal dysplasia is present, the maxillary molars tend to be in infraocclusion (Janson et al. 1994). Beckmann et al. (1998) suggested that increased overbite is also related to larger anterior alveolar and basal areas. On the contrary, other investigators found no differences in the lower facial height, maxillary and mandibular anterior alveolar and basal height between deep bite and normal overbite subjects (Al-Zubaidi and Obaidi 2006).

Deep bite can be associated with any type of anteroposterior malocclusion (Class I, Class II or Class III); however, a skeletal deep bite typically presents a Class II division 2 dental malocclusion, reflecting an underlying Class II skeletal base anteroposterior relationship (Beckmann et al. 1998, Ghafari et al. 2013, Cobourne 2016). In contrast to open bites that are often caused by pathologic and environmental factors (e.g. blocked airway, mouth breathing, anterior tongue posture, digit sucking habit), Class II division 2 malocclusions are mostly attributed to heredity and developmental factors (Hartsfield, 2011). Dental deep bites typically present either overeruption of the incisors (Strang 1950, Prakash & Margolis 1952), undereruption of molars (Strang 1950, Flemming 1961, Prakash & Margolis 1952, Wylie 1946), or a combination of both. Other factors such as premature loss of permanent teeth, mesiodistal width of anterior teeth and age-related natural deepening of the bite also may have an influence (Nanda 2015).

Environmental factors may also play a role in development of deep bite (Nanda 2015). A lateral tongue thrust or abnormal tongue posture might impede the eruption of posterior teeth. Extensive wear or abrasion of the occlusal surface of the posterior teeth can also result in excessive overbite (Nanda 2015).

In both dental and skeletal deepbite malocclusions, the mandibular incisors are often upright, overerupted and associated with an increased curve of Spee (Baydas et al. 2004, Marshall et al. 2008, El-Dawlatly et al. 2012). The steepness of the curve of Spee is caused by a lack of occlusal contact with the maxillary incisors, resulting in an overeruption of the mandibular incisors (Cobourne 2016). As a result of the incisor retroclination, the lips can lack support and appear retrusive relative to the nose and chin.

El-Dawlatly and colleagues' study (2012) showed that deep bite malocclusion has a multifactorial etiology and that the greatest contributing factors were a deep mandibular curve of Spee and a decreased gonial angle. A longitudinal study conducted by Naumann et al. (2000) investigating the vertical components of overbite change showed that the skeletal component was more effective than the dental component in changing the overbite. Furthermore, it was noted that the mandible has a greater influence on overbite changes in comparison to the maxilla. Bjork's implant study (1969) also showed that the mandibular skeletal changes were twice as important as the mandibular dental changes and about 2.5 times as important as the maxillary changes in inducing overbite changes. Other investigations concluded that the difference between deep bite and normal overbite subjects was due to either maxillary dentoalveolar morphology (Trouten et al. 1983, Ellis & MacNamara 1884, Subtelny & Sakuda 1964, Prakash & Margolis 1952), mandibular dentoalveolar morphology (Parker 1964), or a combination of both (Betzenberger et al. 1999 and Haskell 1979). A more recent study investigating the influence of skeletal and dentoalveolar features on deep bite malocclusion (Fattahi et al. 2014) revealed that the most significant findings associated with deep bite malocclusion were retroclination of upper and lower incisors, counterclockwise rotation of the mandible associated with a decreased lower facial height, increase in upper facial height to compensate for decreased lower anterior facial height, upper incisor extrusion indicating a maxillary reverse curve of Spee and lower first molar extrusion indicating a mandibular deep curve of Spee.

2.3 Basics of overbite correction

Correction of mild deep bite is usually not mandatory unless the patient requests correction for esthetics purposes. However, severe overbite represents a clinical problem that needs to be addressed orthodontically or surgically depending on the etiology (Fattahi et al. 2014). If left untreated, severe deep bite may cause temporomandibular joint dysfunction, tooth wearing, trauma of the incisive papilla with periodontal problems, increase in anterior crowding and maxillary dental flaring (Hug 1982, Bergersen 1988, Nielsen 1991, Zachrisson 1997). It may also negatively affect function such as mastication, chewing and speaking, as well as the smile and facial profile esthetics (Amarnath et al. 2010, Cobourne 2016, Tai 2018). In very extreme cases of deep impinging overbite, it can also lead to the loss of maxillary incisors (Ghafari et al. 2013).

Treatment aiming to correct deep overbite should be based on the etiology of the malocclusion (Burstone 1977, Engel 1980). It is important to properly diagnose the cause of the deep bite in order to determine what mechanotherapy will be used in its correction. The choice of treatment usually depends on numerous factors, such as the amount of growth anticipated, the vertical dimension, the maxillary incisor position relative to the lip (maxillary incisor display at rest and on smiling), and the desired position of the occlusal plane (Nanda, 1981 and 2015).

As a general statement, vertical malocclusions are more challenging to correct than the sagittal ones (Richardson, 1969). Correcting deep bite in growing patients is much easier and predictable than in adult patients (Nanda 2015). In growing individuals, any posterior extrusion will result in vertical compensatory growth at the condyles, producing relative incisor intrusion (Proffit 2013, Cobourne 2016).

Another important diagnostic consideration is the maxillary incisor position relative to the upper lip at rest and on smiling (Proffit 2013). With careful analysis of the surrounding facial soft tissues, a decision can be made whether the upper incisor position need to be maintained or changed. An incisor show of 2 to 4 mm at rest is considered average (Nanda 2015). On smiling, almost two-thirds of upper incisor show is acceptable (Maulik & Nanda, 2007). Ideally, for the most pleasing smile, males should not have any gingival display, whereas females may have 1 to 2 mm of gingival show. In presence of adequate incisor show at rest and on smiling, deep overbite correction should be focused on either lower incisor intrusion or posterior extrusion (Proffit 2013, Nanda 2015).

In addition, a non-extraction approach is usually favored in low-angle deep bite cases to avoid deepening the overbite and worsening facial esthetics (Ghafari et al. 2013). Vertical control can become very challenging if teeth are extracted because the incisors will tend to upright as the spaces are closing (Cobourne 2016).

Retention of deep overbite correction is a critical part of orthodontic treatment. The key to stable overbite reduction is the establishment of an adequate inter-incisal angle, creating an occlusal stop and thus preventing the incisors from erupting past each other (Riedel 1960, Nanda & Burzin 1993). If an occlusal stop is not established, deep overbite is highly likely to relapse (Cobourne 2016). Relapse is common, especially if the deep bite etiology has not properly been identified before initiating treatment (Fattahi et al. 2014). Since extruding posterior teeth in adult patients with hypodivergent skeletal leads to muscular stretching and imbalance, deep bite correction is very likely to relapse in these patients (Nanda 2015).

2.3.1 Mechanotherapy for overbite correction

There are mainly three non-surgical orthodontic mechanics to reduce a deep overbite (Engel et, 1980, Ghafari 2013): intrusion of the incisors, proclination of the incisors (relative intrusion), extrusion of posterior teeth, or a combination of any them (Aydoğdu et al. 2011) (Figure 2.2).

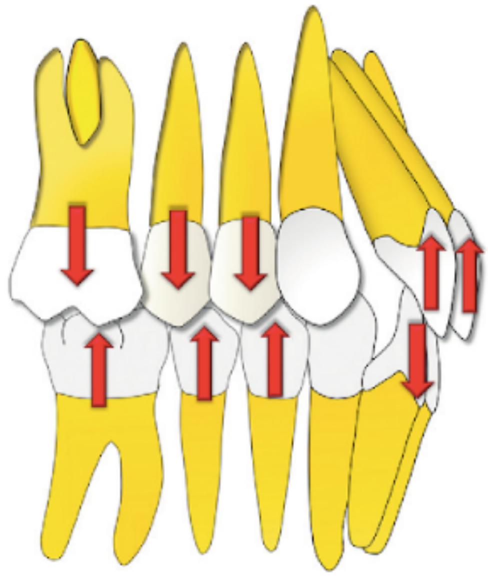

Figure 2.2 *Intrusion of incisors and extrusion of posterior teeth for deep bite correction* (Nanda, 2015)

The skeletal pattern also needs to be taken into consideration when planning the specific biomechanics for deep bite correction (Ghafari et al. 2013). Moreover, patients with significant underlying vertical skeletal discrepancy may require orthognathic surgery for full correction (Hering et al. 1999). As summarized in Table 2.2, some adjunctive tooth movements can also assist in overbite reduction.

Table 2.2 *Treatment modalities for deep bite correction*

Treatment modalities		Authors
Premolar extrusion	Maxillary premolar extrusion	Otto et al. (1980) Dake and Sinclair (1989) Ball and Hunt (1991) Schudy (1968)
	Mandibular premolar extrusion	Mitchell and Stewart (1973) Otto et al. (1980) Greig (1983) Dake and Sinclair (1989) Schudy (1968)

Incisor intrusion	Maxillary incisor intrusion	Dellinger (1967) Burstone (1977) Ricketts (1979) Ng et al (2005)
	Mandibular incisor intrusion	Mershon (1937) Dellinger (1967) TM Burstone (1977) Lefkowitz and Waugh (1945) Mitchell and Stewart (1973) Ricketts (1979) Otto et al. (1980) Greig (1983) Woods (1988) Dake and Sinclair (1989) Ball and Hunt (1991) Ng et al (2005)
Incisor proclination	Maxillary incisor proclination and Mandibular incisor proclination	Engel et al. (1980) Ball and Hunt (1991) Harrison et al. (2007) Franchi et al. (2011)
Adjunctive mechanics	Buccal expansion, creating a plunging molar palatal cusp	
	Maxillary posterior distalization	
	Molar tip back	

In most cases, overbite reduction will be achieved using a combination of any of the above. The presence of a normal or vertical growth pattern can significantly help open the bite.

2.3.1.1 Premolar extrusion for overbite correction

According to Schudy (1968), extrusion of premolars and molars is the treatment of choice for overbite reduction. Extrusion of buccal segments is indicated in brachyfacial patients presenting a deep curve of Spee and normal to minimal upper incisor display upon smiling (Ghafari et al. 2013, Tai 2018). However, their strong musculature function might resist any posterior extrusion (Ricketts 1979, Nanda 2015). Posterior extrusion is an effective way of reducing a deep overbite, particularly in growing patients, where these tooth movements will lead to vertical compensatory growth at the condyles and simultaneous relative incisor intrusion (Nanda 2015, Cobourne 2016). In adults, posterior extrusion causes a downward and backward rotation of the mandible because there is no compensatory growth potential at the condyle (Burstone 1977, Betzenberger et al. 1999). This results in a steepening of the occlusal plane and an increase in the lower face height. For this reason, it is not desirable to extrude posterior teeth in non-growing individuals with a vertical skeletal pattern (Nanda, 2015). Moreover, in presence of underlying skeletal Class II relationship, posterior extrusion worsens the skeletal antero-posterior discrepancy and makes deep bite patients prone to relapse. In this case, maxillary and mandibular intrusion without posterior extrusion should be considered instead (Burstone 1977).

With traditional fixed orthodontics, an anterior bite plane with posterior vertical elastics can be used to open up the bite and allow for posterior extrusion (Ghafari et al. 2013). A deep curve of Spee can be leveled with a continuous archwire to get buccal segment extrusion. As a side effect, some incisor intrusion and proclination are also produced. For more accentuated changes, a heavy rectangular stainless steel archwire with a reverse curve of Spee can also be used (Weiland et al. 1996). To increase the vertical anchorage, it is critical to include the lower second molars which act as a lever arm to aid the necessary posterior extrusion for bite opening. Another strategy employed to extrude posterior teeth is to alter bracket heights. Interarch elastics, such as Class II and Class III elastics, can also assist in reducing the overbite by extruding the molars.

2.3.1.2 Incisor intrusion for overbite correction

According to El-Dawlatly et al. (2012), the highest contributing factor for deep bite in the general population is a deep curve of Spee. For this reason, incisor intrusion is a critical modality in deepbite correction (Ricketts, 1979), especially in adults with vertical maxillary excess, a large interlabial gap at rest and a long face pattern (Nanda 2015). Intrusion of mandibular incisors is indicated in patients with excessive distance between the incisal edge and stomion (lower incisors overeruption), large interlabial gap at rest and deep curve of Spee (Ghafari et al. 2013). The need for intruding maxillary incisors is determined by the upper lip line at rest and on smiling (Ghafari et al. 2013).

Absolute intrusion of the incisors is mechanically difficult to achieve (Cobourne, 2016). Intrusive forces need to be applied close to the center of resistance to achieve true intrusion without proclination (Melsen et al. 1989, Polat-Özsoy et al. 2011). The cumulative literature suggests that intrusion of teeth is more difficult to accomplish than extrusion (Ghafari et al. 2013). To obtain true incisor intrusion, segmental techniques such as Ricketts' utility arch and Burstone intrusive arch can be used (Bench et al. 1978, Burstone 1977, Ricketts et al. 1979, Cozza et al. 2005). An anchorage unit is established in the buccal segments and the incisors are intruded with a bypass arch. To produce the intrusive forces, segmental mechanics include tip backs bends on the molars (Shroff et al. 1997). Around 1-2mm of true incisor intrusion can be achieved (Ng et al, 2005). Temporary anchorage devices can also be used to intrude the incisors (Kanomi 1997, Lee et al. 2007, Aydoğdu et al. 2011, Proffit 2013). Intrusion appears to be more successful with the use of mini-implants with no side effects on the molars (Polat-Özsoy et al. 2011, Ohnishi et al. 2005). The forces for intrusion need to be kept light to decrease the risk of root resorption (McFadden et al. 1989, Upadhyay et al. 2008).

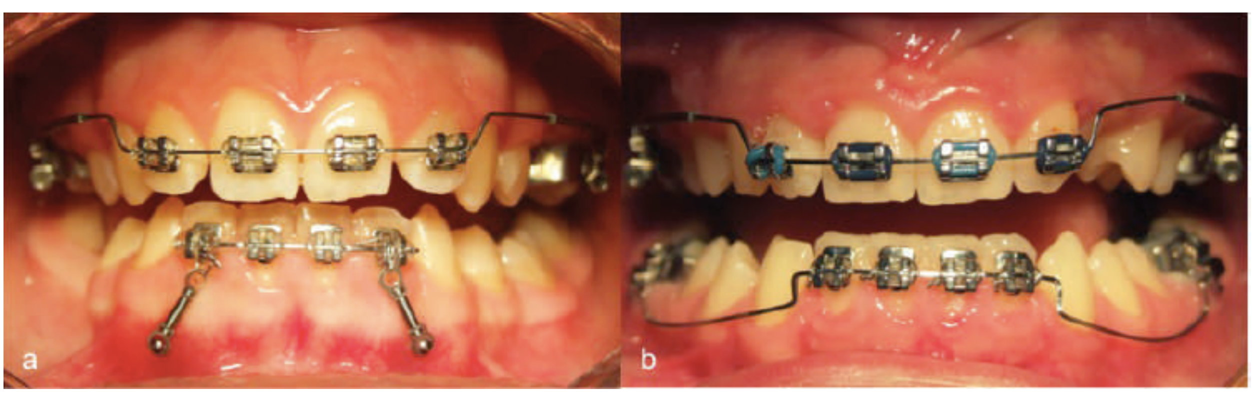

Figure 2.3 *(a) Intrusion with mini-implants. (b) Intrusion with mandibular utility arch* (Aydoğdu et al. 2011)

2.3.1.3 Incisor proclination for overbite reduction

A deep overbite can also be reduced by incisor proclination (Engel et al, 1980, Ball and Hunt 1991, Harrison et al. 2007, Franchi et al. 2011,), which occurs as a side effect of treatment as the crowding is unraveled. Incisors undergo relative intrusion as they are being proclined for alignment. Incisor proclination is especially useful in Class II division 2 malocclusion cases for which labial inclination of maxillary and mandibular incisors is necessary in obtaining an acceptable inter-incisal angle (Nanda 2015).

2.3.2 Overbite correction with the Invisalign® system

The same basic orthodontic principles apply to clear aligner technique when managing deepbites. Similar to traditional fixed edgewise appliances, deep overbites can be corrected by incisor proclination, incisor intrusion, posterior extrusion or a combination of them. The difference resides in their mechanisms of action to move teeth (Tai, 2018). To date, the available literature on the management of deep overbite with the Invisalign appliance consists mostly of case reports and series (Khosravi et al. 2017). Joffe (2003) suggested that deep bites can be corrected with the Invisalign technique, while Kamatovic's study (2004) reported contrary evidence. A recent retrospective study investigating the effectiveness in overbite correction with clear aligner therapy showed that the Invisalign® appliance was capable of reducing overbite in patients with pretreatment deepbite (Khosravi et al. 2017). However, their study was conducted before the introduction of the Invisalign® G5 deep bite technology. Their cephalometric analyses indicated that deepbite was mainly reduced by proclination of mandibular incisors, intrusion of maxillary incisors and extrusion of mandibular molars. Their conclusions disagreed with a recent systematic review suggesting that Invisalign® can only be used to treat mild deepbites (Rossini et al. 2015).

Since the introduction of the Invisalign® system in the early 2000s, it has been anecdotally reported by multiple practitioners that the appliance tends to deepen the overbite as a result of the posterior plastic coverage intruding the posterior teeth (Boyd et al. 2000, Kruster and Ingervall, 1992). To assure a better vertical control in deepbite malocclusions, various strategies have been developed (Khosravi et al. 2017). In February 2014, Align Technology® launched their G5 Deep Bite protocol with the aim of improving the predictability of deep overbite correction (Align

Technology, 2013). The innovations include pressure areas, optimized deep bite attachments and precision bite ramps.

I. Pressure areas

Intrusive forces exerted from aligners are not always directed along the long axis of the teeth, resulting in incomplete reduction of the overbite. Pressure areas are concavities incorporated into the aligner material on the lingual surface of the anterior teeth aiming to redirect intrusive force through the long axis of the tooth, thus creating pure intrusion movement (Figure 2.4). This feature is available for incisors and mandibular canines (Tai 2018). They are automatically placed when 0.5mm intrusion is planned (https://learn.invisalign.com/smartforce/features)

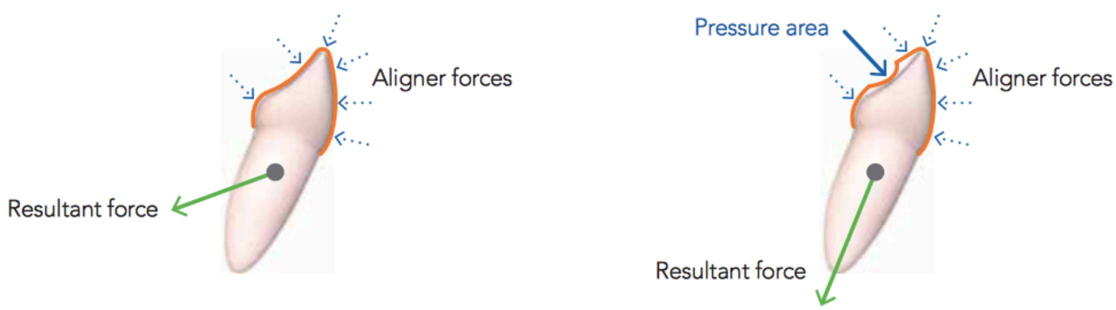

Figure 2.4 *Pressure areas for intrusion in the G5 Deep Bite protocol*
(Align Technology, Inc. 2018)

II. Optimized deep bite attachments

Optimized deep bite attachments are 1-mm thick (buccal-lingual dimension) horizontal beveled attachments placed on mandibular premolars (Figure 2.5). They are automatically placed when anterior intrusion and/or 0.5mm premolar extrusion is planned (https://learn.invisalign.com/smartforce/features). They are programmed to be active or passive. Passive deep bite attachments provide anchorage for lower incisor intrusion and are usually placed on first or second lower premolars, or both. Vertical anchorage prevents the aligner from lifting posteriorly as the anterior teeth are being intruded. Active deep bite attachments have a gingival active surface to deliver extrusive forces to the mandibular premolars and level the curve of Spee (Tai 2018).

Figure 2.5 *Optimized deep bite attachments in the G5 Deep Bite protocol*
(Align Technology, Inc. 2018)

If a premolar is rotated more than 5 degrees, the current ClinCheck protocol will automatically place an optimized rotation attachment instead of an optimized deep bite attachment. Various designs of attachment can be used for anchorage purposes. They are listed below in order of preference (Tai 2018):

a. Optimized deepbite attachment
b. Horizontal rectangular attachment beveled on the gingival
c. Optimized rotation attachment
d. Vertical rectangular attachment

III. Precision bite ramps

Precision bite ramps can be placed on the palatal surfaces of either the maxillary incisors or the maxillary canines to disocclude the posterior teeth and aid in deep bite correction. They may function similar to bite turbos, but their exact mechanism of action remains unclear (Khosravi et al. 2017). They cannot be used simultaneously with the pressure areas since they occupy the same palatal surface of the maxillary incisors. An alternative is to program pressure areas on the central and lateral incisors and bite ramps on the maxillary canines (Tai 2018)

Figure 2.6 *Precision bite ramps*

(Align Technology, Inc. 2018)

Power ridges are another feature helping in overbite correction. They are placed on the labial surface of the incisors and deliver lingual root torque to produce proclination. They are particularly useful in proclining retroclined maxillary incisors in Class II division 2 cases (Malik et al. 2013).

When setting up a treatment plan in the ClinCheck® software**,** staging is of particular importance in obtaining acceptable clinical predictability (Tai, 2018). It is challenging mechanically to accomplish different tooth movements in several planes of space at the same time. Conversely, staging the tooth movements in separate planes of space is considered as more clinically predictable (Tai, 2018). This is an important concept because the software automatically stages simultaneous tooth movement by default. In deep bite cases presenting over-erupted and retroclined maxillary incisors, it is recommended to 1) procline first, then 2) intrude and finally 3) retract to avoid occlusal interference during retraction. As described in the Bioprogressive Therapy by Ricketts (1979), it has been recommended to treat the overbite before the overjet. Power ridges and bite ramps can be used to procline the maxillary incisors. Once the incisor proclination has been achieved, bite ramps can be removed and replaced by pressure areas. The incisors can then be intruded along the long axis of the tooth. Once the deep bite is corrected, if there is any residual overjet, the incisors can be retracted without interference (Tai, 2018).

When correcting a deep bite, anterior intrusion can be programmed to level out the curve of Spee. Clear aligners are capable of successfully intruding entire segments of teeth (Khosravi et al. 2017, Boyd & Vlaskalic 2001) by engaging the occlusal, buccal and lingual surfaces of the teeth (Tai, 2018). This can be accomplished with or without concurrent extrusion of the posterior teeth by providing vertical anchorage. The recommended rate of intrusion per aligner is 0.125 mm, which represents half of the normal 0.25 mm suggested for other movements (Align Technology® 2018). Relative intrusion also occurs simultaneously as the teeth are proclined for alignment. To maximize overbite correction, it is important to have sufficient anchorage for incisor intrusion with retentive attachments on the premolars (Tai 2018).

In the ChinCheck® software, it is possible for the clinician to determine the degree of difficulty of tooth movement using the tooth movement assessment table (TMA). To improve the clinical predictability, it has been recommended to use additional treatment modalities for movements that fall within the moderate and advanced range of difficulty (Malik et al. 2013). These may involve the use of auxiliaries such as buttons and elastics, segmental fixed appliances, interarch Class II and Class III elastics and anchorage reinforcement with temporary anchorage devices (Tai, 2018). In deep bite cases, inter-arch elastics may assist in opening the bite by extruding the posterior teeth. Significant increase in arch width may also indirectly assist deep bite correction. Temporary anchorage devices can be used along with aligners to obtain true incisor intrusion.

Overtreatment has also been recommended when the pretreatment overbite is of 80% or more (Tai, 2018). Concretely, in such cases, it has been suggested that the clinician should request the following in the ClinCheck software (Tai, 2018):

- Correct to 0 mm overbite
- Engineer a mandibular reverse curve of Spee
- Finish the occlusion with heavy posterior contacts

2.4 Increased interest in esthetic orthodontics such as Invisalign

Although orthodontic treatment aims to improve dentofacial esthetics, wearing an orthodontic appliance may temporarily affect overall facial appearance (Ziuchkovski et al. 2008). Over the last few decades, many treatment modalities such as lingual braces, brackets of smaller size, ceramic brackets, plastic brackets, clear aligners, as well as esthetic auxiliaries such as clear elastic ties and white archwires, have been developed to enhance esthetics during treatment (Ziuchkovski et al. 2008, Tai et al. 2018). Development of more esthetically appealing appliances could be one of the major factors explaining the increasing demand in orthodontic treatment in adults (Jeremiah et al. 2011, Khosravi et al. 2017). This may also result from improved dental and orthodontic awareness and increased social acceptance of appliance therapy in adults (Breece and Nieberg, 1986). Invisible orthodontic appliances such as clear aligners have also been associated with greater perceived intellectual ability than those made of metal or ceramic (Jeremiah et al. 2010). Adults are also primarily concerned about the reaction of others to apparent orthodontic treatment, which make clear aligners more socially acceptable in this population (Proffit 2013).

When planning orthodontic treatment, any aesthetic concern should be taken into consideration. Since clear aligners maintain aesthetics and minimally interfere with speech during treatment (Meier et al, 2003, Giancotti et al. 2008, Ali & Miethke 2012), acceptability of orthodontic treatment in adults has increased significantly, especially in women. Children and adolescents also prefer Invisalign® treatment over conventional fixed appliances because of its superior esthetics (Walton et al. 2010). Furthermore, Invisalign® is particularly useful for patients who work in public areas (Ali & Miethke, 2012).

In a survey conducted by Rosvall and coworkers (2009), laypersons were asked to rank orthodontic appliances in function of their attractiveness, acceptability and monetary value. It was found that clear aligners were considered as the most appealing, followed by ceramic brackets, self-ligating brackets and finally metallic brackets. The authors also revealed that adults were willing to pay an extra cost for appliances they judge more esthetic. Another investigation conducted by Ziuchkovski et al (2008) came to a similar conclusion stating that clear aligners and lingual appliances had the highest ranking in terms of attractiveness. Despite the increasing popularity in esthetic orthodontic treatment, the British Lingual Orthodontic Society found in a 2009 survey that 72% of adults were unaware of the existence of invisible braces. Furthermore, when asked, 90% of these same subjects considered clear aligners to be attractive and acceptable, whereas only 55% perceived the same for stainless steel brackets (Malik et al 2013).

2.5 Plaster models vs. digital models for treatment planning with Invisalign®

Recent technologic developments in dentistry have led to important advances in orthodontic diagnosis and treatment planning tools, including study models (Ghafari 2015, Peluso et al. 2004). Dental casts made of plaster or stone have gradually been replaced by digital models acquired from mouth scanners (Jacob et al. 2015). Digitized study models were introduced in the 1990s (Joffe 2004, Mah 2007). By 2014, 55% of Pacific orthodontic practices and 21% of Northeast practices were using digital study models as part of their records (Keim et al. 2014). Digital casts can now be used to perform accurate and reliable measurements electronically in all three planes of space (Grüheid et al. 2014, Santoro et al. 2013, Sousa et al. 2012, Fleming et al. 2011). Traditionally, measurements were done directly on plaster models with a ruler or caliper.

Digital models can be obtained indirectly from scanning plaster models, scanning of an alginate or PVS impression or directly scanning the patient's dental arches. The advantages of using this technology over plaster models include less storage space, ease of fabrication, easy access and share of information between different practitioners (Camardella et al. 2017, Sousa et al. 2012, Peluso et al. 2004). Furthermore, with three-dimensional orthodontic software, digital models can be used to examine intra-arch and interarch relationships. Important diagnostic parameters such as overbite, overjet and arch length can be measured (Westerlund et al. 2015). Digital casts also allow for better 3D manipulation, space analysis and simulations (Ghafari 2015).

Several studies have investigated the accuracy and reproducibility of linear measurements on digital models using different software and scanners (Sousa et al. 2012, Quimby et al. 2004, Leifert et al. 2009, Zilberman et al. 2003, Santoro et al. 2003, Costalos et al. 2005, Asquith et al. 2007, Mullen et al. 2007, Stevens et al. 2006, Kusnoto et al. 2002, Redlich et al. 2008). Numerous investigations have reported that measurements taken on digital models are as accurate and reliable as on plaster models (Grüheid et al. 2014, Sousa et al. 2012, Fleming et al. 2001, Mayers et al. 2005, Santoro et al. 2003, Bell et al. 2003). Moreover, a systematic review conducted by Luu and colleagues (2012) reported that digital models were equivalent to plaster models in terms of intra-rater reliability and validity. Some studies found that measurements on the digital models were significantly larger compared to those on plaster models (Asquith and al. 2007, Stevens et al. 2006, Goonewardene et al. 2008, Naidu & Freer 2013), whereas others found significantly lower values for the measurements on digital models (Abiadeh et al. 2012, Mullen et al. 2007, Watanabe-Kanno et al. 2009). Questionable linear measurement accuracy was reported by Redlich and coworkers (2008) on digital models, especially in severely crowded dentition.

It was reported that digital models were valid and reliable in assessing PAR index scores (Mayers et al. 2005). The PAR index includes the overbite component.

To date, a considerable number of studies investigating on Invisalign® accuracy have used digital dental casts for measurements of pre- and post-treatment records as part of their study design (Papadimitriou et al. 2018).

2.6 Intra-oral scanners and iTero® Element scanner

Intra-oral scanners capture series of digital images of the dentition and adjacent structures, generating three-dimensional (3D) digital study models for diagnosis and treatment planning purposes. The dental arches can be recorded separately and in occlusion (Kamimura et al. 2017). The practitioner can visualize the arches, the position of the teeth and the occlusion in three dimensions on the computer (Align Technology Inc, 2018). Furthermore, digital models can be used for computer aided design (CAD) and manufacture (CAM) of dental appliances, such as aligners (Kamimura et al. 2017).

In contrast to conventional impression materials, intra-oral scanners simplify workflow and make the procedure easier for practitioners, patients and dental technicians. Inaccuracies related to the conventional impression technique such as dimensional instability are avoided. Excellent dimensional accuracy and precision of digital impression have been reported in several *in vitro* investigations (Patzelt et al. 2014, Van der Meer et al. 2012, Karl et al. 2012, Schaefer et al. 2014, Yang et al. 2015, Lee et al. 2015, Cho et al. 2015, Kamimura et al. 2017). The available literature counts very few *in vivo* studies regarding their precision (Ender, Attin & Mehi 2016, Ender & Mehi 2013, Kamimura 2017). However, a recent *in vivo* study conducted by Kamimura and colleagues (2017) found that inter-operator reproducibility of digital impression was superior compared to that of conventional impression technique. Their findings were independent of the operator’s clinical experience and patient’s condition.

The iTero® scanner (Align Technology, San Jose, California) has been available since 2011 as part of the Invisalign® system (Garino et al. 2014). Previously, polyvinyl siloxane impressions were used to build the virtual planning process, known as the ClinCheck®. To date, iTero® have generated more than 1.2 million Invisalign® scans (www.itero.com). The iTero® scanner uses the confocal imaging-based technology; the dental arches, the gingival contours and the bite registration are captured through optical scanning and laser at a rate of 6000 frames per second. Emission of light at different wavelengths makes it possible to construct a digital image and a three-dimensional representation of hard and soft tissue structures (Garino et al. 2014). Structures are topographically sliced and being assembled together to create a complete picture through a process called stitching (Porter et al. 2018). Indeed, the ability of the scanner to correctly transform the geometric information into 3D models greatly influence the accuracy of measurements to be done later in software (Mack et al. 2017).

Several investigations using linear, diagnostic and volumetric measurements have reported a high degree of accuracy of impression-free digital models obtained from intra-oral scanners (Sousa et al. 2012, Wiranto et al. 2013, Akyalcin et al. 2013). Furthermore, recent studies comparing the intra and interarch measurements obtained from intraoral scans and conventional gypsum models have been conducted by several investigators (Wiranto et al. 2013, Grünheid et al. 2014, Aragon et al. 2016, Naidu & Freer 2013, Flügge et al. 2013). These studies concluded that chair-side digital impressions had a good level of reliability and accuracy. It was shown that the accuracy of the iTero® scanner was comparable to that of the polyether material which is of 61.3 ± 17.9 microns (Flügge et al. 2013). A recent study using dry skulls also found that the iTero® scanner was accurate in terms of 3-dimensional curvilinear measurements (Mack et al. 2017). Furthermore, it was demonstrated that the iTero® scanner was able to generate accurate articulation of digital models, which is of particular importance when it comes to overbite measurement since it relies on correctly articulated models (Porter et al. 2018).

Once the digital scan is sent to Invisalign®, a virtual 3D treatment plan is generated in the ClinCheck® software. The correction of the malocclusion is segmented in multiples stages, each of them representing an .stl file. The software program arranges the .stl files in a specific sequence and a simulation of the tooth movements will be built into the final occlusion. The ClinCheck® plan is then reviewed by the practitioner, modifications are made and the final plan is approved. The aligners are then manufactured using CAD/CAM laboratory techniques (Phan & Ling 2007, Tai 2018).

2.7 Methods of overbite measurements and Ortho Analyzer® software

There has been a wide heterogenicity in the methodology of overbite measurements in the current orthodontic literature. Depending on the study, the overbite has been measured on conventional gypsum models, lateral cephalometric radiographs or three-dimensional digital models using different software. The amount of vertical overlap can be defined in percentage or millimetres (Proffit 2013, Nanda 2015, Cobourne 2016). According to Ghafari (2013) and Nanda (2015), the percentage measurement is more accurate because of the variation in mandibular incisor crown height.

The American Board of Orthodontics (ABO) Discrepancy Index (www.americanboardortho.com) stated that the overbite should be measured in millimeters between the two antagonist incisors at the point where the overlap is the greatest. Impingement of the palatal tissues should be taken into consideration when assessing overbite severity.

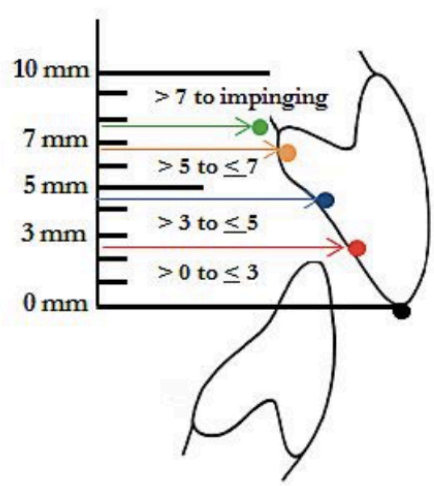

Figure 2.7 *Overbite (vertical overlap) relationship according to the ABO DI.*
(American Board of Orthodontics 2016)

Krieger et al. (2011 and 2012) used the same definition for measuring the overbite in the ClinCheck® with the ToothMeasure® tool from the Invisalign® software. The frontal grid plane was first positioned to determine the landmark where the incisal edge of the maxillary incisors overlapped the mandibular incisors the furthest. To measure the overbite, the maxilla's virtual image was removed and measured in millimeters. Abizadeh and colleagues (2012) also defined the overbite as the maximum vertical overlap either of mandibular central incisor by its corresponding maxillary central incisor.

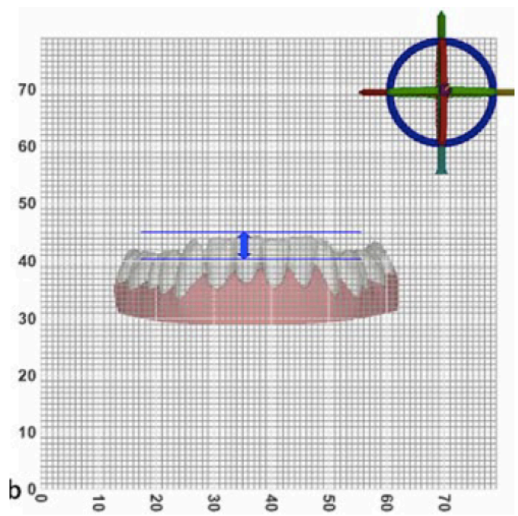

Figure 2.8 *Overbite measurement in the ClinCheck® using the ToothMeasure® tool*
(Krieger et al. 2011)

In most of the longitudinal studies conducted before the introduction of digital models in the 1990s, the changes in overbite were typically measured on lateral cephalometric radiographs (Bishara et al. 1985, Bishara et al. 1994, Bishara et al. 1998, Ceylan et al. 2002). In one of Bishara's longitudinal studies (1985), the overbite was measured on lateral cephalometric radiographs in millimeters. It was defined as the distance between perpendicular lines from the incisal edges having the most labial maxillary and mandibular incisors on N-Me. Cephalometric radiographs were also used in a more recent retrospective study investigating the vertical dimension changes in patients treated exclusively with the Invisalign® appliance (Khosravi et al. 2017). They measured the overbite at the shortest vertical distance between the incisal edge of the maxillary incisor and the incisal edge of the mandibular incisor perpendicular to the functional occlusal plane.

In another study conducted by Baydas et al. (2004) investigating the relationship between the depth of the curve of Spee and different dental parameters, the overbite measurements were made on dental casts. The measurement was taken in millimeters between the incisal edges of the maxillary and mandibular central incisors.

As part of their methodology, some previous studies have used OrthoAnalyzer® (3Shape®, Copenhagen, Denmark) to perform inter-arch dental measurements such as overbite (Massaro et al. 2018, Camardella et al. 2017). A study conducted by Camardella et al. (2017) compared different methods to evaluate the accuracy and reliability of digital models. The investigators performed their measurements on plaster models using a caliper and on digital models using the Ortho Analyzer software (3Shape®, Copenhagen, Denmark). The overbite was measured from the incisal edge of the maxillary right central incisor to the buccal surface of the mandibular incisor antagonist incisal edge. In a recent 40-year follow-up study evaluating the dental changes in patients with normal occlusion (Massaro et al. 2018), the overbite parameter was measured consistently at 3 time points on digital models with OrthoAnalyzer (3Shape®, Copenhagen, Denmark). The overbite was measured on a slice passing through the middle of the upper central incisors and the mean was taken into consideration.

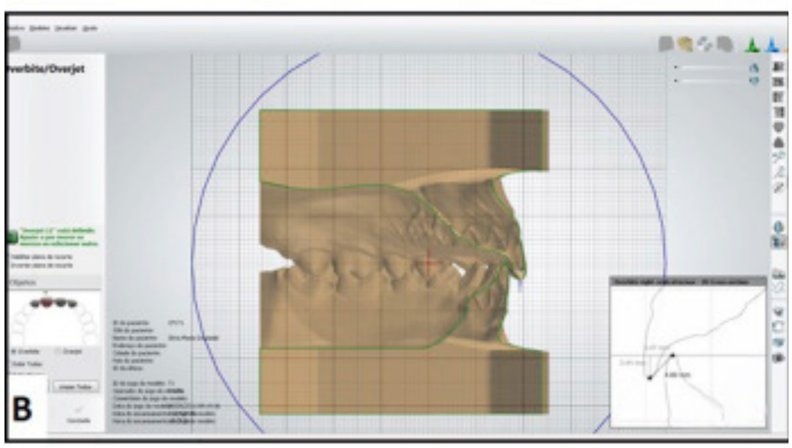

Figure 2.9 *Overbite measurement in OrthoAnalyzer*

(Massaro et al. 2018)

Furthermore, Westerlun et al. (2015) compared four orthodontic digital software systems in terms of service, features and usability. One of their conclusions was that OrthoAnalyzer® (version 1.5; 3Shape, Copenhagen, Denmark) was the most accurate for overbite measurement.

Digital models acquired from an intraoral scanner are saved and stored as stereolithography files (.stl format). These .stl files are a three-dimensional image of the dental arches and can be imported into a specialized software to measure specific dental parameters. For optimal results, the software should be capable of visualizing and rotating the models in in any direction to get a full view of the model from any angle. OrthoAnalyzer® (3Shape, Copenhagen, Denmark) is a 3D orthodontic software that enables the use of .stl files on a computer. The software is equipped with a virtual digital caliper that allows for precise linear measurements to the hundredth of a millimeter. The software also includes a magnifying function that can be used to zoom in on specific parts of the models to aid in landmark identification.

2.8 Invisalign® limitations

Since Invisalign® is a removable appliance, one of the greatest challenges encountered by orthodontists is the patient's compliance (Phan & Ling, 2007). The aligners should be worn 22 hours a day (Malik et al. 2013). It was recommended to wear each aligner for a total of 400 hours before progressing to the next one (Phan & Ling, 2007). However, since the introduction of the Invisalign G7 protocol in 2016, the company has recommended to change aligners on a weekly basis (Align Technology Inc, 2016). Each aligner generates 0.25 to 0.33 mm of tooth movement (Krieger et al. 2011, Malik et al. 2013). Patient's cooperation is a critical factor for success with clear aligner therapy (Boyd 2008) and failure in compliance may result in poor tracking, need for midcourse correction, longer treatment time and inferior treatment outcome (Tai, 2018).

In the early 2000s, the Invisalign® system was initially recommended to treat mild orthodontic problems, such as crowding, spacing or treatment of minor alignment relapse (Joffe 2003, Bollen et al. 2003, Phan et al. 2007, Vlaskalic & Boyd 2011). Since its introduction on the market, Invisalign® has mostly treated adult patients wanting to address their crowding, spacing or incisor flaring (Meier et al. 2003, Vlaskalic & Boyd, 2001). However, there is still no absolute consensus in the literature with regards to whether moderate and complex cases can be routinely treated with aligners (Boyd, 2008). The majority of the studies consists of case reports based on individual anecdotal experiences (Shin, 2017). Successful treatment of moderate to severe malocclusions have been reported (Boyd et al. 2006, Boyd 2005, Womack 2006, Hönn & Güz 2006, Boyd 2007, Krieger et al. 2012, Castroflorio et al. 2013, Guarneri et al. 2013), however, earlier reports have raised important limitations in the treatment of complex cases with Invisalign® (Djeu et al. 2005, Taylor et al. 2003). An important consideration may be that the earlier studies were carried out during the first years of the appliance development, even before the existence of attachments. At that time, there were still significant problems with bodily movement, torque, extrusion and rotations (Boyd, 2008). Throughout the last decade, there has been major changes in materials and protocols to help address issues with managing more complex cases (Gu et al. 2017, Malik et al. 2013). The improvements brought by Align® include the SmarTrack® material, SmartForce® features, the optimized attachments and the different protocol innovations (G3, G4, G5, G6 and G7).

The malocclusions cited below were reported as being less suitable for Invisalign® treatment (Joffe 2003, Malik et al. 2013):

- Moderate and severe crowding of more than 5 mm
- Moderate and severe spacing of more than 5 mm
- Dental expansion for blocked out teeth
- Alignment of high canines
- Skeletal anteroposterior discrepancies over 2 mm
- Severely rotated teeth over 20 degrees
- Anterior and posterior open bites
- Cases requiring extrusion of teeth
- Closure of premolar extraction spaces
- Uprighting of severely tipped teeth (more than 45 degrees)

To overcome some of these limitations and improve clinical predictability, the use of adjunctive therapies have been suggested (Krieger et al. 2011, Ali & Miethke 2012, Malik et al. 2013, Houle et al. 2017, Shin 2017, Tai 2018).

A recent systematic review conducted by Papadimitriou an colleagues (2018) evaluated the available literature regarding the clinical effectiveness of the Invisalign® system. Although there is a high level of methodological heterogeneity amongst the studies, important limitations were found for arch expansion through bodily movement, canine and premolar rotations, extraction space closure, corrections of occlusal contacts and larger antero-posterior and vertical discrepancies.

Clinical crown length is another important factor to consider. Patients presenting with short clinical crowns, such as in cases with extensive tooth wear and attrition, are less likely to track properly compared to those having long clinical crowns (Tai 2018, Joffe 2003). Teeth with short clinical crowns and less surface area offer less engagement of the aligner material and therefore less expression of tooth movement clinically (Tai, 2018).

Although Joffe (2013) and Clements et al. (2003) indicated that Invisalign® was successful in correcting deep overbites, other studies have reported contradictory results. In a retrospective study conducted by Kamatovic (2004), it was concluded that deep bite cases treated with Invisalign® had a poor peer assessment rating (PAR) index at the completion of treatment. Krieger and colleagues (2011 & 2012) reported that overbite control was an important limitation of the Invisalign® system. There is also a general belief among practitioners that Invisalign tends to deepen the bite as a result of the posterior plastic coverage. This would lead to possible creation of posterior open bite (Bollen et al. 2003). However, a recent retrospective study conducted by Khosravi and coworkers (2017) refuted this idea. The nature of overbite correction was assessed in 120 adult patients stratified into 3 groups: open bite, normal overbite and deep bite. The authors demonstrated that the Invisalign® appliance was successful in managing the vertical dimension regardless of the severity of the pre-treatment overbite. One of their conclusions was that the Invisalign® appliance was relatively successful at managing mild to moderate overbite malocclusions. Deepbites were improved primarily by lower incisor proclination. However, it is important to keep in mind that this study was carried out before the implementation of the G5 deep bite protocol. Despite the advancements in the Invisalign® deep bite technologies, evidence supporting the effectiveness of these treatment modalities is mostly limited to case reports and case series (Khosravi et al, 2017).

A recent systematic review (Papadimitriou et al. 2018) examined the existing orthodontic literature to assess the level of evidence concerning the clinical effectiveness of Invisalign®. To date, most of the literature regarding this topic consist of retrospective and prospective studies. In general, the level of evidence was moderate, and the risk of bias ranged from low to high. Specifically, the accuracy of Invisalign® was reported in nine studies. Due to high heterogeneity amongst the studies, no clear recommendations have been made.

Increased clinician experience and knowledge with the Invisalign® system, along with the patient's motivation and compliance, remain the key factors in a successful outcome (Tai 2018, Gu et al. 2017).

2.9 Predictability of Invisalign®

Previous studies about the Invisalign® technique have predominantly focused on individual case reports (Boyd 2005, Giancotti & Farina 2010, Hönn & Göz 2006, Marcuzzi et al 2010, Miller et al. 2002, Schupp et al. 2010), material-specific or technical aspects (Bollen et al. 2003, Eliades et al. 2009, Gracco et al. 2009, Melkos 2005, Schott & Göz 2011, Schuster et al. 2004, Wheeler 2004), or they assessed quality of life (Schaefer & Braumann 2010, Shalish et al. 2011) and oral hygiene (Low et al. 2011, Schaefer & Braumann 2010). A few studies investigating the effectiveness (Boyd 2007, Boyd 2008, Clements et al. 2003, Djeu et al. 2005, Joffe 2003, Duncan et al. 2016) and the prediction accuracy of aligner therapy (Kravitz et al. 2008, Kravitz et al. 2009, Krieger et al. 2011, Krieger et al. 2012, Houle et al. 2017) are present in the literature.

Several studies have reported that treatment results with the Invisalign® system are inferior to those using fixed appliances (Djeu et al. 2005). Invisalign® treatment outcomes were compared with conventional fixed appliances treatments in two retrospective cohort studies (Djeu et al. 2005, Kuncio et al. 2007). In both studies, treatment results were assessed using the ABO objective grading system. Djeu and colleagues (2005) reported that Invisalign® patients reached a passing rate 27% lower than for fixed appliances. On average, patients with fixed appliances gained 13 more objective grading system points than did Invisalign patients. The aligners were less successful at correcting occlusal contacts, posterior torque and anteroposterior discrepancies. Their follow-up study (Kuncio et al. 2007) found that Invisalign® treatments were less stable than those with fixed appliances, especially in the maxillary anterior segment. However, a systematic review that was done in 2005 by Lagravère and Flores did not support this conclusion. It is important to consider that these studies were conducted when clear aligners were still relatively new; the introduction of the several technologic innovations brought by Align Technology® have been made since these preliminary studies were initiated. In a recent retrospective case-control study (Gu et al. 2017), it was found that fixed appliances improved malocclusion to a greater extent than did Invisalign®. The authors concluded that the likelihood of achieving “great improvement” in a malocclusion was higher with fixed appliances.

The final virtual models on ClinCheck® do not accurately reflect the final clinical outcome (Houle et al. 2017, Shin 2017, Buschang et al. 2015, Simon et al. 2014, Malik et al. 2013, Krieger et al. 2011 and 2012, Kravitz et al. 2008 and 2009, Nguyen & Cheng 2006). From the orthodontist perspective, as much concordance as possible between the ClinCheck® and the clinical result is ideal (Krieger et al. 2011). As of today, nine studies have focused on the accuracy of Invisalign® (Papadimitriou et al. 2018), where the deviation between the achieved and predicted tooth movements was evaluated. Sufficient accuracy in resolving anterior crowding (Krieger et al. 2011 and 2012) and distalizing maxillary molars (Simon et al. 2014) was reported. On the other hand, findings in upper incisor root control were inconsistent (Castroflorio et al. 2013, Simon et al. 2014) and lack of accuracy was found in bodily expansion of the maxillary posterior teeth (Solano-Mendoza et al. 2017, Buschang et al. 2015, Houle et al. 2017), canine (Kravitz et al. 200) and premolars (Simon et al. 2014) rotations, extrusion of maxillary incisors (Kravitz et al. 2009) and overbite control (Krieger et al. 2011 and 2012). Randomized controlled trials investigating the clinical predictability of Invisalign® have not been undertaken yet (Malik et al. 2013, Papadimitriou et al. 2018).

Boyd and Vlaskalic (2001) stated that deep overbite reduction is predictable with Invisalign®. Similarly, Nguyen and Cheng (2006) reported that anterior intrusion was 79% accurate. Later in 2009, Kravitz and colleagues conducted a prospective study to assess the accuracy of different tooth movements with Invisalign® in the anterior region. Movements such as expansion, constriction, intrusion, extrusion, mesiodistal tip, labiolingual tip and rotated were evaluated. A total of 401 teeth were analyzed. The mean accuracy of tooth movement with Invisalign® was found to be 41%. Likewise, anterior intrusion showed an accuracy of 41.3%. The maxillary and mandibular central incisors had the highest accuracy of intrusion, whereas the lowest one was achieved by the maxillary lateral incisor. In their study, most of the teeth aimed intrusions lower than 1.0mm. On average, 0.72mm of intrusion was attempted. The authors also concluded that intrusion was more predictable than extrusion in the anterior region (Kravitz et al. 2009). Clements et al. (2003) also reported that achieving a 100% accurate intrusion was unlikely. However, intrusion mechanics are in general more predictable with Invisalign® compared to fixed appliances because disclusion of teeth eliminates problems encountered with fixed appliances from occlusal interferences (Boyd 2008). Aligners' ability to engage the occlusal, buccal and lingual surfaces of the teeth makes them successful at intrusion (Tai 2018).

Krieger et al. published two retrospective studies in 2011 and 2012 investigating the accuracy of Invisalign® treatment in the anterior region. The pilot study of 2011 included 35 patients and the extended study of 2012 comprised 50 patients. In both studies, they concluded that tooth movements in the vertical plane were more challenging to achieve than in the sagittal and transverse planes with Invisalign®. Overbite was the least accurate parameter compared to anterior arch length and intercanine distance, overjet, dental midline shift and irregularity index according to Little (Krieger 2012). Overbite showed a prediction accuracy of only 14.3% and had the highest deviations between the planned and the actual treatment outcome (Krieger et al. 2011). The mean difference between the achieved and predicted overbite was 0.71mm (Krieger et al. 2012). Therefore, refinements should be expected toward the end of treatment when treating patients requiring major vertical correction. The authors also recommended the use of supportive measures (horizontally bevelled attachments or elastics) to achieve optimal result in these patients (Krieger et al. 2011).

Simon and colleagues (2014) investigated the accuracy of tooth movements using Invisalign®. The following movements were studied: incisor torque greater than 10°, premolar derotation greater than 10° and molar distalization greater than 1.5mm. They reported that overall mean accuracy of tooth movement was 59%. However, this should be interpreted with caution due to the high risk of bias (Papadimitriou et al. 2018).

A prospective study conducted by Buschang et al (2015) examining the accuracy of Invisalign® with respect to the ABO Objective Grading System (OGS) reported that the ClinCheck models overestimate alignment, buccolingual inclinations, occlusal contacts and occlusal relations.

To date, there have been no studies focusing on the prediction accuracy of deep overbite correction using Invisalign®. Moreover, most previous studies were conducted before the implementation of the G5 deep bite protocol and the introduction of the SmartTrack® material to which we are exposed to today.

CHAPTER 3

Purpose and Null hypothesis

3.1 Purpose

The aim of this study is to investigate the predictability of deep overbite correction using the Invisalign® system.

3.2 Null hypotheses

1. There is no statistical significant difference between the treatment outcome and the overbite correction planned by ClinCheck.

2. There is no association between the amount of overbite correction planned on ClinCheck and the prediction accuracy.

3. There is no association between the pre-treatment overbite severity and the prediction accuracy.

CHAPTER 4

Material and methods

4.1 Ethics

This retrospective study received approval from the Bannatyne Campus Research Ethics Boards at the University of Manitoba on May 24th 2017 (Appendix 1).

4.2 Sample size calculation

In this study, a maximum of 60 patients was fixed by Align Technology®. The type 1 error is usually set to be 0.05, with a power of 80%, or 90%. These specifications give this study the ability to detect an effect size of 0.73 with 80% power, or an effect size of 0.84 with a 90% power. A sample of size 60 allows estimation of proportions with a precision (95% CI) of 13%.

4.3 Sample selection

An informed consent was obtained for each patient included in this study to allow the use of records needed for research purposes (Appendix 2). The consent form was previously signed by every patient participating in the study.

The study sample was obtained from a single orthodontic specialist experienced with the Invisalign® technique at two orthodontic practices located in Winnipeg and Thunder Bay, Canada. The collected records included (1) the patient's age at the start of treatment, (2) the patient's gender, (3) the number of maxillary and mandibular active aligners used in the first round of aligners, (4) the number of optimized deepbite attachments on the lower premolars, (5) the number of attachments of any type on the lower premolars (6) the ClinCheck® Tooth Movements Table providing information about the amount of anterior intrusion, posterior extrusion and incisor proclination planned by the ClinCheck® and (7) the three .stl files required (pre-treatment, predicted treatment and post-treatment digital models).

Records needed for this study were acquired randomly for patients meeting the inclusion and exclusion criteria as listed below.

Inclusion criteria

- Cases presenting a pre-treatment overbite of more than 3 mm
- Cases with three .stl files available (pre-treatment, predicted treatment, post-treatment or first refinement)
- G5 deep bite protocol (cases treated after February 2014)
- Adult patients with completed growth at the beginning of treatment (>18 years old)
- Permanent dentition
- Dual arch orthodontic treatment exclusively using Invisalign®
- Interproximal reduction (IPR) completed as prescribed in the treatment
- Good compliance during treatment as assessed by the practitioner

Exclusion criteria

- Midcourse correction needed
- Crowding of more than 6 mm
- Extensive space closure (e.g. missing teeth)
- Any anteroposterior change (Class II or Class III elastics)
- Surgical cases
- Extraction cases
- Auxiliary treatment (Inter-arch elastics, Carriere® and TADs®)
- Presence of a cleft lip or palate or syndrome-associated orofacial malformations

A total of 60 participants were included in this study, 40 females and 20 males. The mean age of the sample was 33 years old (male = 31, female = 34). The age range of the subjects included in this study was from 18 to 55 years old (Table 4.1). Each patient received orthodontic treatment exclusively with Invisalign® in the period between February 2014 and October 2017. This study only emphasized on the first series of aligners and no refinements were included. These patients wore each aligner 22 hours a day for 2 weeks.

Gender	Frequency (N)	Percentage (%)	Mean age (years)
Female	40	67	34 (30, 38)
Male	20	33	31 (26, 36)
Total	60	100	33 (30, 36)

Table 4.1. *Sample demographics*

The study sample was stratified into groups of mild overbite, moderate overbite, and severe deep overbite based on the magnitude of pre-treatment overbite. Patients with overbite greater than 3.0 mm were classified as deepbite patients.

- Overbite ranging from 3.0 to 4.5 mm (Mild deep bite group)
- Overbite ranging from 4.6 to 6.0mm (Moderate deep bite group)
- Overbite of more than 6.0mm or impinging on the palatal tissue (Severe deep bite group)

Twenty-five patients composed the mild overbite group, 16 were in the moderate overbite group and 19 were in the severe overbite group (Table 4.2).

Pre-treatment deep bite	Frequency (N)	Percentage (%)
Mild	25	41
Moderate	16	27
Severe	19	32
Total	60	100

Table 4.2 *Pre-treatment deep bite distribution of the sample size*

The patients included in the sample were treated with one of the following Invisalign® treatment options:

- Invisalign® Express 10 (10 active aligners)
- Invisalign® Assist (13 active aligners) or
- Invisalign® Full (more than 13 active aligners)

As shown in table 4.3, almost half of the sample size received the Invisalign® Assist treatment.

Invisalign® Treatment	Frequency (N)	Percentage (%)
Express 10	17	28
Assist	27	45
Full	16	27
Total	60	100

***Table 4.3** Invisalign® treatment option distribution of the sample size*

4.4 Data collection

The data was collected retrospectively from Align Technology Inc. and two orthodontic private offices of a single practitioner. One practice was located in Winnipeg and the other one was in Thunder Bay, Canada. Pre and post-treatment digital models generated from an iTero® scan were obtained for every participant included in this study. The models predicting the final outcome, which corresponded to the last worn aligner by the patient, were requested directly from Align Technology®. Patient confidential data was de-identified by the assignation of an anonymous identification number to each subject suitable for the study.

The digital .stl files from the iTero® scan and the ClinCheck® were uploaded in the OrthoAnalyzer® (3Shape®, Copenhagen, Denmark) software. The digital images of the models were zoomed in to facilitate measurements. Overbite measurements were recorded by the primary investigator using the digital caliper provided by the software. The software also offers a suggested 2D cross-section plane that can be zoomed in. The digital models were measured to the nearest 0.01 mm. Linear values of overbite were measured according to the following points:

- **Overbite:** the greatest vertical distance (mm) between the incisal edge of the maxillary incisor and the incisal edge of the mandibular incisor perpendicular to the occlusal plane.

For each subject, the overbite was consistently measured in millimeters at 3 different timepoints:

- Initial overbite (mm) on pretreatment digital models
- Target overbite (mm) on the predicted final digital models (ClinCheck®)
- Final overbite (mm) on the posttreatment digital models (refinement scan)

For each specific patient, the overbite was consistently measured from the same maxillary incisor and the same mandibular incisor landmark of the corresponding pre-treatment, post-treatment and prediction models.

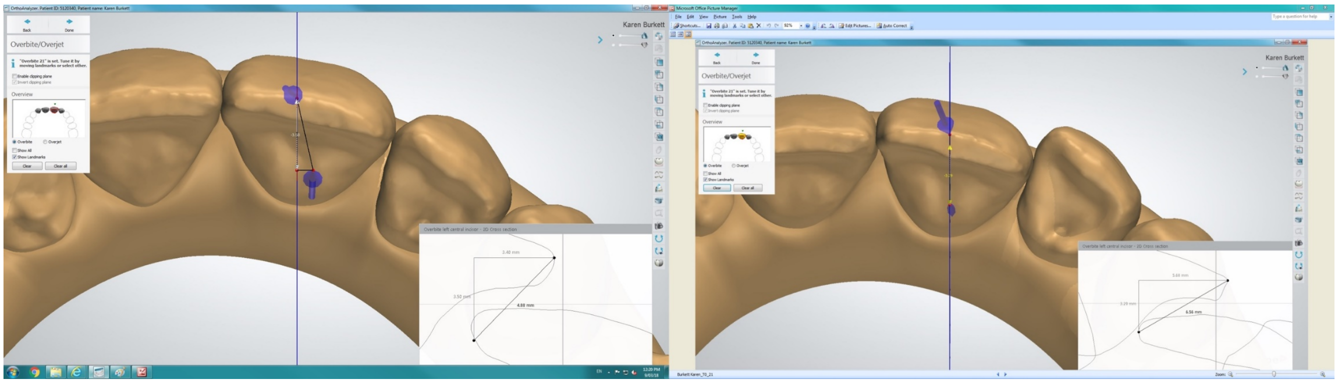

Figure 4.1 *Overbite measurement on maxillary incisor (pre- and post-treatment models)*

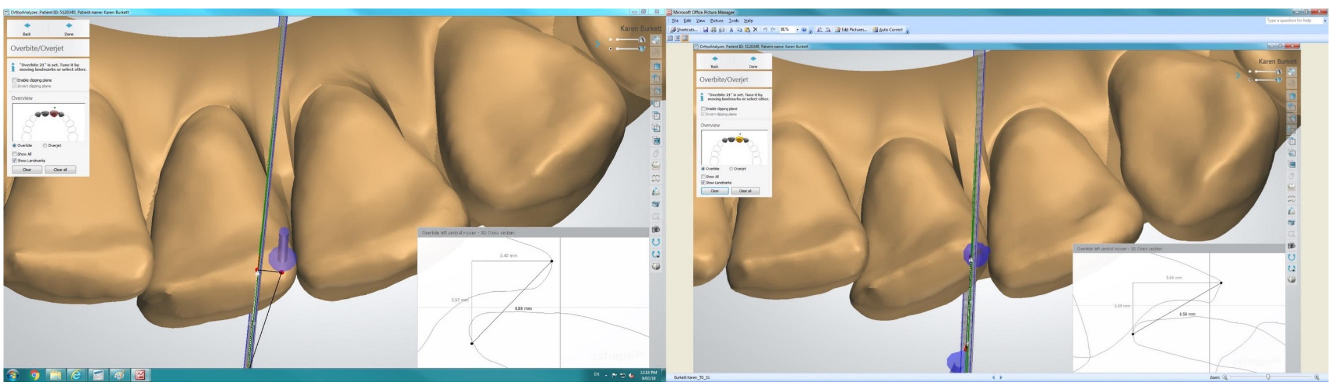

Figure 4.2 *Overbite measurement on mandibular incisor (pre- and post-treatment models)*

Deep overbite correction can be achieved by incisor intrusion, posterior extrusion, incisor proclination or a combination of any of these. Various bite opening mechanisms were programmed in the ClinCheck® to reduce the overbite: (a) Upper incisor proclination, (b) Lower incisor proclination, (c) Upper incisor intrusion, (d) Lower incisor posterior intrusion (e), Upper posterior extrusion, (f) Lower posterior extrusion. This information was recorded from the Tooth Movements Table and the Superimposition tool of the ClinCheck® software. Tooth attachments of various shape, size and position were used according to the doctor's prescription. The number and type of attachments on mandibular premolars were recorded from the ClinCheck®.

In summary, for each subject included in this study, the following variables were recorded:

- Age and gender of patient
- Invisalign® treatment option (Express 10®, Assist®, Full®)
- Pre-treatment, target and final overbite (mm)
- Bite opening mechanisms programmed in the ClinCheck® (quantity and type)
- Attachments on mandibular premolars (quantity and type)

4.5 Calibration

A total of 180 overbite measurements were performed by the primary investigator (CFS) using the OrthoAnalyzer® (3Shape®, Copenhagen, Denmark) software. To test the intra-examiner reliability, 20% of the sample size was randomly selected to be measured again 2 weeks after the first assessment (Houston 1982). Twelve patients, for a total of 36 overbite measurements, were re-measured by the principal investigator. The intra-examiner reliability was assessed with an intraclass correlation coefficient (ICC). SAS System® version 9.4 software was used to analyze the data.

4.6 Statistical analysis

The data of this study was analyzed using the SAS System® version 9.4 (Cary, NC, USA). A paired t-test ($P < 0.05$) compared the pre-treatment overbite and target overbite as per ClinCheck® to determine if significant overbite changes were planned on the software. A paired t-test ($P < 0.05$) was also used to compare the predicted final overbite measurement and the overbite measurement achieved clinically at the end of the first series of aligners. This allows the determination of the reliability of ClinCheck® in predicting overbite changes when planning deep overbite correction.

A percentage of accuracy of tooth movement was calculated to quantify the amount of change achieved (overbite correction obtained clinically) relative to the amount of change planned (predicted overbite correction as per ClinCheck®). The calculation of prediction accuracy was done according to the following formula: 100 * Actual correction / Predicted correction.
The value calculated cannot exceed 100%.

A Spearman correlation coefficient was used to determine if larger overbite corrections predicted were correlated with poorer prediction accuracies. A negative correlation coefficient ($\rho < 0$) would indicate that larger changes predicted are correlated with larger errors. A correlation coefficient of zero ($\rho = 0$) would indicate that no relationship exists between the magnitude of overbite correction predicted and the prediction accuracy.

One-way analysis of variance (ANOVA) tests ($P < 0.05$) were used to determine the significance of differences in overbite correction accuracy between the mild, moderate and severe pre-treatment deep bite groups. Variance ratio tests were also used to determine if a greater number of active aligners, a specific type and number of programmed bite opening mechanics, a higher number of mandibular premolar attachments and the use of optimized deep bite attachments were correlated with higher prediction accuracies.

CHAPTER 5

Results

5.1 Reliability and reproducibility

An almost perfect agreement with regards to intra-rater reliability was showed by the ICC test, with a score of 0.99. There was very little variation in the repeated measurements made by the primary investigator.

5.2 Treatment modalities distribution in the sample

The distribution of the different treatment modalities among the three pre-treatment deep bite groups is illustrated in table 5.1.

Twenty-five patients composed the mild overbite group, 16 were categorized in the moderate overbite group and 19 in the severe overbite group.

Near half of the sample (45%) underwent Invisalign® Assist treatment (13 upper and 13 lower active aligners in their first series). In the mild pre-treatment deep bite group, 76% of the subjects had 13 or less treatment aligners in their first round of aligners. In the moderate group, 62% of the subjects had 13 active upper and lower aligners. In the severe group, 74% of the subjects had more than 13 active aligners in their first round of aligners.

In the three overbite groups, the most frequent bite opening mechanism programmed in the ClinCheck® was incisor intrusion, followed by incisor proclination. Upper and lower posterior extrusion were the least common mechanisms programmed in the ClinCheck®. The moderate and severe overbite groups had a similar distribution in nature of bite opening mechanisms.

More than half of the sample (62%) had 3 or 4 bite opening mechanisms programmed in the ClinCheck®. In the severe overbite group, only 26% of them had 5 or 6 bite opening mechanisms programmed in the software.

Sixty-three percent of the total sample had attachments on all four mandibular premolars in their first series of aligners. Attachments could be of any type (e.g. optimized deepbite attachment, optimized rotation attachment, root angulation control attachment, conventional vertical/horizontal rectangular attachment, etc.). Similarly, in every overbite group, the majority of subjects had attachments on all 4 lower premolars.

Optimized deep bite attachments on mandibular premolars were found to some extent in 78% of the total sample. Twenty-two percent of the sample had no optimized deep bite attachments.

Variables	Pre-treatment deepbite group			
	Mild OB 25 (41%)	**Moderate OB** 16 (27%)	**Severe OB** 19 (32%)	**Total** 60 (100%)
Number of active aligners (frequency and %)				
Express 10 (10 aligners)	9 (36%)	3 (19%)	5 (26%)	17 (28%)
Assist (13 aligners)	10 (40%)	10 (62%)	7 (37%)	27 (45%)
Full (>13 aligners)	6 (24%)	3 (19%)	7 (37%)	16 (27%)
Bite opening mechanism programmed in the ClinCheck® (frequency)				
Upper incisor intrusion	18 (72%)	15 (94%)	17 (89%)	50
Lower incisor intrusion	20 (80%)	14 (56%)	18 (95%)	52
Upper posterior extrusion	11 (44%)	3 (19%)	4 (21%)	18
Lower posterior extrusion	10 (40%)	3 (19%)	5 (26%)	18
Upper incisor proclination	18 (72%)	15 (94%)	15 (79%)	48
Lower incisor proclination	18 (72%)	13 (81%)	13 (68%)	44
Number of bite opening mechanisms programmed in the ClinCheck® (frequency and %)				
1 or 2	5 (20%)	1 (6%)	1 (5%)	7 (11%)
3 or 4	12 (48%)	12 (75%)	13 (69%)	37 (62%)
5 or 6	8 (32%)	3 (19%)	5 (26%)	16 (27%)
Total number of attachments on lower premolars (frequency and %)				
0	2 (8%)	0	1 (5%)	3 (5%)
1	0	0	0	0
2	2 (8%)	1 (6%)	3 (16%)	6 (10%)
3	4 (16%)	4 (25%)	5 (26%)	13 (22%)
4	17 (68%)	11 (69%)	10 (53%)	38 (63%)
Number of optimized deepbite attachments on lower premolars (frequency and %)				
0	7 (28%)	3 (19%)	3 (16%)	13 (22%)
1	10 (40%)	5 (31%)	8 (42%)	23 (38%)
2	6 (24%)	8 (50%)	8 (42%)	22 (37%)
3	2 (8%)	0	0	2 (3%)
4	0	0	0	0

Table 5.1 *Distribution of treatment modalities in the sample*

As shown in table 5.2, the mean pre-treatment overbite value of the studied sample was 4.60 mm (SD = 1.05). A mean 2.55 mm (SD = 1.17) overbite correction was predicted by the ClinCheck®. The mean post-treatment overbite obtained clinically was 3.60 mm (SD = 1.09). An overbite correction of 1.00 mm (SD = 0.79) was achieved overall clinically. The mean prediction accuracy of deep overbite correction for the total sample was 37.67% (SD = 34.42).

	Mean	SD	95% CI
Pre-tx OB (mm)	4.60	1.05	4.33- 4.87
Target OB as per ClinCheck® (mm)	2.05	0.98	1.79-2.30
Predicted OB correction as per ClinCheck® (mm)	2.55	1.17	2.25-2.85
Post-tx OB (mm)	3.60	1.09	3.32-3.88
Actual OB correction	1.00	0.79	0.79-1.2
Accuracy (%)	37.67	34.42	28.78-46.56

Table 5.2 *Mean values of treatment demographics*

5.3 Comparison between pre-treatment overbite and target overbite predicted per ClinCheck®

Pre-treatment overbite measurements were compared with those predicted on the final ClinCheck® plan. The paired t-test revealed a statistically significant difference between pretreatment overbite and target overbite as predicted by the ClinCheck® in the 3 deep bite groups. Overall, a significant amount of overbite correction of 2.55mm (±1.17) was attempted in the first series of aligners. The average amount of overbite correction was statistically different across the 3 pre-treatment overbite groups ($P = 0.0102$). Two millimeters was attempted in the mild deep bite group, whereas almost 3 millimeters was targeted in the moderate and severe groups.

Pre-treatment OB group	Mean pre-treatment overbite (mm)	Mean target overbite as predicted by ClinCheck (mm)	Predicted overbite correction as per ClinCheck (mm)	SD	95% CI	Pretreatment OB v.s. Target OB P-value
Mild	3.78	1.76	2.02	0.59	1.78-2.26	<0.001
Moderate	5.01	2.12	2.89	0.93	2.40-3.39	<0.001
Severe	5.32	2.37	2.96	1.63	2.17-3.74	<0.001
Overall	4.60	2.05	2.55	1.17	2.25-2.85	0.0102

*P < 0.05

Table 5.3 Comparison between pre-treatment and ClinCheck® target overbite measurements

5.4 Comparison between ClinCheck® prediction and post-treatment measurements

The mean planned overbite correction, and the mean difference between overbite prediction and final clinical overbite were calculated. Results from table 5.4 reveal that for every overbite group, there was a statistically significant difference between the predicted overbite as per ClinCheck® and the final overbite obtained clinically (overall $P < 0.001$). The highest accuracy was achieved by the moderate overbite group, in which 48.88% (±24.21) of the predicted correction was obtained clinically, corresponding to a mean difference of 1.58 mm (±0.98). The lowest prediction accuracy was found in the mild overbite group, where 31.18% (±42.42) of the predicted movement was achieved with a mean difference of 1.33mm (±0.75) between the prediction and the outcome. Furthermore, 3 subjects in the mild overbite group got a deeper post-treatment clinical overbite instead of an improvement. The mild overbite group also shows the highest standard deviation (SD = 42.42). No significant difference between target and actual post-treatment overbite was found across the 3 overbite groups ($P = 0.2516$).

Pre-treatment OB group	Predicted overbite correction as per ClinCheck® (mm)	SD	95% CI	Mean difference Target OB (ClinCheck®) vs Post-treatment OB (mm)	SD	95% CI	Target OB (ClinCheck®) vs Post-treatment OB P-value	Accuracy of change (%)	SD
Mild	2.02	0.59	1.78-2.26	1.33	0.75	1.02-1.61	<0.001	31.18	42.42
Moderate	2.89	0.93	2.40-3.39	1.58	0.98	1.05-2.10	<0.001	48.88	24.21
Severe	2.96	1.63	2.17-3.74	1.83	1.20	1.25-2.40	<0.001	36.76	36.76
Overall	2.55	1.17	2.25-2.85	1.55	0.98	1.30 – 1.81	0.2516	37.67	34.42

*P < 0.05

Table 5.4 Predictability of overbite correction

5.5 Comparison between the magnitude of predicted overbite correction and the prediction accuracy

One of the objectives of this study was to investigate if the magnitude of overbite correction planned influenced the magnitude of prediction accuracy. The Spearman correlation coefficients relative to the different overbite groups are listed in table 5.5. The overall Spearman correlation coefficient shows that there was no relationship between the magnitude of predicted overbite correction and the prediction accuracy (ρ = 0.049). Greater vertical changes were not related with larger errors, except for the moderate overbite group. A negative correlation coefficient was found in this group (ρ = -0.424), indicating that larger predicted overbite corrections were associated with poorer prediction accuracies. However this was not statistically significant ($P = 0.10$)

	Spearman correlation coefficients	p-value
Mild OB	0.136	0.52
Moderate OB	-0.424	0.10
Severe OB	0.030	0.90
Overall	0.049	0.71

*P < 0.05

Table 5.5 Spearman correlation coefficients between the predicted overbite correction and prediction accuracy

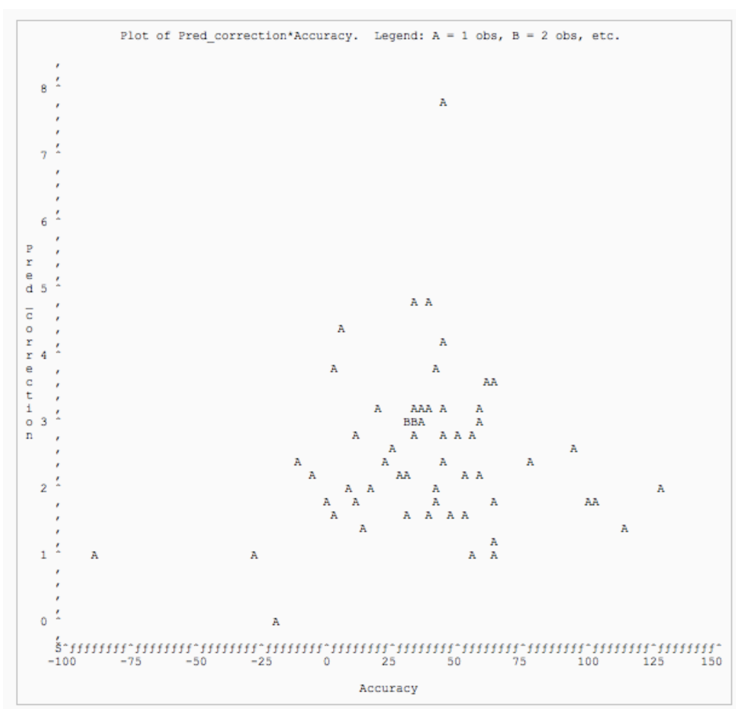

Figure 5.1 Correlation between predicted overbite correction and accuracy with the Spearman Correlation Coefficient.

5.6 Association between the severity of pre-treatment overbite and the prediction accuracy

The mean accuracy of overbite correction for all three groups was 37.67% (SD = 34.42). The highest mean accuracy was achieved by the moderate overbite group (48.88%), with a mean attempted overbite correction of 2.89 mm (SD = 0.93). The next highest mean accuracy was achieved by the severe overbite group (36.76%), with a mean attempted overbite correction of 2.96 mm (SD = 1.63). The mild overbite group had the lowest mean prediction accuracy (31.18%) and the highest standard deviation (SD = 42.42); in this group a mean overbite correction of 2.02 mm (SD = 0.59) was attempted. There was a statistically significant difference (*P* = 0.0102) between the amount of predicted overbite correction between the mild, moderate and severe overbite groups (Table 5.6). However, no statistically significant differences in overbite correction accuracy were found between the three overbite groups (*P* = 0.2769).

Variable	Pre-treatment deepbite group						p-value
	Mild (N=25)		**Moderate** (N=16)		**Severe** (N=19)		
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	
Pre-tx OB (mm)	3.78 (3.62, 3.94)	0.39	5.01 (4.80, 5.23)	0.40	5.32 (4.71, 5.94)	1.28	
Predicted OB correction (mm)	2.02 (1.78, 2.26)	0.59	2.89 (2.40, 3.39)	0.93	2.96 (2.17, 3.74)	1.63	0.0102
Actual OB correction (mm)	0.69 (0.37, 1.01)	0.77	1.32 (0.98, 1.65)	0.63	1.13 (0.73, 1.54)	0.84	
Accuracy (%)	31.18 (13.67, 48.69)	42.42	48.88 (35.98, 61.78)	24.21	36.76 (22.92, 50.60)	28.71	0.2769

*P < 0.05

Table 5.6. *Differences in overbite characteristics and planned treatment by deep bite groups*

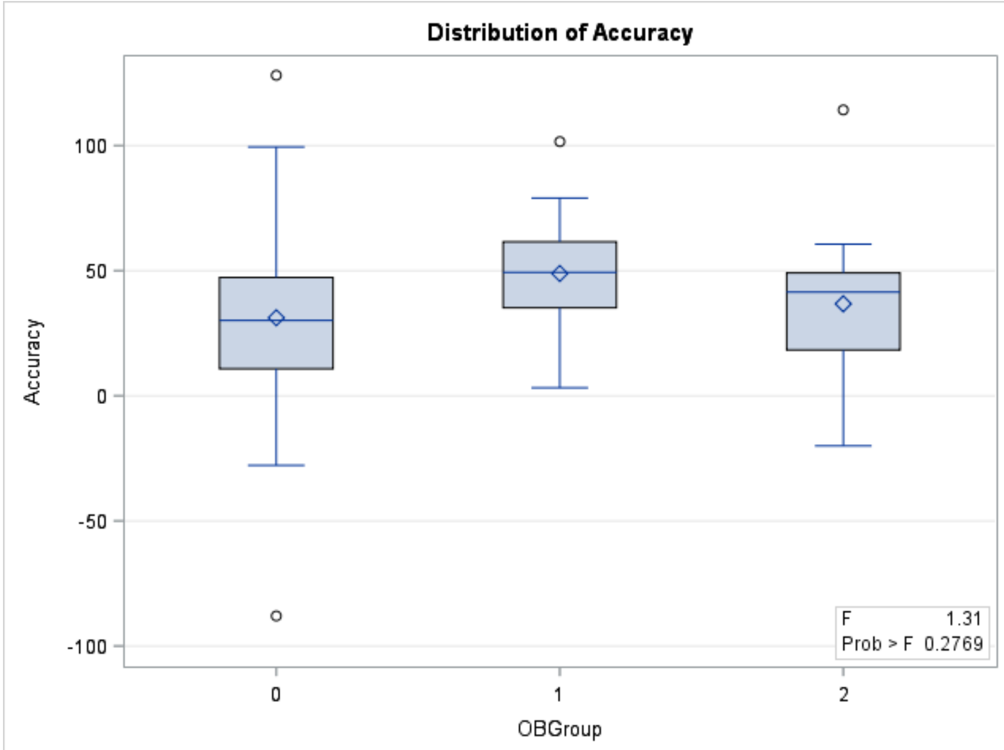

Figure 5.2 Distribution of prediction accuracy (%) as a function of pre-treatment overbite (0 = Mild OB group, 1 = Moderate OB group, 2 = Severe OB group)

5.7 Association between the number of treatment aligners and the prediction accuracy

5.7.1 Distribution of accuracy relative to number of aligners

There is no statistically significant difference in accuracy between Invisalign Express 10 (10 active aligners), Invisalign Assist (13 active aligners) and Invisalign Full (more than 13 active aligners) groups ($P = 0.3538$). The highest accuracy was achieved by the Invisalign Assist group (44.51%), whereas the lowest was found in the Invisalign Express 10 group (29.65%). The amount of predicted overbite correction is almost significantly different across the 3 treatment modalities ($P = 0.0533$).

Variable	Invisalign® treatment						p-value
	Express 10 = 10 aligners (N=17)		Assist = 13 aligners (N=27)		Full >13 aligners (N=16)		
	Mean	SD	Mean	SD	Mean	SD	
Predicted OB correction (mm)	2.38 (1.86, 2.89)	1.00	2.30 (2.02, 2.58)	0.70	3.15 (2.23, 4.07)	1.72	0.0533
Actual OB correction (mm)	0.69 (0.42, 0.97)	0.54	1.06 (0.75, 1.36)	0.78	1.22 (0.70, 1.74)	0.98	0.1423
Accuracy (%)	29.65	26.11	44.51	34.61	34.64	41.09	0.3538

*P < 0.05

Table 5.7 *Number of treatment aligners and prediction accuracy*

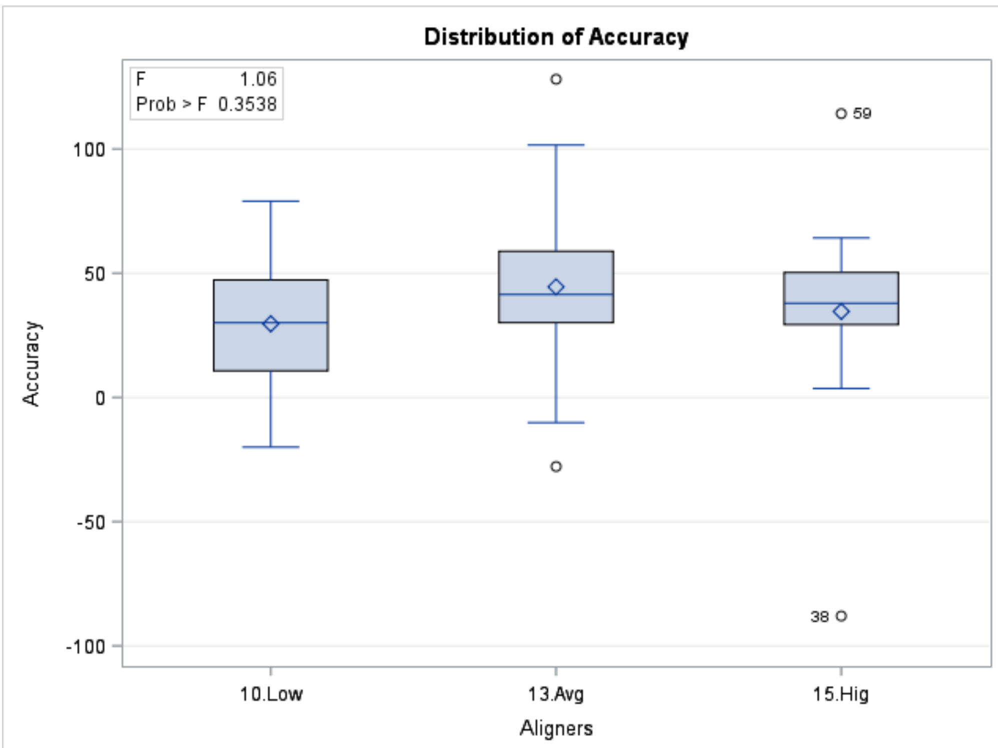

Figure 5.3 Distribution of prediction accuracy (%) as a function of number of treatment aligners

5.7.2 Distribution of accuracy relative to nature and number of bite opening mechanisms programmed in ClinCheck®

As listed in table 5.8, the highest prediction accuracy was achieved by the lower posterior extrusion group (47.40% ± 41.13), but this was not statistically significant (*P* = 0.1534) (Figure 5.7). The lower incisor intrusion group, which comprises 52 subjects, had the lowest prediction accuracy value (31.72% ± 30.84). The prediction accuracy of subjects with lower incisor intrusion was significantly poorer than the subjects without lower incisor intrusion (*P* = 0.0004). The group without lower incisor intrusion was composed of only 8 subjects.

There is a statistically significant difference between subjects with and without lower incisor proclination programmed in their ClinCheck® (*P* = 0.0248). In other words, the prediction accuracy significantly improves when lower incisor proclination is planned in the software. This should be interpreted with caution because of the presence of a significant negative outlier in the group without lower incisor proclination (where the minimum accuracy was -88.0%) and positive outliers in the group with lower incisor proclination (Figure 5.9).

No statistically significant differences were found in the other mechanisms (*P* > 0.05).

		N	Mean accuracy (%)	SD	CI 95%	P-value
U1 intrusion	Present	50	40.73	34.96	30.79 - 50.66	0.1244
	Absent	10	22.36	28.30	2.12 – 42.6	
L1 intrusion	Present	52	31.72	30.84	23.13 - 40.31	**0.0004 ***
	Absent	8	76.32	32.93	48.79 – 103.85	
Upper posterior extrusion	Present	18	42.67	39.07	23.24 - 62.10	0.4659
	Absent	42	35.52	32.50	25.40 – 45.65	
Lower posterior extrusion	Present	18	47.40	41.13	26.94, 67.85	0.1534
	Absent	42	33.50	30.72	23.93, 43.07	
U1 proclination	Present	48	39.10	35.74	28.73 - 49.48	0.5231
	Absent	12	31.93	29.20	13.38 – 50.48	
L1 proclination	Present	44	43.63	30.91	34.23 - 53.03	**0.0248 ***
	Absent	16	21.27	39.12	0.43 – 42.12	

*P < 0.05

Table 5.8 Nature of bite opening mechanisms programmed in ClinCheck® and prediction accuracy

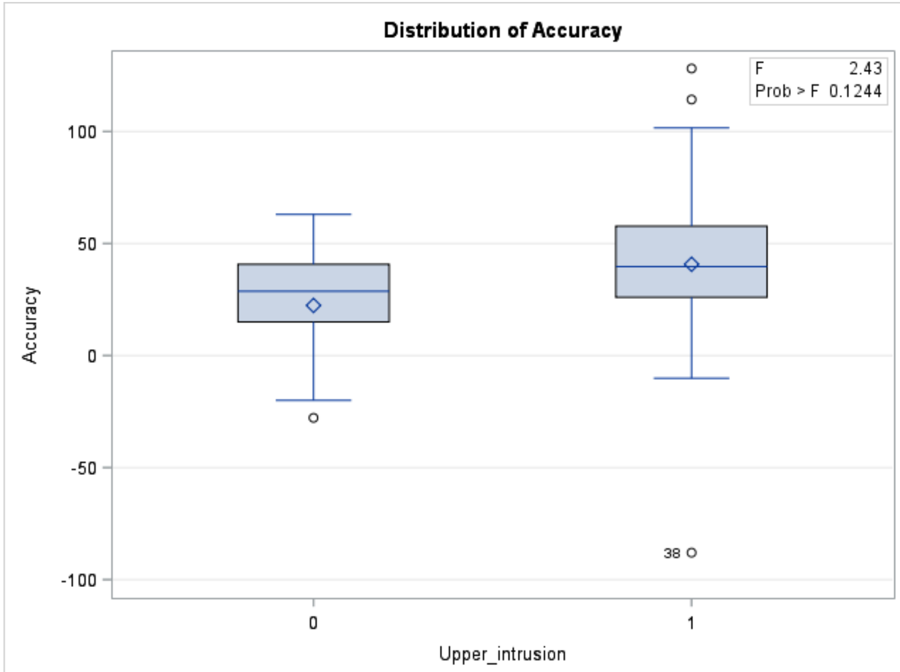

Figure 5.4 Prediction accuracy (%) as a function of upper incisor intrusion programmed in the ClinCheck (0 = absent, 1 = present)

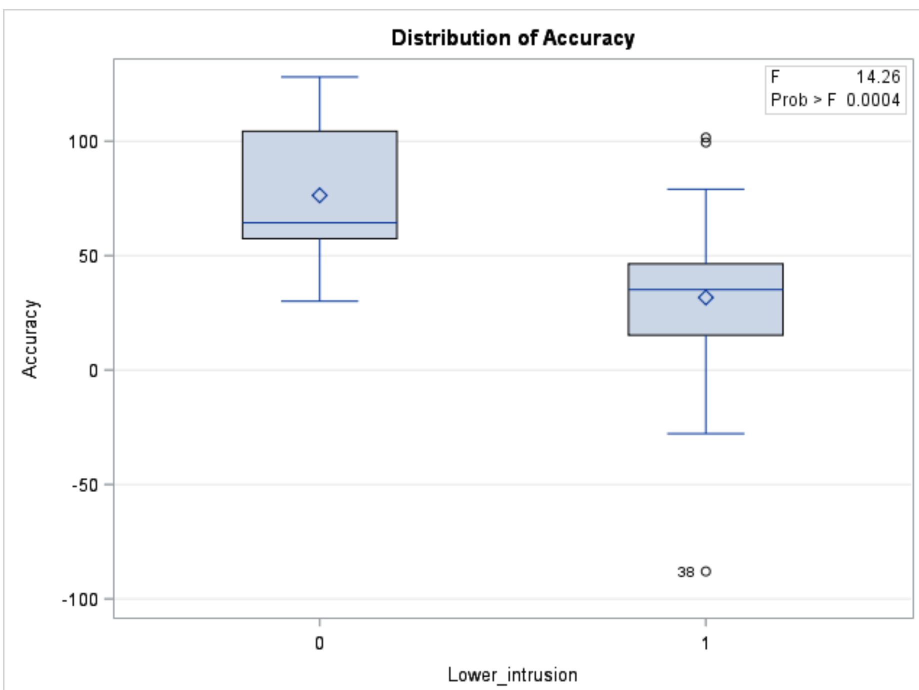

Figure 5.5 Prediction accuracy (%) as a function of lower incisor intrusion programmed in the ClinCheck (0 = absent, 1 = present)

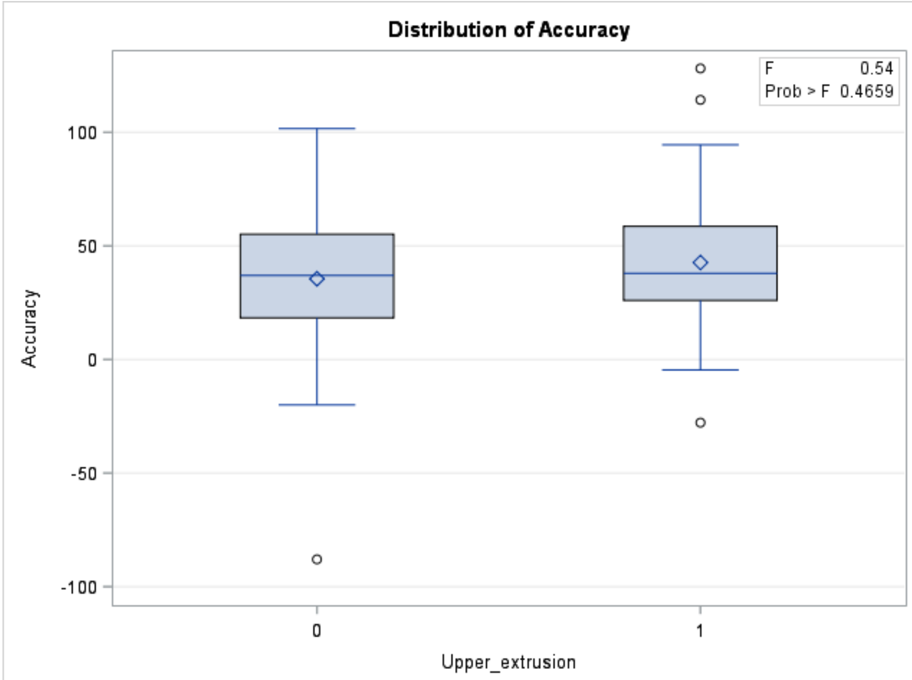

Figure 5.6 Prediction accuracy (%) as a function of upper posterior extrusion programmed in the ClinCheck (0 = absent, 1 = present)

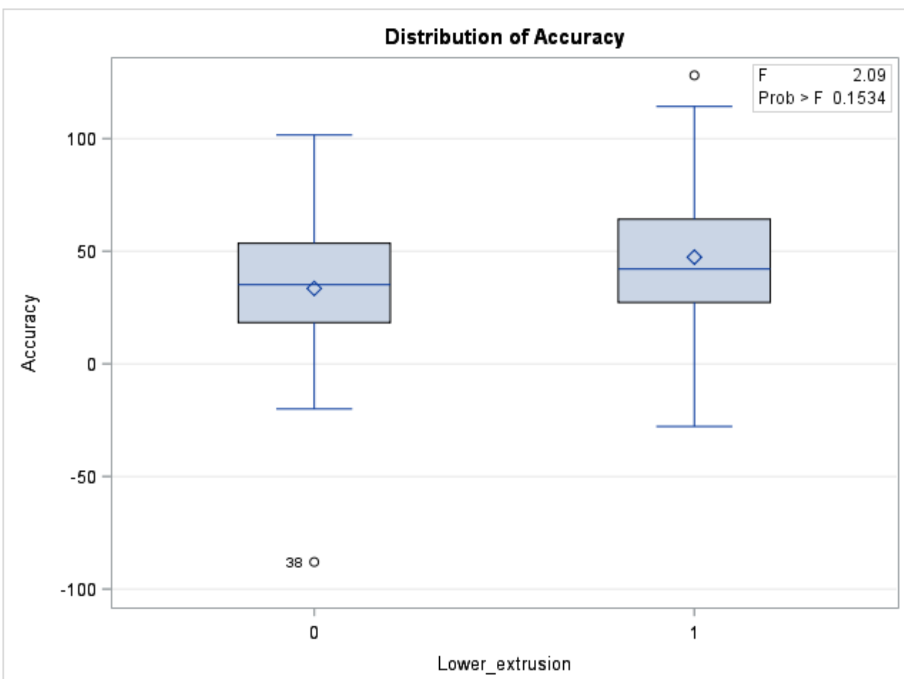

Figure 5.7 Prediction accuracy (%) as a function of lower posterior extrusion programmed in the ClinCheck (0 = absent, 1 = present)

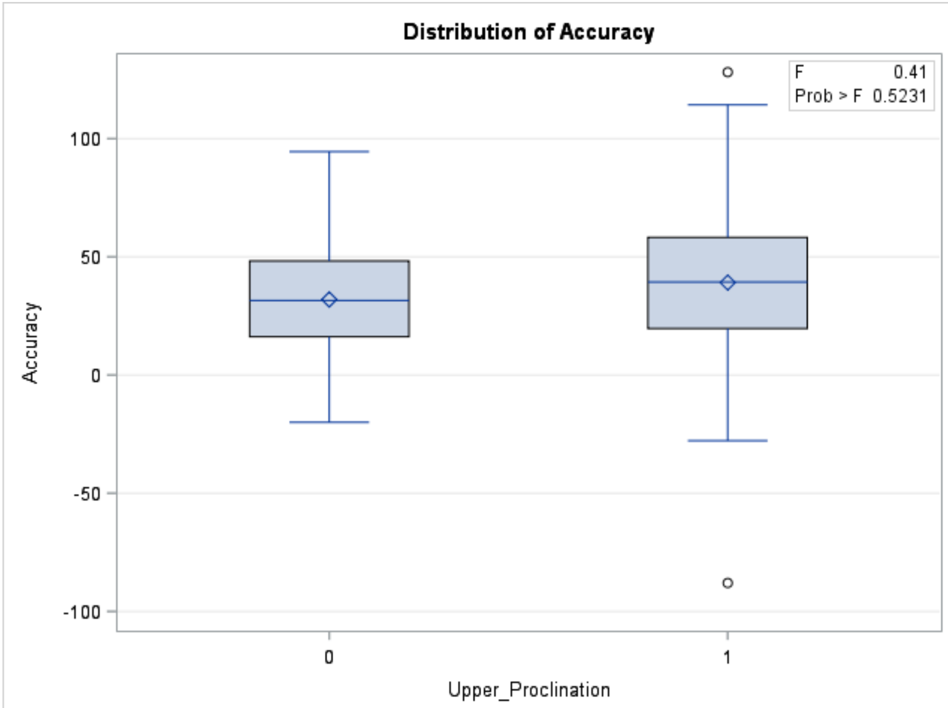

Figure 5.8 Prediction accuracy (%) as a function of upper incisor proclination programmed in the ClinCheck (0 = absent, 1 = present)

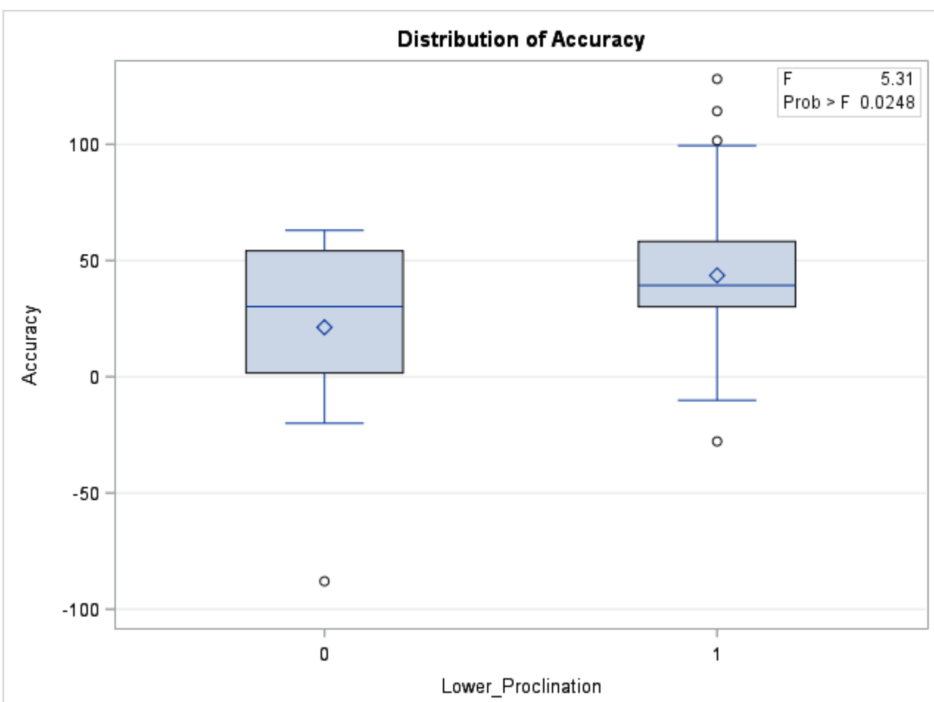

Figure 5.9 Prediction accuracy (%) as a function of lower incisor proclination programmed in the ClinCheck (0 = absent, 1 = present)

In terms of number of bite opening mechanisms, the highest mean accuracy was achieved by the group with 5 or 6 bite opening mechanisms (45.4% ± 41.51). As shown in Figure 5.10, the greater the number of bite opening mechanisms, the greater the accuracy is, but this is not statistically significant ($P = 0.5339$).

Variable	Number of bite opening mechanisms programmed in the ClinCheck®						p-value
	1 or 2 (N=7)		**3 or 4** (N=37)		**5 or 6** (N=16)		
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	
Predicted OB correction (mm)	1.59 (0.68, 2.50)	0.98	2.62 (2.35, 2.89)	0.81	2.81 (1.89, 3.72)	1.71	0.0595
Actual OB correction (mm)	0.56 (0.19, 0.92)	0.40	0.98 (0.73, 1.22)	0.73	1.23 (0.70, 1.76)	0.99	0.1671
Accuracy (%)	29.85 (1.91, 57.59)	30.21	35.79 (25.09, 46.49)	32.08	45.43 (23.31, 67.55)	41.51	0.5339

*P < 0.05

Table 5.9 *Number of bite opening mechanisms programmed in ClinCheck® and prediction accuracy*

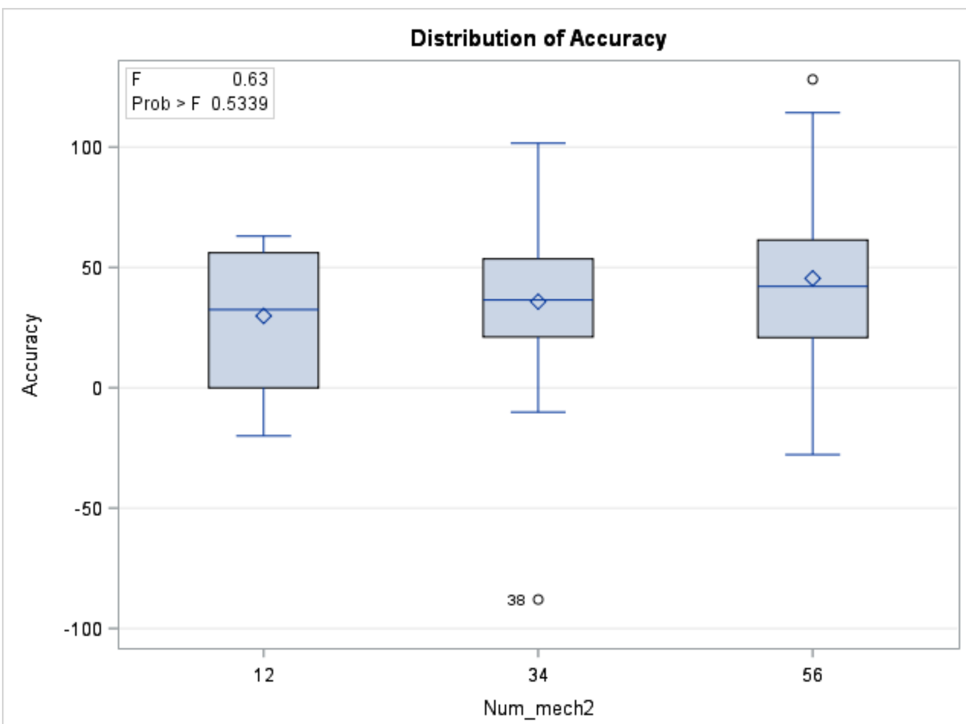

Figure 5.10 Distribution of prediction accuracy (%) as a function of the number of bite opening mechanisms programmed in the ClinCheck®

5.7.3 Distribution of accuracy relative to type and number of mandibular premolar attachments

There were no statistically significant differences (P = 0.9276) in deep overbite correction accuracy for any of the mandibular premolar attachment groups (Table 5.8 and Figure 5.11). The overall number of attachments on the mandibular premolars did not influence the prediction accuracy. About two-thirds of the sample had 4 attachments on the mandibular premolars.

Variable	Total number of attachments on mandibular premolars								p-value
	0 (N=3)		**2** (N=6)		**3** (N=13)		**4** (N=38)		
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	
Predicted OB correction (mm)	3.03 (0.29, 5.78)	1.11	2.38 (0.99, 3.78)	1.33	2.86 (1.78, 3.94)	1.78	2.43 (2.14, 2.72)	0.89	0.5987
Actual OB correction (mm)	1.10 (-1.75, 3.95)	1.15	1.02 (0.37, 1.66)	0.61	1.25 (0.65, 1.86)	1.00	0.90 (0.66, 1.14)	0.90	0.5860
Accuracy (%)	43.23 (-71.32, 157.78)	46.1	32.41 (3.81, 61.01)	27.26	42.13 (20.95, 63.31)	35.05	36.53 (24.87, 48.20)	35.50	0.9276

*P < 0.05

Table 5.10 *Total number of mandibular premolar attachments (any type) and prediction accuracy*

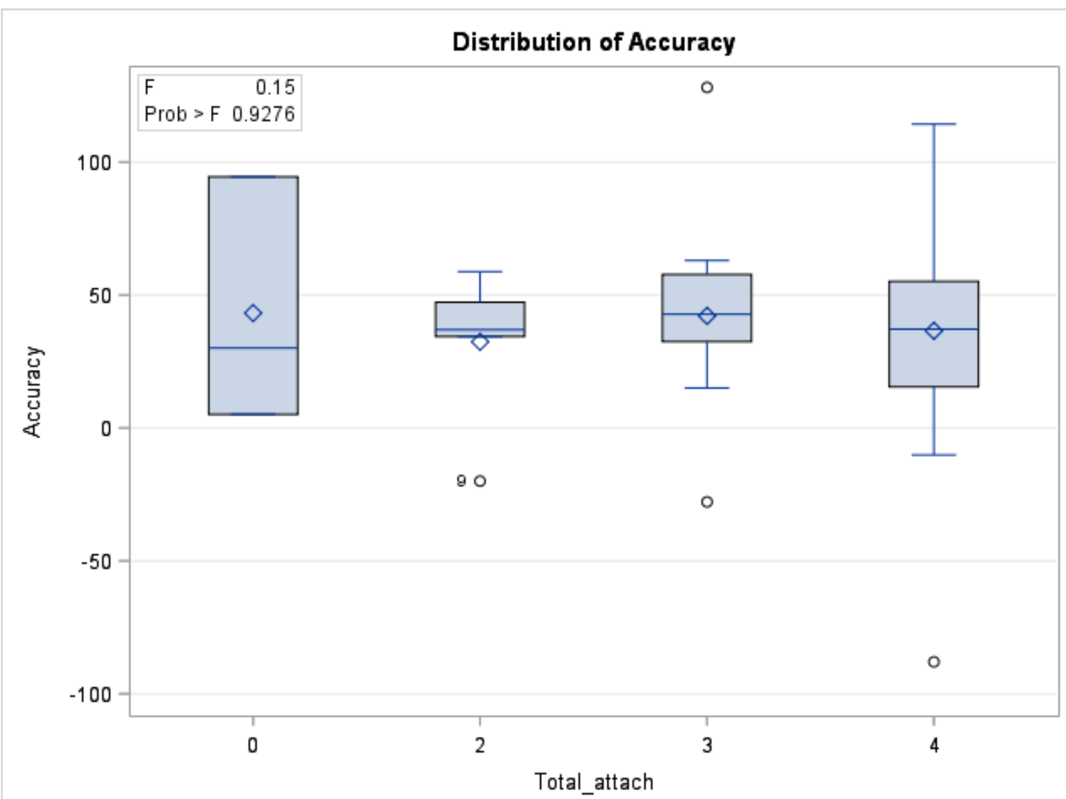

Figure 5.11 Distribution of prediction accuracy (%) as a function of number of mandibular premolar attachments

There were no statistically significant differences (P = 0.3385) in deep overbite correction accuracy across the different optimized deep bite attachment groups (Table 5.9 and Figure 5.12). The number of optimized deep bite attachments on the mandibular premolars does not significantly affect the prediction accuracy. The majority of the sample (75%) had 1 or 2 optimized deep bite attachments in their setup. Only 2 subjects had 3 optimized deep bite attachments.

Variable	Number of optimized deep bite attachments								p-value
	0 (N=13)		**1** (N=23)		**2** (N=22)		**3** (N=2)		
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	
Predicted OB correction (mm)	2.18 (1.50, 2.85)	1.12	2.58 (1.99, 3.16)	1.35	2.81 (2.37, 3.26)	1.01	1.75 (0.48, 3.02)	0.14	0.4006
Actual OB correction (mm)	1.07 (0.52, 1.61)	0.90	0.92 (0.54, 1.31)	0.89	1.11 (0.84, 1.39)	0.62	0.13 (-0.76, 1.02)	0.10	0.8476
Accuracy (%)	46.70 (22.98, 70.41)	39.24	31.67 (14.77, 48.57)	39.08	41.37 (30.03, 52.72)	25.59	7.22 (-38.36, 52.80)	5.07	0.4549

*$P < 0.05$

Table 5.11 Number of optimized deep bite attachments and prediction accuracy

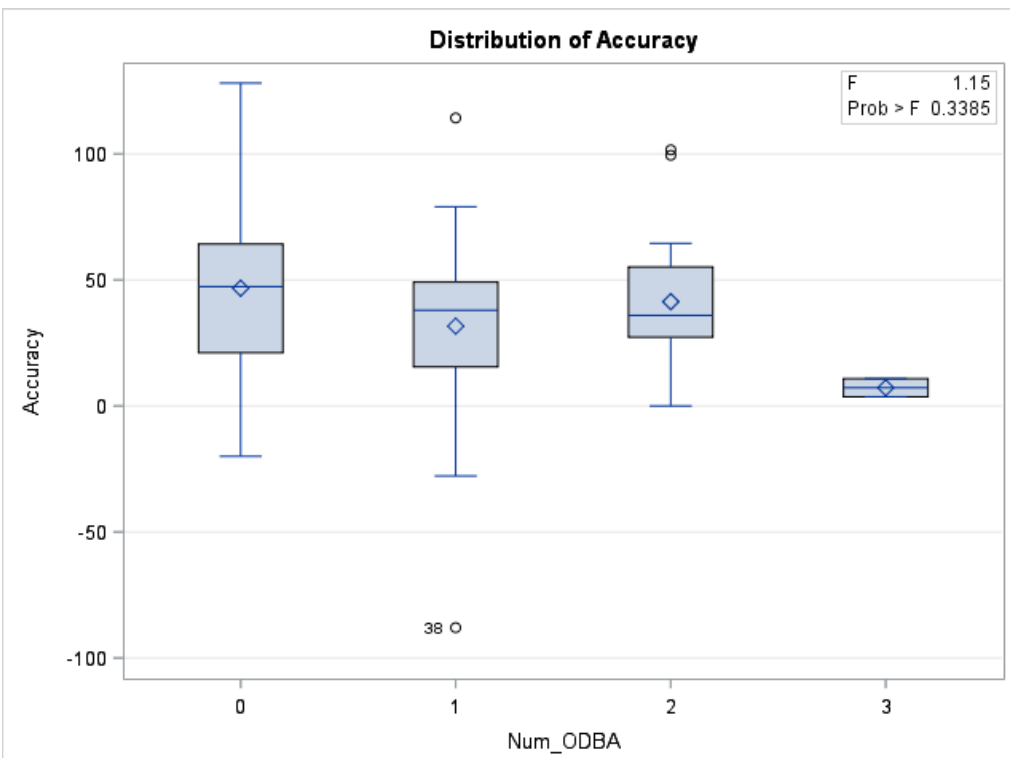

Figure 5.12 Distribution of prediction accuracy (%) as a function of the number of optimized deep bite attachments (ODBA)

CHAPTER 6

Discussion

The main purpose of this study was to investigate the predictability of deep overbite correction using Invisalign®. Assessment of ClinCheck® reliability in planning major vertical changes in deep bite subjects will help orthodontists to better select these patients for clear aligner therapy.

There are multiple ways of managing deep bites. For this reason, our sample was selected from one single practitioner to limit the heterogeneity in treatment. Treatment was rendered by one practitioner. The orthodontist's treatment strategies to manage deep overbite included the following:

- Extra palatal root torque maxillary incisors (power ridges prn)
- No contact on incisors
- Treat to 0mm overbite
- Heavy posterior occlusal contacts
- Level the curve of Spee
- Damon arch form on all cases

Since overbite can be influenced by several factors, it was important to control for confounding variables in this study. An exclusive adult population was selected to minimize the effects of normal vertical growth of the jaws. Additionally, subjects presenting significant crowding (>6mm) were excluded to minimize the vertical side effects of extensive arch development. Similarly, subjects requiring significant sagittal dental movement (Inter-arch elastics, Carriere, TADs) were excluded to reduce the bite opening effect of posterior distalization. Subjects requiring extractions were also excluded to avoid deepening of the bite that occurs concomitantly with space closure.

Subjects starting treatment after February 2014 were included in this study, which corresponds with the introduction of the G5 deep bite protocol (Align Technology® 2018).

The virtual final treatment result predicted by the ClinCheck® does not accurately reflect the clinical outcome (Shin 2017). To date, a limited number of studies comparing the ClinCheck® prediction and the treatment outcome are present in the orthodontic literature (Houle et al. 2017, Solano-Mendoza B et al. 2017, Buschang et al. 2015, Simon et al. 2014, Castroflorio et al. 2013, Kravitz et al. 2008 & 2009, Krieger et al. 2011 & 2012,). Only a few assessed the overbite parameter (Khosravi et al. 2017, Krieger et al. 2011 & 2012, Kravitz et al. 2009), but none of them have specifically focused on accuracy of deep bite correction.

6.1 Accuracy of ClinCheck® prediction for deep overbite correction

Our results show large discrepancies between the overbite correction predicted by the ClinCheck® and the clinical overbite correction obtained clinically. Overall, 37.7% of the planned vertical changes were actually achieved. In other words, slightly more than one third of the predicted overbite correction was achieved throughout the first series of aligners. Although the mean prediction accuracy was found to be low, the standard deviation was large (mean SD ± 34.42). The mean difference between the predicted and achieved overbite was 1.55 mm (SD ± 0.98). The mean predicted overbite correction as per ClinCheck® was 2.55 mm (SD ± 1.17 mm), whereas the actual correction achieved clinically was 1.00 mm (± 0.79 mm), which is statistically significant. This means that the ClinCheck® software was not able to accurately anticipate the amount of overbite correction that would occur.

The low level of mean prediction accuracy for deep bite correction could be explained by a number of factors. First, most of the patients included in this study had a limited number of active aligners in their first round of treatment. Inclusion criteria of this study restricted the selected cases to those that received a limited number of aligners and those that needed refinements. Only 27% of the total sample had more than 13 active aligners in their first series of aligners. Furthermore, patients who choose esthetic orthodontic treatment such as Invisalign® also tend to prefer shorter treatment times (Gu et al. 2017), which could explain why the subjects in our study were overall treated with a small number of aligners.

Our study sample also had an overall limited number of optimized deep bite attachments. Close to one-quarter of the subjects (22%) didn’t have optimized deep bite attachments included in their

ClinCheck® setup. The near totality of the remaining subjects only had 1 or 2 optimized deep bite attachments. None of them had 4 optimized deep bite attachments. When correcting deep overbites, the ClinCheck® won't automatically place optimized deep bite attachments on all mandibular premolars (Tai 2018). In the current ClinCheck® protocol, optimized root control attachments and optimized rotation attachments take precedence over optimized deep bite attachments (Tai 2018, Invisalign Academy 2018). Optimized root control attachments are triggered at a threshold of 0.75mm mesio-distal root movement needed. If premolars are rotated more than 5 degrees, an optimized rotation attachment is automatically placed by the software (Tai, 2018). Therefore, the first ClinCheck® setup often features optimized rotation attachments on the premolars. It is then the clinician's task to modify the setup to switch for optimized deep bite attachments. Optimized deep bite attachments are preferred when opening the bite for posterior anchorage purposes (Tai, 2018).

To some degree, tooth wear commonly found in deep bite adult patients could explain the low level of prediction accuracy for overbite correction. Short clinical crowns with less surface area offer less engagement of the aligner, thus less expression of tooth movement and potentially poorer tracking (Tai 2018).

The concept of staging is especially important in deep bite cases with retroclined and hypererupted maxillary incisors. It is recommended to procline first, then intrude and finally retract the maxillary incisors to ensure more predictable results (Tai 2018). An improper sequence of tooth movements in the ClinCheck® could lead to poorer prediction accuracy when correcting deep bites. In this study, the staging was not assessed but could have had an influence on our results.

As shown in the present study, the ClinCheck® tends to overestimate the quality of the finished occlusion (Kravitz et al. 2009, Buschang et al. 2014). This correlates with recommendations of several investigators (Tai 2018, Krieger 2011 & 2012, Kravitz et al. 2008 & 2009, Houle et al. 2017) who suggested to build overcorrection in the finished occlusion.

6.2 Magnitude of predicted overbite correction and prediction error

Our results show that overall, more overbite correction planned on the ClinCheck® is not associated with poorer prediction accuracy. Tracking will not necessarily be lower if larger vertical changes are requested in the software. This lack of association should be interpreted with caution since the amount of overbite correction requested was overall small (2.55mm). The biggest overbite correction requested was 7.84mm in a subject treated with 44 upper aligners and 23 lower aligners. Also, most of the sample was treated with a limited number of trays in their first series of aligners. Close to 75% of the total sample had less than 13 aligners (Invisalign Assist and Invisalign Express 10). The experience of the clinician may also partially explain the lack of correlation.

A negative correlation was found in the moderate pre-treatment deep bite group (ρ = -0.424), indicating that larger overbite corrections requested in the ClinCheck® were associated with poorer tracking. However this was not statistically significant (P = 0.10). This association could be explained by the fact that 13 out of the 16 subjects composing this group had less than 13 active aligners in their first series of trays. A mean attempted overbite correction of 2.89mm was requested in this group, which is relatively ambitious for a small number of aligners. The subjects in this group also had a minimal number of optimized deep bite attachments in their setup (2 or less optimized deep bite attachments).

6.3 Severity of pre-treatment deep bite and prediction error

Although the amount of attempted overbite correction was statistically different between the mild, moderate and severe deep bite groups (P = 0.0102), no statistically significant difference was found in terms of accuracy (P = 0.2769) across the 3 groups. This suggests that a more severe pre-treatment deep bite will not necessarily lead to poorer tracking and less overbite improvement. This could be explained by the fact that the more severe cases were in general treated with a higher number of aligners, bite opening mechanisms and mandibular premolar attachments (Table 1). Furthermore, the lowest percentage of prediction accuracy was achieved by the mild deep bite group (31.18% ± 42.42). Since the mild group was the largest one (n = 25) compared to the moderate and severe groups, there was more room for variability in accuracy. Indeed, this group also had the largest standard deviation (SD ± 42.42), indicating a wider range of values. Moreover, 3 subjects in the mild deep bite group got a worse clinical post-treatment overbite than where they started (their post-treatment overbite was greater than pre-treatment overbite), which might have affected the overall accuracy of this group.

6.4 Descriptive data: Treatment modalities and prediction error

6.4.1 Number of aligners

The accuracy of correction was higher in the Invisalign Assist group (44.51% ± 34.61), followed by the Invisalign Full group (34.64% ± 41.09) and the Invisalign Express 10 group (29.65% ± 26.11). However, as stated in table 5.7, this was not statistically significant ($P = 0.3538$). The highest accuracy found in the Invisalign Assist treatment group could be caused by the presence of a positive outlier (figure 5.3). It could also be due to the fact that the attempted amount of correction was the smallest across the 3 groups (2.30mm ± .70). Moreover, the Invisalign Full treatment cases were in general more severe and more correction was attempted in this group (3.15mm ± 1.72). The lack of significant difference in terms of accuracy across the groups (Express 10, Assist or Full) should be interpreted with caution as 45% of the sample was treated with the Invisalign Assist option. Also, as shown in Table 5.1, the severity of the cases was variable within each group.

6.4.2. Number and nature of bite opening mechanisms programmed in the ClinCheck®

The bite opening mechanisms that were evaluated in this study were:

1. Upper incisor intrusion
2. Lower incisor intrusion
3. Upper posterior extrusion
4. Lower posterior extrusion
5. Upper incisor proclination
6. Lower incisor proclination

In this study, the most common mechanisms programmed in the ClinCheck® were maxillary and mandibular incisor intrusion and proclination. The least common were maxillary and mandibular posterior extrusion. Posterior extrusion is not stable in adults and results in clockwise rotation of the mandible because there is no compensatory growth at the ramus (Burstone 1977, Proffit 2013, Nanda 2015).

The prediction accuracy was higher when an increased number of bite opening mechanisms was programmed in the ClinCheck®. This means that the ClinCheck® tends to better predict the overbite correction as the number of programmed bite opening mechanisms increases. However, the differences between subjects having 1 or 2, 3 or 4, and 5 or 6 mechanisms were not statistically significant ($P = 0.5339$).

The lower incisor intrusion group had the lowest prediction accuracy value (31.72%). The prediction accuracy of the 52 subjects with lower incisor intrusion was significantly poorer than the 8 subjects without lower incisor intrusion ($P = 0.0004$). This significant difference in prediction accuracy should be interpreted with caution since the groups with and without lower incisor intrusion were not evenly distributed. Moreover, the subjects that did not get lower incisor intrusion programmed in ClinCheck® did not actually need it because their cases were less severe in nature.

The prediction accuracy was statistically significantly improved when mandibular incisor proclination was programmed in ClinCheck® in contrast to when it was not ($P = 0.0248$). In other words, the prediction accuracy is significantly better when the lower incisors are being proclined throughout treatment. This suggests that deep bite might be more predictable to correct when mandibular crowding is present and being resolved without extracting teeth or performing interproximal reduction. However, this should be interpreted with caution since a significant negative outlier was present in the group without lower incisor proclination (where the minimum accuracy was -88.0%), while the group with lower incisor proclination included some positive outliers (Figure 5.9).

No statistically significant differences were found for the other mechanisms ($P > 0.05$).

6.4.3 Number and type of attachments on mandibular premolars

In cases requiring extensive vertical movements, the use of horizontal right-angled attachments in the premolar region bilaterally was recommended to increase aligner retention (Krieger et al. 2012). As of today with the G5 deep bite protocol, optimized deep bite attachments are preferred on the lower premolars when opening deep bite for posterior anchorage purposes (Tai 2018).

In this study, no association was found between the presence of attachments of any type on the mandibular premolars and the magnitude of error ($P = 0.927$). About two-thirds of the sample had 4 attachments of any type on their lower premolars, involving 1 or 2 optimized deep bite attachments for 75% of the subjects. Also, 22% of the sample did not have any optimized deep bite attachments included in their setup at all (Table 5.11). Although the G5 protocol is specifically designed for deep bite cases, the first ClinCheck® setup often features optimized rotation attachments instead of optimized deep bite attachments if the lower premolar is rotated more than 5 degrees. Therefore, it relies on the clinician to virtually substitute for optimized deep bite attachments if desired (Tai 2018). Although the majority of the sample had a limited number of optimized deep bite attachments in their setup, no statistically significant differences in prediction accuracy was found across patients with 0, 1, 2 or 3 optimized deep bite attachments ($P = 0.4549$). In other words, a higher number of optimized deep bite attachments did not necessarily lead to a more accurate deep bite correction. This should be interpreted with caution since the hierarchal attachment placement was followed and not substituted for attachments providing optimal vertical anchorage.

6.5 Comparison with other studies

To our knowledge, no studies have specifically investigated the predictability of deep bite correction using Invisalign®. This is the very first study emphasizing on the reliability of the ClinCheck® in predicting overbite changes in cases presenting excessive incisor overlap.

Our results are similar to the findings of Kravitz and colleagues' prospective study (2009), who reported a mean accuracy of tooth movement of 41%. More specifically, they found a mean accuracy for anterior intrusion of 41.3%. The lowest intrusion accuracy was achieved by the maxillary lateral incisors. One of their conclusions was that intrusion was more predictable than extrusive movements in the anterior region. As for their inclusion criteria, their sample also consisted of an adult population (mean age of 31 years) exclusively treated with Invisalign® and presenting less than 5 mm of crowding or spacing. Only the initial aligners' series was included. The mean number of active aligners was relatively similar to our study (10 maxilla and 12 mandible). However, by its prospective nature, their study design differed from ours. Digital model superimposition was used to assess prediction accuracy. Since the models were superimposed on the posterior teeth, these teeth were not allowed to move during treatment. Our investigation however included cases in which the posterior teeth were free to move.

Krieger conducted two retrospective studies in 2011 and 2012 investigating the accuracy of Invisalign® in the anterior region. As part of their inclusion criteria, they selected cases presenting mild to moderate crowding treated exclusively with Invisalign® without auxiliary treatment. In their pilot study in 2011, a discrepancy of 0.9 mm (+/- 0.9 mm) was found between the predicted and achieved overbite. Similarly, in their 2012 study, a mean difference of 0.71 mm (SD +/- 0.87 mm) was reported between the predicted and actual final overbite. In our study, a mean difference of 1.55 mm (SD ± 0.98) was found between the ClinCheck® and the final clinical overbite. The larger discrepancy found in our study could be partly explained by the fact that only deep bite subjects were included. Our sample had a deeper pre-treatment overbite (4.6 mm ± 1.05mm), in contrast to Krieger et al. in in 2011 (3.5 mm) and 2012 (3.88 mm ± 1.51 mm). The amount of attempted overbite correction was higher in our study (2.55mm ± 1.17 mm) compared to Krieger's in 2011 (1.1 mm) and 2012 (1.27 mm). In their 2011 study, they found a lower prediction accuracy (14.3%) than ours (37.7%) for the overbite parameter. These discrepancies may be due in part to the fact that they used a different software for their overbite measurements (ToothMeasure® tool in the ClinCheck®). Our data suggests that the ClinCheck® overestimates deep bite correction. Likewise, Krieger et al. (2011 and 2012) concluded that the overbite parameter was the least predictable, and that the vertical dimension was the most difficult to control with clear aligners. For cases requiring extensive vertical movements, the use of horizontal right-angled attachments in the premolar region bilaterally was recommended to increase aligner retention (Krieger et al. 2012). They also reported that additional refinements and overcorrection may be necessary.

More recently, a retrospective study that was carried out by Khosravi et al. (2017) reported that Invisalign® was successful at opening the bite in deep bite subjects. More specifically, a 1.5 mm median opening was observed. Our findings show a lesser correction with a median opening of 0.90 mm. This could be due to the fact that our study only included the initial round of aligners, which may have limited the scope of overbite correction. On the other side, Khosravi et al. included cases with a maximum of 3 refinements which could have certainly allowed a bigger correction. Furthermore, their results might differ from ours partly because they measured their overbites using lateral cephalometric radiographs. Measures taken from a 2-D image vs. a 3-D image of the occlusion (digital models) might have led to different overbite measurements. Khosravi et al. concluded that Invisalign® was relatively successful in managing overbite. Likewise, in our study, deep bite was also partially corrected. Our findings also indicate that the prediction accuracy is statistically significantly improved in subjects with lower incisor proclination programmed in their ClinCheck® (P = 0.0248). In other words, the prediction accuracy is significantly superior when lower incisor proclination is planned in the ClinCheck® software. This correlates with Khosravi et al. findings, who reported that mandibular incisor proclination was the primary mechanism of bite opening using Invisalign®. However, no conclusions could be drawn in terms of prediction accuracy in their study since no comparison was made between pre and post-treatment overbite with specific target overbite.

6.6 Clinical relevance

It has been estimated that 70% to 80% of patients treated with Invisalign® may need mid-course corrections, refinements or conversion to fixed appliance to achieve optimal result (Kravitz et al. 2009). These numbers imply that the ability of the ClinCheck® to predict the final outcome is limited and that tracking is not constantly optimal. The ability of the teeth to track properly influences the treatment outcome and overall treatment duration. Mid-course corrections and refinements lead to longer treatment time, increased chair time and increased material demand for the orthodontist (Duncan et al. 2016). Discrepancies between the predicted and final result can arise from the clinician's lack of experience with the technique, the software limitations or the lack of patient compliance. Studies investigating the accuracy of the ClinCheck® in predicting the final clinical outcome may help limit the need for mid-course corrections and refinements.

Our findings indicate that the tracking accuracy with regards to deep overbite correction is relatively low. The number of active aligners, the quantity of bite opening mechanics programmed in the ClinCheck® and the presence of optimized deep bite attachments did not significantly affect the prediction accuracy. However, this lack of association between the prediction accuracy and these different treatment modalities should be interpreted with caution. First, a large variability in overall prediction accuracy was found (SD ± 34.42). Furthermore, the groups composing the different categories (number of aligners, mechanisms, attachments) were not evenly distributed. As an example, 97% of the sample had 2 or less optimized deep bite attachments despite the overall deep bite severity. Also, close to half of the sample (45%) was treated with the Invisalign Assist option. In general, the more severe cases had longer treatment time and higher number of proper retentive attachments. The optimized hierarchal attachment placement was overall followed and not substituted for attachments providing better vertical control. The presence of outliers in the different groups might also have affected the results.

No treatment auxiliaries such as inter-arch elastics, TADs and distalizers were used for any of the cases included in this study. Knowing that deep overbite correction accuracy is somewhat limited with clear aligners may help orthodontists to better estimate treatment duration and give realistic expectations to their patients in that sense. When it comes to severe deep bite correction, the clinician should expect subsequent series of additional aligners to be made to achieve an excellent clinical result. The findings of this study may also help practitioners to better plan their mechanics. As suggested by several investigators and authors (Krieger et al. 2011 & 2012, Ali & Miethke 2012, Malik et al. 2013, Shin 2017, Tai 2018), the addition of auxiliary treatment may help improve the prediction accuracy and maximize the overbite reduction. For example, anchorage for anterior intrusion with clear aligners can be provided by bilateral anchorage attachments in the premolar region or anterior TADs (Tai 2018). Another way to help reduce the rate of mid-course corrections and refinements in deep bite patients would be to build overcorrection of the overbite in the ClinCheck® software. In severe deep bite cases where the overbite is 80% or more, it has been suggested to correct to 0 mm overbite, to engineer a reverse curve of Spee in the mandibular arch and to finish the occlusion with heavy posterior contacts (Tai 2018).

This study suggests that the incorporation of mandibular incisor proclination in the ClinCheck® improves deep bite prediction accuracy. Thus, deep bite cases presenting crowding in the lower anterior region that require incisor proclination may be more predictable to correct. In order to maximize overbite reduction, the orthodontist might want to incorporate mandibular incisor proclination in their virtual setup (Khosravi et al. 2017). Deep bite cases necessitating incisor proclination, incisor intrusion, posterior extrusion, arch development, some degree of posterior distalization and molar uprighting may be more predictable to correct. Torque control is mandatory for obtaining proper interincisal angle and adequate overbite. The orthodontist might want to be prudent when opening deep bite with clear aligners in cases requiring important torque control, such as in closure of pre-existing spaces or spaces created by extractions or interproximal reduction.

6.7 Limitations of the study

Some limitations should be considered when interpreting our results. The retrospective nature of this study introduces selection bias. A common problem encountered with the Invisalign® technique is the lack of compliance from patients (Phan & Ling 2007). Information about patient compliance had to rely on the assessment of the orthodontist. However, the data was collected from a single practitioner, which may have prevented the heterogeneity in evaluation of patient compliance.

The inclusion criteria of this study limited the selected cases to those that received a limited number of aligners in their course of treatment (Invisalign Assist® or Invisalign Express 10®). Therefore, the outcomes may be different in deep bite cases treated with a higher number of aligners. A typical course of treatment with Invisalign® usually involves 25 aligners (Malik et al. 2013) but differs in function of the amount and complexity of required tooth movement (Joffe 2003). Patients who choose Invisalign® for esthetic reasons also tend to prefer shorter treatment times (Jiafeng et al. 2017) which could explain the low number of active aligners in our study sample. These patients also tend to prefer avoiding refinements to accomplish difficult tooth movements (Gu et al. 2017) which could have limited our sample size. Moreover, while selecting the data, the majority of deep bite adult patients also presented an underlying Class II division 2. These patients, who mostly received an Invisalign Full treatment, could not be included in our sample because they needed some degree of antero-posterior correction.

The prediction accuracy may also vary in more complex cases needing multidimensional corrections (A-P, transverse and vertical) or those involving space closure following extractions or extensive interproximal reduction. Our findings cannot be generalized, and this study may not perfectly reflect a typical course of deep overbite treatment using clear aligners.

When measuring overbite in OrthoAnalyzer®, standard reference points were not used, which could have increased the random measurement errors associated with landmark identification. However, the landmark identification was precise to 0.01mm and the same landmarks of the same teeth were consistently used at the three different timepoints. The measurement points were identical to those of the corresponding pre-treatment, predicted and post-treatment overbite. Also, the measurements were performed by the principal investigator only, which could have improved consistency.

It has been reported that the maxillary lateral incisor has the lowest accuracy of intrusion in the anterior region (Kravitz et al. 2009). Since the overbite was measured either from the central or lateral incisor in this study, it is possible that the prediction accuracy may vary depending on the tooth being measured.

This study is the first one to focus on the reliability of deep overbite correction using Invisalign®. Some cofounding variables were not controlled in this study. No information regarding the vertical facial pattern was collected. Subsequently, a correlation between vertical skeletal pattern and prediction accuracy could not be established. The predictability of deep bite correction may be lower in brachycephalic patients. Similarly, the overall clinical crown heights were not considered in this study. Since long clinical crowns provide better engagement for aligners (Tai 2018), subjects presenting shorter clinical crowns and more extensive tooth wear could potentially have a lower prediction accuracy.

Clinician's experience is a key factor in treatment success with clear aligners (Tai 2018). The sample in this study was treated with Invisalign® by a single practitioner. Also, 97% of sample had less than 2 optimized deep bite attachments in their setup. Since a wide variety of mechanics and types of attachments can be used for overbite correction, predictability may vary widely from one clinician to another. It is possible that the results found in this study might differ from those achieved by other clinicians.

This study was designed to assess the reliability of Invisalign® to produce the overbite correction as planned by the orthodontist in the ClinCheck software. The actual tooth movements that occured clinically were not assessed.

Despite these limitations, our findings provide a baseline value to what can be accomplished with aligners alone when addressing deep bites. This study widens the knowledge on deep overbite correction predictability using Invisalign® and, therefore, may aid in better selecting patients for this treatment modality and better plan mechanotherapy in the ClinCheck® software.

6.8 Revisiting the null hypothesis

1. **There is no statistical difference between the treatment outcome and the overbite correction planned by the ClinCheck®.**
    - Statistically significant differences were found between the predicted overbite correction and the treatment outcome ($p<0.05$). Therefore, the first null hypothesis is **rejected**.

2. **There is no association between the extent of overbite correction planned on ClinCheck® and the prediction accuracy.**
    - No association was found between the extent of overbite correction planned on ClinCheck and the prediction accuracy ($p>0.05$). Therefore, the second null hypothesis is **accepted**.

3. **There is no association between the pre-treatment overbite severity and the prediction accuracy.**
    - No association was found between the pre-treatment overbite severity and the prediction accuracy ($p>0.05$). Therefore, the third null hypothesis is **accepted**.

CHAPTER 7

Conclusion

- The mean prediction accuracy of deep overbite correction using Invisalign® is 37.7%.
- The ClinCheck® software significantly overestimates overbite improvement in deep bite subjects.
- Requesting greater overbite correction in the ClinCheck® will not necessarily lead to poorer accuracy.
- Programming mandibular incisor proclination in ClinCheck may improve the prediction accuracy. Thus, deep bite cases with crowding resolved by increase in arch perimeter may be more predictable to correct.

7.1 Recommendations

- When deep bite correction is planned with Invisalign®, overcorrection should be built into the finished occlusion on the ClinCheck® to reduce the rate of midcourse corrections or refinements.
- Successful deep overbite correction does not rely on aligners alone. Careful planning with auxiliary methods may also be used to help reduce the rate of refinements and midcourse corrections. These can be:
    - Additional retentive attachments
    - Inter-arch Class II or Class III elastics when needed
    - Segmental fixed appliances
    - Reinforcement of anchorage with TADs
    - Incisor intrusion with TADs
- Deep bite cases with crowding being addressed with increase in arch perimeter (incisor proclination, arch development and distalization of posterior segments) may be more predictable to correct.
- The orthodontist might want to be prudent in situations in which the incisors tend to upright (extensive IPR, extensive space closures and extractions).

7.2 Future studies

Future research should be encouraged to explore the factors that may influence the predictability of deep overbite correction with Invisalign®.

- The Invisalign® system is a technique that evolves quickly. Improvements of the aligner material and attachment features are continually being developed in the aim of improving clinical predictability. It would be of interest to conduct a similar study and compare the prediction accuracy between subjects treated before the introduction of the G5 deep bite protocol versus subjects treated after its introduction. This way, it would be possible to assess if the G5 deep bite protocol actually improves the prediction accuracy.
- It would be interesting to do a similar study using a sample treated with a higher number of aligners (*Invisalign® Full* treatment) and see if the prediction accuracy improves significantly.
- It would be interesting to do a similar study using a sample treated by a different practitioner using a higher number of retentive attachments for vertical anchorage and assess the potential improvement of the prediction accuracy.
- The vertical facial pattern was not taken into consideration in this study. Since deep overbite correction is more challenging in brachycephalic patients, it would be relevant to conduct a similar study to determine if the facial pattern has a significant influence on the prediction accuracy of deep bite correction with Invisalign®.
- It would be of interest to compare the efficacy of dental deep overbite correction between subjects treated with Invisalign® and subjects treated with fixed multibracket appliances, in terms of treatment time and clinical outcome.

REFERENCES

Abizadeh N, Moles D.R., O'Neill J, Noar J.H. Digital versus plaster study models: how accurate and reproducible are they? J Orthod. 2012 Sept;39(3):151-9.

Ali S.A. A.H., Miethke H.R. Invisalign., an Innovative Invisible Orthodontic Appliance to Correct Malocclusions: Advantages and Limitations. Dent Update 2012;39:254-260.

Align Technology, Inc (2014). Invisalign G5 Innovations for Deep Bite. https://www.aligntech.com/documents/Invisalign_G5_Brochure.pdf
Accessed August 2018

Align Technology, Inc (2018). Invisalign Academy.
https://learn.invisalign.com/deepbite/caseevaluation/meaning
https://learn.invisalign.com/deepbite/treatmentplan/features/smartforce
https://learn.invisalign.com/smartforce/features/hierarchy
Accessed August 2018

Align Technology, Inc (2018). Align Technology announces second Quarter financial 2018 results.
http://investor.aligntech.com/static-files/0b549616-5f1e-4054-a2d7-b7d8aedd4526
Accessed September 2018

Align Technology, Inc. The Invisalign reference guide. Santa Clara, Calif; 2002.

The ABO Discrepancy Index (DI) A Measure of Case Complexity.
https://www.americanboardortho.com/media/1189/discrepancy_index_scoring_system.pdf
Accessed August 2018

Akyalcin S, Cozad B.E., English J.D., Colville C.D., Laman S. Diagnostic accuracy of impression-free digital models. Am J Orthod Dentofacial Orthop 2013;144:916-22.

Al-Zubaidi S.A., Obaidi H.A. The variation of the lower anterior facial heights and its component parameters among the three over-bite relationships (cephalometric study). Al-Rafidain Dent J. 2006 Jul;6(2):106-13.

Amarnath BC, Prashanth CS, Dharma RM. Clinical overview of deep bite management. Int J Contemporary Dent. 2010 Nov;1(2):30-3

Andrews LF. The six keys to normal occlusion. Am J Orthod 1972;62:296-309.

Arag_on ML, Pontes LF, Bichara LM, Flores-Mir C, Normando D. Validity and reliability of intraoral scanners compared to conventional gypsum models measurements: a systematic review. Eur J Orthod 2016;38:429-34.

Asquith J, Gillgrass T, Mossey P. Three-dimensional imaging of orthodontic models: a pilot study. Eur J Orthod 2007;29: 517-22.

Aydoğdu Esen and Ömür Polat Özsoy. Effects of mandibular incisor intrusion obtained using a conventional utility arch vs bone anchorage. The Angle Orthodontist: September 2011, Vol. 81, No. 5, pp. 767-775.

Baldwin DK, King G, Ramsay DS, Huang G, Bollen AM. Activation time and material stiffness of sequential removable orthodontic appliances. Part 3: premolar extraction patients. Am J Orthod Dentofacial Orthop 2008;133:837-45.

Ball JV, Hunt NP. The effect of Andresen, Harvold, and Begg treatment on overbite and molar eruption. Eur J Orthod 1991;13:53-8.

Bansal, Amit. "Long Face Syndrome: A Literature Review." Journal of Dental Health, Oral Disorders & Therapy, vol 2, no. 6, 2015.

Barbosa, Luiz A.G. et al. Longitudinal cephalometric growth of untreated subjects with Class II Division 2 malocclusion. Am J Orthod Dentofacial Orthop 2017;151(5):914-920.

Barthelemi S, Hyppolite MP, Palot C, Wiechmann D. Components of overbite correction in lingual orthodontics: Molar extrusion or incisor intrusion? Int Orthod 2014; 12:395-412.

Baumrind S, Korn EL, West E. Prediction of mandibular rotation: an empirical test of clinician performance. A J Orthod. 1984;86:371.

Baydas B, Yavuz I, Atasaral N, Ceylan I, Dagsuyu I. Investigation of the changes in the positions of upper and lower incisors, overjets, overbite, and irregularity index in subjects with different depths of curve of Spee. Angle Orthod. 2004;74(3):349-55.

Beckmann SH, Kuitert RB, Prahl-Andersen B, Segner D, The RP, Tuinzing DB. Alveolar and skeletal dimensions associated with over-bite. Am J Orthod Dentofacial Orthop. 1998;113(4):443-52.

Behrents RG. An atlas of growth in the aging craniofacial skeleton. Monograph 18, Craniofacial Growth Series. Ann Arbor, Mich: Center for Human Growth and Development, University of Michigan; 1985.

Behrents RG. Adult facial growth. In: Enlow DH, ed. Facial Growth. 3rd ed. Philadelphia, Penn: WB Saunders; 1990.

Bell A, Ayoub AF, Siebert P. Assessment of the accuracy of a three-dimensional imaging systems for archiving dental study models. J Orthod 2003;30:219-23.

Bench RW, Gugino CF, Hilgers JJ. Bioprogressive therapy part 6. J Clin Orthod. 1978;12:123–139.

Bergersen E. A longitudinal study of anterior vertical overbite from eight to twenty years of age. Angle Orthod. 1988;58: 237–256.

Betzenberger D, Ruf S, Pancherz H. The compensatory mechanism in high angle malocclusions: a comparison of subject in the mixed and permanent dentition. Angle Orthod. 1999 Feb;69(1):27-32.

Bishara SE. Longitudinal cephalometric standards from 5 years of age to adulthood. Am J Orthod. 1981;79:35–44.

Bishara SE, Peterson L.C., Bishara EC. Changes in facial dimensions and relationships between the ages of 5 and 25 years. Am J Orthod. 1984;85(3):238-52

Bishara SE, Jakobsen JR. Longitudinal changes in three normal facial types. Am J Orthod. 1985;88(6):466-502.

Bishara SE, Jackbsen JR, Treder JE, Stasi MJ. Changes in the maxillary and mandibular tooth size-arch length relationships from early adolescence to early adulthood: a longitudinal study. Am J Orthod Dentofacial Orthop. 1989;95:46–59.

Bishara SE, Treder JE, Jakobsen JR. Facial and dental changes in adulthood. Am J Orthod Dentofacial Orthop. 1994;106:175–186.

Bishara SE, Jakobson JR. Changes in overbite and face height from 5 to 45 years of age in normal subjects. Angle Orthod. 1998; 68(3):209-16

Björk A. Variability and age changes in overjet and overbite. Am J Orthod 1953;39:779-801.

Björk, A. Prediction of mandibular growth rotation. American Journal of Orthodontics. 1969, vol 55, no. 6, pp. 585-599.

Björk A, Skieller V. Growth of the maxilla in three dimensions as revealed radiographically by the implant method. *Br J Orthod*. 1977;**4**:26–33.

Bollen AM, Huang G, King G, Hujoel P, Ma T. Activation time and material stiffness of sequential removable orthodontic appliances. Part 1: ability to complete treatment. Am J Orthod Dentofacial Orthop 2003;124:496-501.

Bolton WA. Disharmony in tooth size and its relation to the analysis and treatment of malocclusion. Angle Orthod 1958;28:113-23.

Borzabadi-Farahani A, Eslamipour F. Malocclusion and occlusal traits in an urban Iranian population. An epidemiological study of 11- to 14-year-old children. Eur J Orthod. 2009; 31:477–84.

Boyd RL, Miller RJ, Vlaskalic V. The Invisalign system in adult orthodontics: mild crowding and space closure cases. J Clin Orthod 2000;34:203-12.

Boyd RL, Vlaskalic V. Three-dimensional diagnosis and orthodontic treatment of complex malocclusion with the Invisalign appliance. Semin Orthod 2001;7:274-93.

Boyd RL. Complex orthodontic treatment using a new protocol for the Invisalign® appliance. J Clin Orthod. 2007;41:525–547.

Boyd RL. Esthetic Orthodontic Treatment Using the Invisalign Appliance for Moderate to Complex Malocclusions. J Dent Educ. 2008;72(8):948-67.

Braun S, Hnat WP, Johnson BE. The curve of Spee revisited. Am J Orthod Dentofacial Orthop 1996;110:206-210

Breece G L, Nieberg L G 1986 Motivations for adult orthodontic treatment. Journal of Clinical Orthodontics 20: 166-171

Bresonis WL, Greive JM. Treatment and posttreatment changes in orthodontic cases: overbite and overjet. Angle Orthod 1974;44:295-9.

Brunelle JA, Bhat M, Lipton JA. Prevalence and distribution of selected occlusal characteristics in the US population, 1988-91. J Dent Res. 75, 1996, 706–713.

Burstone CR. Deep overbite correction by intrusion. Am J Orthod 1977;72:1-22

Burzin J, Nanda R. The stability of deep overbite correction. In: Nanda R, Burstone CJ, eds. Retention and Stability in Orthodontics. Philadelphia, PA: WB Saunders; 1993:61-79.

Buschang, PH. et al. "The Morphological Characteristics, Growth, And Etiology Of The Hyperdivergent Phenotype." Seminars In Orthodontics, vol 19, no. 4, 2013, pp. 212-226

Buschang PH, Sankey W, English JP: Early treatment of hyperdivergent open-bite malocclusions. Semin Orthod 8:130-140, 2002

Buschang PH, Ross M, Shaw SG, Crosby D, Campbell PM. Predicted and actual end-of-treatment occlusion produced with aligner therapy. Angle Orthod. 2015 Sep;85(5):723–7.

Callaway GS. The use of bite plates. Am J Orthod Oral Surg 1940;26:120-6.

Camardella L.T., Breuning H., Vilella O.V. Are there differences between comparison methods used to evaluate the accuracy and reliability of digital models? Dental Press J Orthod. 2017;22(1):65-74.

Carter GA, McNamara JA. Longitudinal dental arch changes in adults. Am J Orthod Dentofacial Orthop 1998;114:88-99.

Castroflorio T, Garino F, Lazzaro A, Debernardi C. Upper-incisor root control with Invisalign appliances. J Clin Orthod 2013;47:346-51.

Ceylan I, Eroz U. The effects of overbite on the maxillary and mandibular morphology. Angle Orthod 2001;71:110-5.

Ceylan I, Baydas B, B€ol€ukbasi B. Longitudinal cephalometric changes in incisor position, overjet, and overbite between 10 and 14 years of age. Angle Orthod 2002;72:246-50.

Chiqueto K, Martins DR, Janson G. Effects of accentuated and reversed curve of Spee on apical root resorption. Am J Orthod Dentofacial Orthop 2008;133:261-268

Cho S-H, Schaefer O, Thompson GA, Guentsch A. Comparison of accuracy and reproducibility of casts made by digital and conventional methods. J Prosthet Dent. 2015; 113: 310±315.

Clements KM, Bollen AM, Huang G, King G, Hujoel P, Ma T. Activation time and material stiffness of sequential removable orthodontic appliances. Part 2: dental improvements. Am J Orthod Dentofacial Orthop 2003;124:502-8.

Cobourne M, DiBiase A. Handbook of Orthodontics, 2nd Edition. Elsevier 2016.

Costalos PA, Sarraf K, Cangialosi TJ, Efstratiadis S. Evaluation of the accuracy of digital model analysis for the American Board of Orthodontics objective grading system for dental casts. Am J Orthod Dentofacial Orthop 2005;128:624-9.

Cozza P, Mucedero M, Baccetti T, et al: Early orthodontic treatment of skeletal open-bite malocclusion: a systematic review. Angle Orthod 75:707-713, 2005

Dake ML, Sinclair PM. A comparison of the Ricketts and Tweed-type arch leveling techniques. AM J ORTHOD DENTOFAC ORTHOP 1989;95:72-8.

DeCoster L. Open bite. Int J Orthod Oral Surg. 1936;22:912-38.

Dellinger EL. A histologic and cephalometric investigation of premolar intrusion in the macaca speciosa monkey. AM J ORTHOD 1967;53:325-55.

Dermaut LR, Pauw GD. Biomechanical aspects of Class II mechanics with special emphasis on deep bite correction as a part of the treatment goal. In: Nanda R, ed. Biomechanics in Clinical Orthodontics, Philadelphia, PA; WB Saunders; 1997:86-69.

Djeu G, Shelton C, Maganzini A. Outcome assessment of Invisalign and traditional orthodontic treatment compared with the American Board of Orthodontics objective grading system. Am J Orthod Dentofacial Orthop 2005;128:292-8.

Duncan L, Piedade L, Lekic L, Cunha RS, and Wiltshire WA. Changes in mandibular incisor position and arch form resulting from Invisalign correction of the crowded dentition treated nonextraction. Angle Orthod: 2016, Vol. 86, No. 4, pp. 577-583.

El-Dawlatly MM, Fayed MM, Mostafa YA. Deep overbite malocclusion: analysis of the underlying components. Am J Orthod Dentofacial Orthop. 2012;142(4):473-80.

Ellis E 3rd, McNamara JA Jr. Components of adult class III malocclusion. Am J Orthod Dentofacial Orthop. 1984 Oct;86(4):277-90.

Ender A, Attin T, Mehl A. In vivo precision of conventional and digital methods of obtaining complete arch dental impressions. J Prosthet Dent. 2016; 115: 313±320.

Ender A, Mehl A. Accuracy of complete-arch dental impressions: A new method of measuring trueness and precision. J Prosthet Dent. 2013; 109: 121±128.

Engel G, Cornforth G, Damerall JM, et al. Treatment of deep-bite cases. Am J Orthod 1980;77:1-13.

Enlow DH. Factors in the intrinsic control of facial growth. In: Carlson D, ed. *Craniofacial growth theories and orthodontic treatment. Craniofacial growth series*. Vol. **23**, Ann Arbor: University of Michigan; 1990:1–12.

Enlow, Donald H, and Mark G Hans. Essentials Of Facial Growth. Philadelphia, PN., Saunders, 1996.

Faerovig E, Zachrisson BU. Effects of mandibular incisor extraction on anterior occlusion in adults with Class III malocclusion and reduced overbite. Am J Orthod Dentofacial Orthop 1999;115: 113-24.

Farella M, Michelotti A, Martina R. The curve of Spee and craniofacial morphology: a multiple regression analysis. Eur J Oral Sci 2002;110:277-81.

Fattahi H, Pakshir H, Afali Baghdadabadi N, Shahian Jahromi S. Skeletal and Dentoalveolar Features in Patients with Deep Overbite Malocclusion. J Dent (Tehran). 2014;11(6):629-38.

Feldmann I, Lundstro ̈m F, Peck S. Occlusal changes from adolescence to adulthood in untreated patients with Class II division 1 deep bite malocclusion. Angle Orthod. 1999;69: 33–38.

Flemming HB. An investigation of the vertical overbite during the eruption of the permanent dentition. Angle Orthod. 1961;31:53-62.

Fleming PS, Marinho V, Johal A: Orthodontic measurements on digital study models compared with plaster models: a systematic review. *Orthod Craniofac Res.* 2011;**14**:1–16.

Flügge TV, Schlager S, Nelson K, Nahles S, Metzger MC. Precision of intraoral digital dental impressions with iTero and extraoral digitization with the iTero and a model scanner. Am J Orthod Dentofacial Orthop 2013;144:471-8.

Forsberg CM. Facial morphology and ageing: a longitudinal cephalometric investigation of young adults. Eur J Orthod. 1979;1:15–23.

Franchi L, Baccetti T, Giuntini V, Masucci C, Vangelisti A, Defraia E: Outcomes of two-phase orthodontic treatment of deepbite malocclusions. Angle Orthod 81:945-952, 2011

Garino F, Garino G.B., Castroflorio T. The iTero intraoral scanner in Invisalign treatment: A two-year report. J Clin Orthod. 2014;48(2):98-106.

Gay G, Ravera S, Castroflorio T, et al. Root resorption during orthodontic treatment with Invisalign®: A radiometric study. Prog Orthod 2017;18:12

Ghafari JG, Street KW. Dental development in children with Class II, division 2 malocclusion—Four types of the malocclusion defined In: Davidovitch Z, Mah J eds. Biological Mechanisms of Tooth Eruption, Resorption, and Replacement by Implants. Boston, The Harvard Society for the Advancement of Orthodontics 1998, pp 8589-8596

Ghafari JG, Macari A.T., Haddad R.V. Deep bite: Treatment options and challenges. Semin Orthod 2013;19(4):253-266.

Ghafari JG. Centennial inventory: The changing face of orthodontics. Am J Orthod Dentofacial Orthop 2015; 148:732-739.

Giancotti A, Mampieri G, Greco M. Correction of deep bite in adults using the Invisalign system. J Clin Orthod 2008;42:719-726.

Giancotti A, Farina A. Treatment of collapsed arches using the Invisalign system. J Clin Orthod. 2010;44(7):416-25.

Goldstein MS, Stanton FL. Various types of occlusion and amounts of overbite in normal and abnormal occlusion between two and twelve years. Int J Orthod Oral Surg 1936;22:549-69.

Goonewardene RW, Goonewardene MS, Razza JM, Murray K. Accuracy and validity of space analysis and irregularity index measurements using digital models. Aust Orthod J. 2008 Nov;24(2):83-90.

Greig DGM. Bioprogressive therapy: overbite reduction with the lower utility arch. Br J Orthod 1983;10:214-6.

Grieve GW. The most difficult problem in orthodontia -the elimination of the deep overbite. Dental Cosmos 1928;19:704-7.

Grünheid T, McCarthy SD, Larson BE. Clinical use of a direct chairside oral scanner: an assessment of accuracy, time, and patient acceptance. Am J Orthod Dentofacial Orthop 2014; 146:673-82.

Gu J, Tang J.S., Skulski B., Fields H.W. Jr, Beck F.M., Firestone A.R., Kim D.G., Deguchi T. Evaluation of Invisalign treatment effectiveness and efficiency compared with conventional fixed appliances using the Peer Assessment Rating index. Am J Orthod Dentofacial Orthop 2017;15.

Guarneri MP, Oliverio T, Silvestre I, Lombardo L, Siciliani G. Open bite treatment using clear aligners. Angle Orthod 2013; 83:913-9.

Hartsfield JK Jr. Genetics and orthodontics In: Graber LW, Vanarsdall RL, Vig KW Leds. Orthodontics: Current Principles and Techniques 5th ed. St-Louis, Elsevier Mosby, 2011, pp139-156

Haskell BS. The human chin and its relationship to mandibular morphology. Angle Orthod. 1979 Jul;49(3):153-66.

Hering, H.K.; Ruf, S.; and Pancherz, H.: Orthodontic treatment of openbite and deepbite high-angle malocclusions, Angle Orthod. 69:470-477, 1999.

Herness L.E., Rule J.T., Williams B.H. A longitudinal cephalometric study of incisor overbite from ages five to eleven. Angle Orthod 1973;43:279-88.

Houle J.P., Piedade L, Todescan R Jr, Pinheiro F.H. The predictability of transverse changes with Invisalign. Angle Orthod. 2017;87(1):19–24.

Houston, W.J. A comparison of the reliability of measurement of cephalometric radiographs tracings and direct digitization. 1982. Swed Dent J Suppl, 15, 99-103.

Huang G.J. et al. Stability of deep-bite correction: A systematic review. J World Fed Orthod. 2012; 1 (3): e89-e86.

Hug H.U. Periodontal status and its relationship to variations in tooth position. An analysis of the findings reported in the literature. Helv Odontol Acta. 1982;26:11–24.

Jacob H.B., Buschang P.H. Vertical craniofacial Vertical craniofacial growth changes in French-Canadians between 10 and 15 years of age. Am J Orthod Dentofac Orthop. 2011;139(6):797-805.

Jacob H.B., Wyatt G.D. & Buschang P.H. Reliability and validity of intraoral and extraoral scanners. Progress in Orthodontics, 2015, 16:38.

Jeremiah, H.G., Bister D. & Newton, J.T. Social perceptions of adults wearing orthodontic appliances: a cross-sectional study. Eur J Orthod, 2011;33(5):476-482.

Joffe L. Invisalign®: early experience. J Orthod 2003;30(4):348-352.

Joffe L. OrthoCAD: digital models for a digital era. J Orthod 2004; 31: 344–47.

Jonsson, T, Karlsson, KO, Ragnarsson, B, et al.: Long-term development of malocclusion traits in orthodontically treated and untreated subjects. Am J Orthod Dentofac Orthop. 137, 2010, 277–284.

Jonsson T, Arnlaugsson S, Karlsson KO, Ragnarsson B, Arnarson EO, Magnusson TE. Orthodontic treatment experience and prevalence of malocclusion traits in an Icelandic adult population. Am J Orthod Dentofacial Orthop. 2007; 131:8.e11–8.

Kale Varlik S, Onur Alpakan O, Turkoz C. Deepbite correction with incisor intrusion in adults: A long-term cephalometric study. Am J Orthod Dentofacial Orthop 2013; 144:414-419

Kamatovic M. A retrospective evaluation of the effectiveness of the Invisalign appliance using the PAR and irregularity indices [dissertation]. Toronto (Ont.): University of Toronto; 2004.

Kamimura E, Tanaka S, Takaba M, Tachi K, Baba K. In vivo evaluation of inter-operator reproducibility of digital dental and conventional impression techniques. PLoS One. 2017;12(6): e0179188.

Kanomi R. Mini-implant for orthodontic anchorage. J Clin Orthod. 1997;31:763–767.

Karl M, Graef F, Schubinski P, Taylor T. Effect of intraoral scanning on the passivity of fit of implant-supported fixed dental prostheses. Quintessence Int. 2012; 43: 555±562.

Keim RG, Gottlieb EL, Vogels III DS, Vogels PB. 2014 JCO study of orthodontic diagnosis and treatment procedures, part1: results and trends. J Clin Orthod. 2014;48:607–30.

Kesling H.D. Coordinating the predetermined pattern and tooth positioner with conventional treatment. Am J Orthod Oral Surg. 1946;32:285–293.

Khosravi R, Cohanim B, Hujoel P, et al. Management of overbite with the Invisalign appliance. Am J Orthod Dentofacial Orthop 2017;151:691-699.

Kravitz N.D., Kusnoto B, Agran B, Viana G. Influence of attachments and interproximal reduction on the accuracy of canine rotation with Invisalign®. A prospective clinical study. Angle Orthod. 2008;78(4):682–7.

Kravitz N.D., 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;135:27-35.

Krieger E, Seiferth J, Marinello I, Jung BA, Wriedt S, Jacobs C, et al. Invisalign® treatment in the anterior region were the predicted tooth movements achieved? J Orofac Orthop. 2012;73(5):365–76.

Krieger E, Seiferth J, Saric I, Jung BA, Wehrbein H. Accuracy of Invisalign® treatments in the anterior tooth region. First results. J Orofac Orthop. 2011;72(2):141–9.

Kuncio D, Maganzini A, Shelton C, Freeman K. Invisalign and traditional orthodontic treatment postretention outcomes compared using the American Board of Orthodontics objective grading system. Angle Orthod 2007;77:864-9.

Kusnoto B, Evans C.A. Reliability of a 3D surface laser scanner for orthodontic applications. Am J Orthod Dentofacial Orthop 2002;122:342-8.

Kuster R, Ingervall B. The effect of treatment of skeletal open bite with two types of bite-blocks. Eur J Orthod 1992;14: 489-99.

Kwon JS, Lee YK, Lim BS, Lim YK. Force delivery properties of thermoplastic orthodontic materials. Am J Orthod Dentofacial Orthop 2008; 133(2): 228–234.

Lagravère MO, Flores-Mir C. The treatment effects of Invisalign orthodontic aligners: a systematic review. J Am Dent Assoc 2005;136(12): 1724–1729.

Lee JS, Kim JK, Park YC, Vanarsdall RL. Applications of Orthodontic Mini-Implants. Hanover Park, Ill: Quintessence Publishing Co, Inc; 2007:222.

Lee SJ, Betensky RA, Gianneschi GE, Gallucci GO. Accuracy of digital versus conventional implant impressions. Clinical Oral Implants Research. 2015; 26: 715±719.

Leifert MF, Leifert MM, Efstratiadis SS, Cangialosi TJ. Comparison of space analysis evaluations with digital models and plaster dental casts. Am J Orthod Dentofacial Orthop 2009;136: 16.e1-4.

Lefkowitz W, Waugh LM. Experimental depression of teeth. AM J ORTHOD ORAL SURG 1945;31:21-36.

Ludwig MK. A cephalometric analysis of the relationship between facial pattern, interincisal angulation and anterior overbite changes. Angle Orthod. 1967;37:194-204.

Luu N.S., Nikolcheva L.G., Retrouvey J.M., Flores-Mir C., El-Bialy T, Carey J.P., Major P.W. Linear measurements using virtual study models. Angle Orthod. 2012;82(6):1098-106.

Mack S., Bonilla T., English J.D., Cozad B., Akyalcin S. Accuracy of 3-dimensional curvilinear measurements on digital models with intraoral scanners. Am J of Orthod Dentofacial Orthop 2017;152:3:420-425.

Mah J. The evolution of digital study models. J Clin Orthod 2007; 41: 557–61.

Malik OH, McMullin A, Waring DT. Invisible orthodontics part I: Invisalign. Dent Update 2013;40:203-204, 207-210, 213-215.

Marshall SD, Caspersen M, Hardinger RR, Franciscus RG, Steven A, Aquilino SA, et al. Development of the curve of Spee. Am J Orthod Dentofacial Orthop 2008;134:344-52.

Martins DR, Tibola D, Janson G, Maria FR. Effects of intrusion combined with anterior retraction on apical root resorption. Eur J Orthod 2012;34:170-175.

Massaro C et al. Maturational changes of the normal occlusion: A 40-year follow-up. Am J Orthod Dentofacial Orthop. 2018;154:2;188-200

Maulik C, Nanda R. Dynamics mile analysis in young adults. Am J Orthod Dentofacial Orthop. 2007;132(3):307-15.

Mayers M, Firestone AR, Rashid R, Vig KW. Comparison of peer assessment rating index scores of plaster and computer-based digital models. Am J Orthod Dentofacial Orthop 2005;128:431-4.

McFadden WM, Engstrom C, Engstrom H, et al: A study of the relationship between incisor intrusion and root shortening. Am J Orthod Dentofacial Orthop 96:390-396, 1989.

Meier B, Wiemer KB, Miethke RR. Invisalign – patient profiling. Analysis of a prospective survey. J Orofac Orthop 2003; 64(5): 352–358.

Melsen B, Agerbaek N, Markenstam G: Intrusion of incisors in adult patients with marginal bone loss. Am J Orthod Dentofacial Orthop 96:232-241, 1989

Melsen B. Northcroft Lecture: how has the spectrum of orthodontics changed over the past decades? J Orthod. 2011;38:134–143.

Mershon JV. Possibilities and limitations in the treatment of closed-bites. Int J Orthod Oral Surg 1937;23:581-9.

Mitchell DL, Stewart WE Documented leveling of the lower arch using metallic implants for reference. AM J ORTHOD 1973;63:526-32.

Moorrees C. *The dentition of the growing child. A longitudinal study of dental development between 3 and 18 years*. Cambridge: Harvard University Press; 1959.

Moorrees CFA, Gron AM, Lebret LM, et al: Growth studies of the dentition: a review. Am J Orthod 55:600- 616, 1963

Moyers R.E. Handbook of Orthodontics, 4th ed. Chicago, IL: Year Book Medical Publishers; 1998:422-424.

Mullen S.R., Martin CA, Ngan P, Gladwin M. Accuracy of space analysis with emodels and plaster models. Am J Orthod Dentofacial Orthop 2007;132:346-52.

Naidu D, Freer TJ. Validity, reliability, and reproducibility of the iOC intraoral scanner: a comparison of tooth widths and Bolton ratios. Am J Orthod Dentofacial Orthop 2013;144:304-10.

Nanda R.S. The differential diagnosis and treatment of excessive overbite. Dent Clin North Am. 1981;25:69–84.

Nanda R.S, Khan I, Anand R. Age changes in the occlusal pattern of deciduous dentition. J Dent Res 1973;52:221-4.

Nanda R.S, Surender K. Growth Patterns In Subjects With Long And Short Faces. American Journal Of Orthodontics And Dentofacial Orthopedics, 1990; 98(3):247-58.

Nanda R.S. Esthetics and Biomachenics in Orthodontics, 2nd Edition. 2015. Elsevier.

Naumann SA, Behrents RG, Buschang PH. Vertical components of overbite change: a mathematical model. Am J Orthod Dentofacial Orthop. 2000 Apr;117(4):486-95.

Neff CW. Tailored occlusion with the anterior coefficient. Am J Orthod Oral Surg 1949;35:309-14.

Nemeth RB, Isaacson RJ. Vertical anterior relapse. AM J ORTHOD 1974;65:565-85.

Nielsen L. Vertical malocclusions: etiology, development, diagnosis and some aspects of treatment. Angle Orthod. 1991;61:247–260.

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: 212-219.

Nguyen CV, Chen J. Chapter 14. In: Tuncay OC, ed. The Invisalign system. New Malden, United Kingdom: Quintessence Publishing Company, Ltd; 2006 p. 12-32.

Ohnishi H, Yagi T, Yasuda Y, et al: A mini-implant for orthodontic anchorage in a deep overbite case. Angle Orthod 75:444-452, 2005

Opdebeeck H, Bell WH. The short face syndrome. Am J Orthod. 1978;73:499-511.

Otto RL, Anholm JM, Engel GA. A comparative analysis of intrusion of incisor teeth achieved in adults and children according to facial type. Am J Orthod 1980;77:437-446.

Papadimitriou A, Mousoulea S, Gkantidis N, Kloukos D. Clinical effectiveness of Invisalign® orthodontic treatment: a systematic review. Prog Orthod. 2018; 19:37.

Patzelt SBM, Emmanouilidi A, Stampf S, Strub JR, Att W. Accuracy of full-arch scans using intraoral scanners. Clin Oral Investig. 2014; 18: 1687±1694.

Parker CD, Nanda RS, Currier GF. Skeletal and dental changes associated with the treatment of deep bite malocclusion. Am Journal of Orthod and Dentofacial Orthop 1995;107:382-393.

Parker CD. A comparative study of inter-maxillary spaces with treated and untreated occlusion. Dent Pract Dent Rec. 1964;15:66-82.

Peck S, Peck L, Kataja M. Class II Div 2 malocclusion: a heritable pattern of small teeth in well-developed jaws. Angle Orthod. 1998;68:9-17.

Pecora, Nikole G., et al. “The Aging Craniofacial Complex: A Longitudinal Cephalometric Study from Late Adolescence toLate Adulthood.” Am J Orthod Dentofacial Orthop, 2008;134(4): 496–505.

Peluso MJ, Sd J, Levine SW, Lorei BJ. Digital models: an introduction. Semin Orthod. 2004;10:226–38.

Petrovic A, Stutzmann J, Lavergne J. Mechanisms of craniofacial growth and modus operandi of functional appliances. A cell-level and cybernetic approach to orthodontic decision making. In: Carlson D, ed. *Craniofacial growth theories and orthodontic treatment. Craniofacial growth series*. **Vol 23**, Ann Arbor: University of Michigan; 1990:13–74.

Phan X, Ling PH. Clinical limitations of Invisalign. J Can Dent Assoc 2007;73:263-266.

Polat-Özsoy Ö, Arman-Özçırpıcı A, Veziroğlu F, Çetinşa-hin A: Comparison of the intrusive effects of miniscrews and utility arches. Am J Orthod Dentofacial Orthop 139:526-532, 2011

Popovich F. Cephalometric evaluation of vertical overbite in young adults. J Canadian Dent Assoc 1955;21:209-22.

Porter J.L., Carrico C.K., Lindauer S.J. & Tüfekçi E. Comparison of intraoral and extraoral scanners on the accuracy of digital model articulation, Journal of Orthodontics, 2018; 19:1-8.

Prakash P, Margolis H. Dento-cranio-facial relations in varying degree of overbite. Am J Orthod Dentofacial Orthop. 1952;38:657-73.

Proffit, William R et al. Contemporary Orthodontics. 5th ed., St. Louis, MO., Elsevier/Mosby, 2013

Proffit, WR, Fields, HW, Moray, LJ: Prevalence of malocclusion and orthodontic treatment need in the United States: estimates from the NHANES III survey. Int J Adult Orthod Orthogn Surg. 13, 1998, 97–106.

Quimby ML, Vig KWL, Rashid RG, Firestone AR. The accuracy and reliability of measurements made on computer-based digital models. Angle Orthod 2004;74:298-303.

Redlich M, Weinstock T, Abed Y, Schneor R, Holdstein Y, Fischer A. A new system for scanning, measuring and analyzing dental casts based on a 3D holographic sensor. Orthod Craniofac Res 2008;11:90-5.

Reis, Silvia et al. "Agreement Among Orthodontists Regarding Facial Pattern Diagnosis." Dental Press Journal Of Orthodontics, vol 16, no. 4, 2011, pp. 60-72

Richardson, A. A cephalometric investigation of skeletal factors in anterior open bite and deep overbite, Tr. European Orthodont. Sot., pp. 159-171, 1967.

Richardson, A. Skeletal factors in anterior open-bite and deep overbite. Am J Orthod. 1969;56(2):114-27.

Ricketts R.M. et al. Bioprogressive Therapy. Rocky Mountain/Orthodontics, 1979.

Riedel, RA. A review of the retention problem. Angle Orthod. 1960; 30:179-194.

Riolo, Michael L., et al. Associations between Occlusal Characteristics and Signs and Symptoms of TMJ Dysfunction in Children and Young Adults. *American Journal of Orthodontics and Dentofacial Orthopedics*, vol. 92, no. 6, 1987, pp. 467–477., doi:10.1016/0889-5406(87)90228-9

Rosvall M.D., Fields H.W., Rosenstiel S.F., Johnston W.M. Attractiveness, acceptability, and value of orthodontic appliances. Am J Orthod Dentofacial Orthop 2009;135(3):276.

Rossini G, Parrini S, Castroflorio T, Deregibus A, Debernardi CL. Efficacy of clear aligners in controlling orthodontic tooth movement: a systematic review. Angle Orthod 2015;85:881-9.

Rozzi M, Mucedero M, Pezzuto C, Cozza P. Leveling the curve of Spee with continuous archwire appliances in different vertical skeletal patterns: A retrospective study. Am J Orthod Dentofacial Orthop 2017;151:758-766.

Salem OH, Al-Sehaibany F, Preston CB. Aspects of mandibular morphology, with specific reference to the antegonial notch and the curve of Spee. J Clin Pediatr Dent 2003;27:261-5.

Sangcharearn Y, Christopher HO. Effect of incisors angulation on overjet and overbite in Class II camouflage treatment. Angle Orthod;2007;77:1011-8.

Santoro M, Galkin S, Teredesai M, Nicolay OF, Cangialosi TJ. Comparison of measurements made on digital and plaster models. Am J Orthod Dentofacial Orthop 2003;124:101-5.

Schaefer O, Decker M, Wittstock F, Kuepper H, Guentsch A. Impact of digital impression techniques on the adaption of ceramic partial crowns in vitro. J Dent. 2014; 42: 677±683.

Schendel SA, Eisenfeld J, Bell WH, Epker B. The long face syndrome: vertical maxillary excess. Am J Orthod. 1976;70:398-408.

Schudy FF. The control of vertical overbite in clinical orthodontics. Angle Orthod 1968;38:19-38.

Schudy FF. Cant of the occlusal plane and axial inclinations of teeth. Angle Orthod 1963;33:69-82.

Shannon KR, Nanda R. Changes in the curve of Spee with treatment and at 2 years posttreatment. Am J Orthod Dentofacial Orthop 2004;125:589-96.

Shin K. The Invisalign appliance could be an effective modality for treating overbite malocclusions within a mild to moderate range. J Evid Based Dent Pract 2017;17:278-280.

Shroff B, Yoon WM, Lindauer SJ, et al: Simultaneous intrusion and retraction using a three-piece base arch. Angle Orthod 67:455-461, 1997

Sifakakis I, Pandis N, Makou M, Eliades T, Bourauel C. A comparative assessment of the forces and moments generated with various maxillary incisor intrusion biomechanics. Eur J Orthod 2010;32:159-164.

Sifakakis I, Pandis N, Makou M, Eliades T, Bourauel C. Forces and moments generated with various incisor intrusion systems on maxillary and mandibular anterior teeth. Angle Orthod 2009;79:928-933.

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.

Sinclair PM, Little RM. Maturation of untreated normal occlusions. Am J Orthod. 1983;83:114–123.

Siriwat PP, Jarabak JR. Malocclusion and facial morphology: is there a relationship? Angle Orthod 1985;55:127-38.

Skieller V, Bj&k A, Linde-Hanson T. Prediction of mandibular growth rotation evaluated from a longitudinal implant sample. Am J Orthod. 1984;86:359-370.

Solano-Mendoza B, Sonnemberg B, Solano-Reina E, Iglesias-Linares A. How effective is the Invisalign® system in expansion movement with Ex30' aligners? Clin Oral Investig. 2017;21(5):1475–84.

Sousa MV, Vasconcelos EC, Janson G, Garib D, Pinzan A. Accuracy and reproducibility of 3-dimensional digital model measurements. Am J Orthod Dentofacial Orthop 2012;142:269-73.

Sreedhar C, Baratam S. Deep overbite-A review (Deep bite, Deep overbite, Excessive overbite). Ann Essence Dent. 2009 Jul;1(1):8-25

Steadman SR. Predetermining the overbite and overjet. Angle Orthod 1947;19:101-5.

Stevens DR, Flores-Mir C, Nebbe B, Raboud DW, Heo G, Major PW. Validity, reliability, and reproducibility of plaster vs digital study models: comparison of peer assessment rating and Bolton analysis and their constituent measurements. Am J Orthod Dentofacial Orthop 2006;129:794-803.

Strang RHW. A textbook of orthodontia. Philadelphia: Lea and Febiger, 1950.

Subtelny JD, Sakuda M. open bite diagno-sis and treatment. Am J Orthod Dentofacial Orthop. 1964;50:337-58.

Tausche E, Luck O, Harzer W; Prevalence of malocclusions in the early mixed dentition and orthodontic treatment need, *European Journal of Orthodontics*, Volume 26, Issue 3, 1 June 2004, Pages 237–244

Taylor MG, McGorray SP, Durrett S, Pavlow S, Downey N, Lenk M, et al. Effect of Invisalign aligners on periodontal tissues. J Dent Res 2003;82(a):abstract 1483.

Thilander B, Persson M, Adolfsson U. Roentgen-cephalometric standards for a Swedish population. A longitudinal study between the ages of 5 and 31 years. *Eur J Orthod*. 2005;**27**:370–389.

Thilander, B. Orthodontic space closure versus implant placement in subjects with missing teeth. Journal of Oral Rehabilitation. 2008;35: 64-71.

Trouten JC, Enlow DH, Rabine M, Phelps AE, Swedlow D. Morphologic factors in open bite and deep bite. Angle Orthod 1983;53(3):192-211.

Upadhyay M, Yadav S, Nagaraj K, Patil S: Treatment effects of mini-implants for en-masse retraction of anterior teeth in bialveolar dental protrusion patients: a randomized controlled trial. Am J Orthod Dentofacial Orthop. 2008;134:18-29.

Van der Beek M.C., Hoeksma J.B., Prahi-Andersen B. Vertical facial growth: a longitudinal study from 7 to 14 years of age. Eur J Orthod. 1991;13(3):202-8

Van der Meer WJ, Andriessen FS, Wismeijer D, Ren Y. Application of Intra-Oral Dental Scanners in the Digital Workflow of Implantology. Glogauer M, editor. PLoS ONE. 2012; 7: e43312.

Van't Spijker, A, et al. “Occlusal Wear and Occlusal Condition in a Convenience Sample of Young Adults.” *Journal of Dentistry*, vol. 43, no. 1, Jan. 2015, pp. 72–77., doi:https://doi.org/10.1016/j.jdent.2014.11.001

Vlaskalic V, Boyd R. Orthodontic treatment of a mildly crowded malocclusion using the Invisalign System. Aust Orthod J 2001; 17(1): 41–46.

Walton DK, Fields HW, Johnston WM, Rosenstiel SF, Firestone AR, Christensen JC. Orthodontic appliance preferences of children and adolescents. Am J Orthod Dentofacial Orthop 2010;138:

698.e1-12: discussion, 698-9.

Watanabe E, Demirjian A, Buschang P. Longitudinal post-eruptive mandibular tooth movements of males and females. Eur J Orthod.1999;21:459–468.

Watanabe-Kanno GA, Abrão J, Miasiro Junior H, Sánchez-Ayala A, Lagravère MO. Reproducibility, reliability and validity of measurements obtained from Cecile3 digital models. Braz Oral Res. 2009;23(3):288-95.

Weiland FJ, Banthleon H, Droschi H. Evaluation of continuous arch and segmented arch levelling techniques in adult patients—a clinical study. Am J Orthod Dentofac Orthop. 1996;110:647–655.

Westerlund A, Tancredi W, Ransjö M, Bresin A, Psonis S, Torgersson O. 2015. Digital casts in orthodontics: a comparison of 4 software systems. 2015. Am J Orthod Dentofacial Orthop. 147(4):509–516.

Wheeler TT. Orthodontic clear aligner treatment. Semin Orthod 2017;23(1):83-9.

Wiranto MG, Engelbrecht WP, Tutein Nolthenius HE, van der Meer WJ, Ren Y. Validity, reliability, and reproducibility of linear measurements on digital models obtained from intraoral and cone-beam computed tomography scans of alginate impressions. Am J Orthod Dentofacial Orthop 2013;143:140-7.

Woods MG. The mechanics of lower incisor intrusion: experiments in nongrowing baboons. AM J ORTHOD DENTOFAC ORTHOP 1988;93:186-95.

Wylie WL. Overbite and vertical facial dimensions in terms of muscle balance. Angle Orthod 1944;19:13-7.

Wylie WE The relationship between ramus height, dental height, and overbite. AM J ORTHOD ORAL SURG 1946;32:57-67.

Yang X, Lv P, Liu Y, Si W, Feng H. Accuracy of Digital Impressions and Fitness of Single Crowns Based on Digital Impressions. Materials. 2015; 8: 3945-3957.

Zachrisson BU. Important aspects of long term stability. J Clin Orthod. 1997;31:562–583.

Zilberman O, Huggare JA, Parikakis KA. Evaluation of the validity of tooth size and arch width measurements using conventional and three-dimensional virtual orthodontic models. Angle Orthod 2003;73:301-6.

Ziuchkovski, J.P., Fields, H.W., Johnston, W.M. & Lindsey, D.T. Assessment of perceived orthodontic appliance attractiveness. Am J Orthod Dentofacial Orthop, 2008;133(4 Suppl):S68-78.

APPENDICES

Appendix 1

Certificate from the Bannatyne Campus Research Ethics Boards at the University of Manitoba

University of Manitoba | Research Ethics - Bannatyne
Office of the Vice-President (Research and International)

P126-770 Bannatyne Avenue
Winnipeg, Manitoba
Canada, R3E 0W3
Telephone : 204-789-3255
Fax: 204-789-3414

HEALTH RESEARCH ETHICS BOARD (HREB)
CERTIFICATE OF FINAL APPROVAL FOR NEW STUDIES
Delegated Review

PRINCIPAL INVESTIGATOR:	INSTITUTION/DEPARTMENT:	ETHICS #:
Dr. Catherine Fontaine-Sylvestre	U of M/Dentistry/Preventive Dental Science	HS20715 (H2017:128)

APPROVAL DATE:	EXPIRY DATE:
May 24, 2017	**May 24, 2018**

STUDENT PRINCIPAL INVESTIGATOR SUPERVISOR (If applicable):
Dr. Robert Drummond

PROTOCOL NUMBER:	PROJECT OR PROTOCOL TITLE;
NA	Predictability of Overbite Correction Using Invisalign® in Deep Bite Cases

SPONSORING AGENCIES AND/OR COORDINATING GROUPS:
NA

Submission Date of Investigator Documents:	HREB Receipt Date of Documents:
February 22 and May 2, 2017	March 23 and May 12, 2017

THE FOLLOWING ARE APPROVED FOR USE:

Document Name	Version(if applicable)	Date
Protocol:		
Proposal signed May 5, 2017		
Clarification Letter dated May 2, 2017		
Consent and Assent Form(s):		
Informed Consent for the Orthodontic Patient		20-Mar-2017
Other:		
Master List		February 22, 2017
Data Collection Sheet/Capture Sheet		May 2, 2017

CERTIFICATION
The above named research study/project has been reviewed in a ***delegated manner*** by the University of Manitoba (UM) Health Research Board (HREB) and was found to be acceptable on ethical grounds for research involving human participants. The study/project and documents listed above was granted final approval by the Chair or Acting Chair, UM HREB.

HREB ATTESTATION
The University of Manitoba (UM) Research Board (HREB) is organized and operates according to Health Canada/ICH Good Clinical Practices, Tri-Council Policy Statement 2, and the applicable laws and regulations of Manitoba. In respect to clinical trials, the HREB complies with the membership requirements for Research Ethics Boards defined in Division 5

- 1 -

umanitoba.ca/research

Appendix 2
Informed consent

Notice to treating office: This form is to be signed by your Invisalign® patients prior to treatment and kept for your records and should not be sent to Align Technology, Inc.

PATIENT'S INFORMED CONSENT AND AGREEMENT REGARDING INVISALIGN® ORTHODONTIC TREATMENT

Your doctor has recommended the Invisalign® system for your orthodontic treatment. Although orthodontic treatment can lead to a healthier and more attractive smile, you should also be aware that any orthodontic treatment (including orthodontic treatment with Invisalign aligners) has limitations and potential risks that you should consider before undergoing treatment.

DEVICE DESCRIPTION

Invisalign® aligners, developed by Align Technology, Inc. ("Align") consist of a series of clear plastic, removable appliances that move your teeth in small increments. Invisalign products combine your doctor's diagnosis and prescription with sophisticated computer graphics technology to develop a treatment plan which specifies the desired movements of your teeth during the course of your treatment. Upon approval of a treatment plan developed by your doctor, a series of customized Invisalign aligners is produced specifically for your treatment.

PROCEDURE

You may undergo a routine orthodontic pre-treatment examination including radiographs (x-rays) and photographs. Your doctor will take impressions of your teeth and send them along with a prescription to the Align laboratory. Align technicians will follow your doctor's prescription to create a ClinCheck® software model of your prescribed treatment. Upon approval of the ClinCheck treatment plan by your doctor, Align will produce and ship a series of customized aligners to your doctor. The total number of aligners will vary depending on the complexity of your malocclusion and the doctor's treatment plan. The aligners will be individually numbered and will be dispensed to you by your doctor with specific instructions for use. Unless otherwise instructed by your doctor, you should wear your aligners for approximately 20 to 22 hours per day, removing them only to eat, brush and floss. As directed by your doctor, you will switch to the next aligner in the series every two to three weeks. Treatment duration varies depending on the complexity of your doctor's prescription. Unless instructed otherwise, you should follow up with your doctor at a minimum of every 6 to 8 weeks. Some patients may require bonded aesthetic attachments and/or the use of elastics during treatment to facilitate specific orthodontic movements. Patients may require additional impressions and/or refinement aligners after the initial series of aligners.

BENEFITS

- Invisalign® aligners offer an esthetic alternative to conventional braces.
- Aligners are nearly invisible so many people won't realize you are in treatment.
- Treatment plans can be visualized through the ClinCheck® software.
- Aligners allow for normal brushing and flossing tasks that are generally impaired by conventional braces.
- Aligners do not have the metal wires or brackets associated with conventional braces.
- The wearing of aligners may improve oral hygiene habits during treatment.
- Invisalign patients may notice improved periodontal (gum) health during treatment.

RISKS AND INCONVENIENCES

Like other orthodontic treatments, the use of Invisalign® product(s) may involve some of the risks outlined below:

(i) Failure to wear the appliances for the required number of hours per day, not using the product as directed by your doctor, missing appointments, and erupting or atypically shaped teeth can lengthen the treatment time and affect the ability to achieve the desired results;

(ii) Dental tenderness may be experienced after switching to the next aligner in the series;

(iii) Gums, cheeks and lips may be scratched or irritated;

(iv) Teeth may shift position after treatment. Consistent wearing of retainers at the end of treatment should reduce this tendency;

(v) Tooth decay, periodontal disease, inflammation of the gums or permanent markings (e.g. decalcification) may occur if patients consume foods or beverages containing sugar, do not brush and floss their teeth properly before wearing the Invisalign products, or do not use proper oral hygiene and preventative maintenance;

(vi) The aligners may temporarily affect speech and may result in a lisp, although any speech impediment caused by the Invisalign products should disappear within one or two weeks;

(vii) Aligners may cause a temporary increase in salivation or mouth dryness and certain medications can heighten this effect;

(viii) Attachments may be bonded to one or more teeth during the course of treatment to facilitate tooth movement and/or appliance retention. These will be removed after treatment is completed;

(ix) Teeth may require interproximal recontouring or slenderizing in order to create space needed for dental alignment to occur;

(x) The bite may change throughout the course of treatment and may result in temporary patient discomfort.

(xi) At the end of orthodontic treatment, the bite may require adjustment ("occlusal adjustment").

(xii) Supplemental orthodontic treatment, including the use of bonded buttons, orthodontic elastics, auxiliary appliances/ dental devices (e.g. temporary anchorage devices, sectional fixed appliances), and/or restorative dental procedures may be needed for more complicated treatment plans where aligners alone may not be adequate to achieve the desired outcome.

(xiii) Teeth which have been overlapped for long periods of time may be missing the gingival tissue below the interproximal contact once the teeth are aligned, leading to the appearance of a "black triangle" space.

(xiv) Aligners are not effective in the movement of dental implants.

(xv) General medical conditions and use of medications can affect orthodontic treatment;

(xvi) Health of the bone and gums which support the teeth may be impaired or aggravated;

(xvii) Oral surgery may be necessary to correct crowding or severe jaw imbalances that are present prior to wearing the Invisalign product. If oral surgery is required, risks associated with anesthesia and proper healing must be taken into account prior to treatment;

(xviii) A tooth that has been previously traumatized, or significantly restored may be aggravated. In rare instances the useful life of the tooth may be reduced, the tooth may require additional dental treatment such as endodontic and/or additional restorative work and the tooth may be lost;

(xix) Existing dental restorations (e.g. crowns) may become dislodged and require re-cementation or in some instances, replacement;

(xx) Short clinical crowns can pose appliance retention issues and inhibit tooth movement;

(xxi) The length of the roots of the teeth may be shortened during orthodontic treatment and may become a threat to the useful life of teeth;

(xxii) Product breakage is more likely in patients with severe crowding and/or multiple missing teeth;

(xxiii) Orthodontic appliances or parts thereof may be accidentally swallowed or aspirated;

(xxiv) In rare instances, problems may also occur in the jaw joint, causing joint pain, headaches or ear problems;

(xxv) Allergic reactions may occur; and

(xxvi) Teeth that are not at least partially covered by the aligner may undergo supraeruption;

INFORMED CONSENT

I have been given adequate time to read and have read the preceding information describing orthodontic treatment with Invisalign aligners. I understand the benefits, risks, alternatives and inconveniences associated with treatment as well as the option of no treatment. I have been sufficiently informed and have had the opportunity to ask questions and discuss concerns about orthodontic treatment with Invisalign® products with my doctor from whom I intend to receive treatment. I understand that I should only use the Invisalign products after consultation and prescription from an Invisalign trained doctor, and I hereby consent to orthodontic treatment with Invisalign products that have been prescribed by my doctor.

Due to the fact that orthodontics is not an exact science, I acknowledge that my doctor and Align Technology, Inc. ("Align") have not and cannot make any guarantees or assurances concerning the outcome of my treatment. I understand that Align is not a provider of medical, dental or health care services and does not and cannot practice medicine, dentistry or give medical advice. No assurances or guarantees of any kind have been made to me by my doctor or Align, its representatives, successors, assigns, and agents concerning any specific outcome of my treatment.

I authorize my doctor to release my medical records, including, but not be limited to, radiographs (x-rays), reports, charts, medical history, photographs, findings, plaster models or impressions of teeth, prescriptions, diagnosis, medical testing, test results, billing, and other treatment records in my doctor's possession ("Medical Records") (i) to other licensed dentists or orthodontists and organizations employing licensed dentists and orthodontists and to Align, its representatives, employees, successors, assigns, and agents for the purposes of investigating and reviewing my medical history as it pertains to orthodontic treatment with product(s) from Align and (ii) for educational and research purposes.

I understand that use of my Medical Records may result in disclosure of my "individually identifiable health information" as defined by the Health Insurance Portability and Accountability Act ("HIPAA"). I hereby consent to the disclosure(s) as set forth above. I will not, nor shall anyone on my behalf seek legal, equitable or monetary damages or remedies for such disclosure. I acknowledge that use of my Medical Records is without compensation and that I will not nor shall anyone on my behalf have any right of approval, claim of compensation, or seek or obtain legal, equitable or monetary damages or remedies arising out of any use such that comply with the terms of this Consent.

A photostatic copy of this Consent shall be considered as effective and valid as an original. I have read, understand and agree to the terms set forth in this Consent as indicated by my signature below.

Signature

Print Name

Address

City, State, Zip

Date

Witness

Print Name

Signature of Parent/Guardian

If signatory is under 21, the parent of legal Guardian must also sign to signify agreement.

invisalign

Align Technology, Inc.
(888) 822-5446
WWW.INVISALIGN.COM

Appendix 3
Raw data

Gender	# U aligners	# L aligners	OB Group (0,	Pre-tx OB (mn	Target OB (m	Predicted cor	Post-tx OB (m	Actual correc	Intrusion U1	Intrusion L1	Extrusion U p	Extrusion L p	Proclination U	Proclination L	ODBA L4s	ODBA L5s	Conv Attache	Conv Attachn	Number of OI	Number of conv a
1	10	10	2	7.06	2.76	4.3	6.84	0.22	1	1	0	0	0	1	0	0	0	0	0	0
0	10	10	0	3.89	1.63	2.26	3.21	0.68	1	0	0	0	0	1	0	0	0	0	0	0
1	10	10	1	5.23	2.75	2.48	3.27	1.96	1	1	0	0	1	1	0	1	1	1	1	3
1	10	10	2	5.88	2.71	3.17	5.3	0.58	1	1	0	0	1	0	1	1	1	1	2	1
1	10	10	0	3.72	1.86	1.86	2.5	1.2	1	0	0	0	1	1	1	0	0	1	2	2
1	10	10	0	3.7	1.98	1.72	3	0.7	0	1	0	1	1	1	1	0	1	1	1	3
0	10	10	0	3.2	1.02	2.18	3.3	-0.1	1	1	1	1	1	0	1	0	1	1	1	3
1	10	10	2	4.7	1.85	2.85	3.3	1.4	1	1	0	0	0	1	1	0	1	1	1	3
1	10	10	2	3.8	3.85	-0.05	3.79	0.01	0	1	0	0	0	0	0	0	1	0	0	2
0	10	10	0	3.7	1.33	2.37	3.2	0.5	1	1	0	0	1	1	0	0	1	1	0	4
1	20	20	0	4.31	2.23	2.08	4.12	0.19	1	1	1	0	1	1	0	0	1	1	0	4
0	17	20	0	4.1	1.38	2.72	3.2	0.9	1	1	1	0	0	1	1	0	1	1	1	2
0	13	13	1	5.6	3.12	2.48	4.5	1.1	1	1	0	0	1	1	0	1	1	1	1	3
0	13	13	0	3.3	0.36	2.94	2.4	0.9	1	1	0	0	0	1	0	1	1	1	1	3
0	30	22	0	3.76	2.11	1.65	3.7	0.06	1	1	0	1	1	0	1	1	0	0	3	1
1	13	13	0	3.9	2.24	1.66	3.4	0.5	0	1	0	0	1	1	0	1	1	1	1	3
1	13	13	0	4.4	2.46	1.94	4.1	0.3	0	1	0	0	1	1	0	1	1	1	1	3
1	13	13	2	3.8	1.56	2.24	2.6	1.2	1	1	0	0	0	1	1	0	1	1	1	3
1	23	16	2	6.1	2.36	3.74	4.5	1.6	1	1	1	1	1	1	0	1	1	0	2	1
1	13	13	2	5.2	2.73	2.47	5.45	-0.25	1	1	0	0	1	1	1	0	1	1	1	3
1	13	13	1	4.9	1.95	2.95	3.9	1	1	1	0	0	1	1	1	1	1	1	2	2
1	13	13	1	5.68	2.13	3.55	3.4	2.28	1	0	0	0	1	1	0	0	1	1	0	4
0	13	13	0	4.2	2.39	1.81	2.4	1.8	1	1	0	1	1	1	1	0	0	1	2	2
0	25	14	1	5	0.25	4.75	3.2	1.8	1	1	1	0	1	0	1	0	0	1	2	2
0	10	10	0	3.4	1.71	1.69	2.6	0.8	0	1	0	0	0	1	0	0	1	1	0	2
1	10	10	0	4.2	1.29	2.91	3.3	0.9	1	1	1	0	1	1	1	1	1	1	2	2
0	19	19	2	4.9	2.18	2.72	3.4	1.5	1	1	0	0	1	0	0	1	1	0	2	2
1	15	21	0	3.7	0.54	3.16	2.5	1.2	1	1	1	1	1	1	1	0	1	0	1	1
1	10	10	1	4.61	0.88	3.73	4.49	0.12	1	1	0	0	1	0	0	1	1	0	2	2
1	13	13	2	7.9	4.7	3.2	6.8	1.1	1	1	0	0	1	0	1	0	0	0	2	0
0	19	31	1	4.6	0.42	4.18	2.7	1.9	1	1	0	1	1	1	0	1	1	0	2	1
0	13	13	2	4.9	3.57	1.33	4.7	0.2	0	1	0	0	1	1	1	0	0	1	2	1
1	13	13	1	4.9	2.65	2.25	3.6	1.3	1	1	0	0	1	1	1	1	1	0	2	1
1	31	31	2	3.8	0.74	3.06	2.7	1.1	1	1	0	0	1	1	1	0	1	0	1	1
1	13	13	0	3.3	1.27	2.03	0.7	2.6	1	0	1	1	1	1	0	0	1	1	0	3
1	13	13	0	3.5	1.65	1.85	3.3	0.2	1	1	1	1	1	1	1	1	0	0	3	1
1	44	23	2	7.2	-0.64	7.84	3.8	3.4	1	1	1	1	1	1	0	1	1	0	1	2
1	24	25	0	4	3	1	4.88	-0.88	1	1	0	0	1	0	1	0	1	1	1	3
1	13	13	0	3.9	2.63	1.27	3.1	0.8	0	1	0	0	1	0	0	0	1	1	0	3
0	13	13	0	4.5	1.96	2.54	2.1	2.4	1	0	1	1	0	1	0	0	0	0	0	0
1	13	13	2	5.9	2.73	3.17	4.5	1.4	1	1	0	0	1	1	0	1	1	1	1	3
0	25	25	0	3.4	0.71	2.69	2.7	0.7	1	1	1	0	1	0	0	1	1	0	2	2
1	13	13	1	4.6	1.7	2.9	2.9	1.7	1	1	1	0	1	1	1	0	1	1	1	2
0	29	28	2	6.09	1.38	4.71	4.55	1.54	1	1	0	1	1	1	1	1	1	1	2	2
1	13	13	1	4.9	1.61	3.29	3.7	1.2	1	1	0	0	1	1	1	0	1	1	1	3
0	22	22	1	4.5	3.41	1.09	3.8	0.7	1	1	1	1	1	1	0	0	1	1	0	4
0	13	13	0	3.7	2.62	1.08	4	-0.3	0	1	1	1	1	1	1	0	1	1	1	2
1	13	13	1	5.7	2.62	3.08	4.7	1	0	1	0	0	0	1	1	0	0	1	2	1
0	13	13	2	5.6	4	1.6	5	0.6	1	1	0	0	1	1	0	1	1	0	2	1
1	13	13	1	4.9	3.21	1.69	4	0.9	1	1	0	0	1	0	0	1	1	0	2	2
1	13	13	1	5	3.13	1.87	3.1	1.9	1	1	0	0	1	1	1	0	0	1	2	2
1	10	10	1	5.4	2.61	2.79	5.1	0.3	1	1	0	0	1	1	1	0	1	1	1	3
1	42	13	2	5.8	2.17	3.63	3.6	2.2	1	1	0	0	1	0	0	1	1	0	2	2
1	10	10	0	3.2	1	2.2	2.6	0.6	0	1	1	1	0	1	1	1	1	1	2	2
1	10	10	2	5.4	2.52	2.88	4.1	1.3	1	1	0	0	1	1	0	1	1	1	1	3
0	13	13	0	4.2	2.38	1.82	4.2	0	1	1	0	0	0	0	0	1	1	0	2	2
1	10	10	0	3.3	2.23	1.07	2.7	0.6	1	0	0	0	1	0	0	1	1	1	1	3
1	13	13	2	3.6	1.67	1.93	2.8	0.8	1	1	1	1	1	0	0	0	1	1	0	4
1	35	35	2	3.5	2.1	1.4	1.9	1.6	1	0	1	1	1	1	0	1	1	1	1	3
1	13	13	1	4.7	1.47	3.23	2.8	1.9	1	0	0	1	1	1	0	0	1	1	0	2

Appendix 4
Journal article and submission confirmation

Manuscript #	052119-353
Current Revision #	0
Submission Date	2019-05-16 19:58:18
Current Stage	Under Review
Title	Predictability of deep bite correction with Invisalign
Running Title	Deep bite correction with Invisalign
Manuscript Type	Original Article
Special Section	N/A
Corresponding Author	Catherine Fontaine-Sylvestre (University of Manitoba)
Contributing Authors	Robert Drummond , Luis Piedade , Reynaldo Todescan Jr
Financial Disclosure	I have no relevant financial interests in this manuscript.
Abstract	Objective: To investigate the predictability of deep bite correction with Invisalign. Materials and Methods: This retrospective study included 60 adult patients treated with Invisalign. Pre- and post-treatment digital models acquired from an iTero scan were obtained from a single orthodontic practitioner. The ClinCheck models of the final predicted outcome were obtained from Align Technology. Linear values of pre-treatment, prediction and post-treatment overbite were measured. A paired t-test ($P < 0.05$) was used to compare overbite changes planned by the ClinCheck with overbite corrections obtained clinically. A Spearman correlation coefficient was used to determine if larger overbite corrections predicted were correlated with poorer prediction accuracies. Variance ratio tests were used to determine if the severity of pre-treatment overbite, the number of active aligners, the bite opening mechanisms programmed in the ClinCheck, and the mandibular premolars attachments significantly affected the prediction accuracy. Results: There was a statistically significant difference between the ClinCheck prediction and the clinical final outcome regardless of the pre-treatment deep bite severity ($P < 0.05$). Requesting larger overbite correction in the ClinCheck did not significantly affect the accuracy ($\rho = 0.049$). Variance ratio tests were not significant ($P > 0.05$), except for cases programmed with mandibular incisor proclination ($P < 0.05$). Conclusion: The mean prediction accuracy of deep bite correction using Invisalign was 37.67 %. Programming mandibular incisor proclination seems to improve the prediction accuracy. Since the ClinCheck software significantly overestimates vertical changes, overcorrection of the finished occlusion is indicated.
Associate Editor	Not Assigned
Key Words	Invisalign, Predictability
Conflict of Interest	**I have no conflict of interest that I should disclose.**

Predictability of deep bite correction with Invisalign

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ABSTRACT

Objective: To investigate the predictability of deep bite correction with Invisalign.

Materials and Methods: This retrospective study included 60 adult patients treated with Invisalign. Pre- and post-treatment digital models acquired from an iTero scan were obtained from a single orthodontic practitioner. The ClinCheck models of the final predicted outcome were obtained from Align Technology. Linear values of pre-treatment, prediction and post-treatment overbite were measured. A paired t-test ($P < 0.05$) was used to compare overbite changes planned by the ClinCheck with overbite corrections obtained clinically. A Spearman correlation coefficient was used to determine if larger overbite corrections predicted were correlated with poorer prediction accuracies. Variance ratio tests were used to determine if the severity of pre-treatment overbite, the number of active aligners, the bite opening mechanisms programmed in the ClinCheck, and the mandibular premolars attachments significantly affected the prediction accuracy.

Results: There was a statistically significant difference between the ClinCheck prediction and the clinical final outcome regardless of the pre-treatment deep bite severity ($P < 0.05$). Requesting larger overbite correction in the ClinCheck did not significantly affect the accuracy ($\rho = 0.049$). Variance ratio tests were not significant ($P > 0.05$), except for cases programmed with mandibular incisor proclination ($P < 0.05$).

Conclusion: The mean prediction accuracy of deep bite correction using Invisalign was 37.67 %. Programming mandibular incisor proclination seems to improve the prediction accuracy. Since the ClinCheck software significantly overestimates vertical changes, overcorrection of the finished occlusion is indicated.

INTRODUCTION

The Invisalign system involves a series of customized removable clear plastic aligners that move teeth incrementally. The Invisalign trays are made of 0.75 mm thick polyurethane[1,2], and each of them can generate 0.25 to 0.33mm of tooth movement[3].The patient's compliance is a key factor for treatment success since the appliance has to be worn for a minimum of 22 hours a day to be effective[2]. Align Technology uses the stereolithographic technology and CAD/CAM laboratory techniques to fabricate their aligners[4,5].

Deep overbite is one of the most common malocclusions encountered in the general population. Overall, it is estimated that deep bite represents about 95.2% of vertical occlusal problems[5]. If left untreated, an excessive overbite has the potential to cause harmful effects on the dentition, function, esthetics, surrounding periodontium, and TMJ[6,7,8,9].

Deep bite correction can be very challenging with Invisalign[4,10]. Several practitioners anecdotally noticed that clear aligners tend to induce deepening of the bite[11]. Although some studies didn't support this idea[11,12], it was suggested that the layer of plastic covering the posterior teeth could act as a posterior bite-block, resulting in a reduction of the posterior vertical dimension and increase in overbite[13,14]. To assure better predictability of deep bite correction, Align Technology launched the G5 Deep Bite Protocol in February 2014[15]. The innovations include pressure areas, precision bite ramps and optimized deep bite attachments.

It has been estimated that 70% to 80% of patients treated with Invisalign may need mid-course corrections, refinements or conversion to fixed appliance to achieve optimal result[16]. Midcourse corrections and refinements lead to longer treatment time, increased chair time and increased material demand for the orthodontist[17]. Discrepancies between the predicted and final result can arise from the clinician's lack of experience with the technique, the software limitations or the lack of patient compliance[5].

As of today, nine studies have focused on the predictability of Invisalign[18]. In a prospective study conducted by Kravitz and colleagues, the mean accuracy of tooth movement in the anterior region with Invisalign was found to be 41%[16]. In their retrospective studies, Krieger and colleagues reported that vertical tooth movements were the most difficult to achieve with Invisalign[4,10]. Overbite was the least accurate parameter and showed the lowest prediction accuracy. Khosravi and colleagues concluded that Invisalign was successful at improving deep bite primarily through mandibular incisor proclination[11].

To date, no studies have focused yet on the predictability of deep bite correction using Invisalign. Since the demand for esthetic orthodontic treatment is increasing in adults and that correcting deep bite is an almost routine part of orthodontic treatment in this population, it is in the clinician's best interest to better understand the predictability of its correction with clear aligners. The present study analyzes the extent to which the final overbite predicted by the ClinCheck corresponds to the clinical overbite achieved at the end of treatment. A better understanding of deep bite correction accuracy could help the orthodontist to better anticipate the need and extent of overcorrection and auxiliary treatments, limit the number of refinements, midcourse corrections, and reduce overall treatment time.

MATERIALS AND METHODS

This retrospective study received ethics approval from the Bannatyne Campus Research Ethics Boards at the University of Manitoba on May 24th 2017.

The study sample consisted of 60 adult patients who had undergone dual-arch orthodontic treatment exclusively with Invisalign. The sample was obtained from a single orthodontic specialist experienced with the Invisalign technique. The collected records included (1) patient age at the start of treatment, (2) patient gender, (3) number of active aligners used, (4) number of optimized deep bite attachments on the lower premolars, (5) number of attachments of any type on the lower premolars (6) ClinCheck "Tooth Movements Table" providing information about the amount of anterior intrusion, posterior extrusion and incisor proclination planned by the software, and (7) the three .stl files required.

Records needed for this study were acquired randomly for patients meeting the inclusion and exclusion criteria. Adult patients treated exclusively with Invisalign after February 2014 presenting a pre-treatment overbite greater than 3 mm, crowding of less than 6 mm with good compliance were included in this study. Those requiring auxiliary treatment, anteroposterior change (inter-arch elastics), extensive space closure, extractions, surgery, and midcourse correction were excluded. The study sample included 40 females and 20 males with a mean age of 33 years, ranging from 18 to 55 years. This study only emphasized on the first series of aligners and no refinements were included. The patients were instructed to wear each aligner 22 hours a day, every day for 2 weeks. Based on the magnitude of pre-treatment overbite, the study sample was stratified into groups of mild (3 to 4.5mm), moderate (4.6 to 6mm), and severe overbite (6mm or impinging). Patients received either Invisalign Express 10 (10 aligners), Assist (13 aligners) or Full (more than 13 aligners) treatment.

Pre- and post-treatment digital models (.stl files), generated from an iTero digital scan, were obtained for every participant. The models predicting the final outcome, which corresponded to the last worn aligner by the patient on ClinCheck, were requested directly from Align Technology. The digital .stl files from the iTero and the ClinCheck were uploaded in OrthoAnalyzer (3Shape®, Copenhagen, Denmark) software. Linear values of overbite were measured by the primary investigator using the digital caliper provided by the software. The software offers a suggested 2D cross-section plane that can be zoomed in. In this study, overbite was defined as the greatest vertical distance (mm) between the incisal edge of the maxillary incisor and the incisal edge of the mandibular incisor perpendicular to the occlusal plane. For each subject, the overbite was consistently measured in hundredth of millimeters at 3 different timepoints: (1) Initial overbite on pretreatment digital models, (2) Target overbite on the predicted final digital models (ClinCheck), and (3) Final overbite on the posttreatment digital models (refinement scan). The same maxillary and mandibular incisor landmarks of the corresponding pre-treatment, post-treatment and prediction models were used for each patient (Figures 1 and 2).

To test the intra-examiner reliability, 20% of the sample size was randomly chosen to be measured again 2 weeks after the first assessment (Houston 1982). The intra-examiner reliability was assessed with an intraclass correlation coefficient (ICC).

The data of this study was analyzed using the SAS System® version 9.4 software (Cary, NC, USA). A paired t-test was used to compare the predicted overbite measurement and the overbite measurement achieved clinically at the end of the first series of aligners. The level of significance was set at 5%. A percentage of accuracy of tooth movement was calculated to quantify the amount of overbite correction obtained clinically relative to the amount of change planned by ClinCheck. The calculation of prediction accuracy was: 100 x Actual correction / Predicted correction. A Spearman correlation coefficient was used to determine if larger overbite corrections predicted were correlated with poorer prediction accuracies. One-way analysis of variance (ANOVA) tests were used to determine if the extent of pre-treatment overbite, the number of aligners, a specific type and number of programmed bite opening mechanics, and the number and type of mandibular premolar attachments were correlated with different prediction accuracies.

RESULTS

The ICC test showed almost perfect agreement with regards to intra-rater reliability, with a score of 0.99.

Table 1 shows the distribution of the different treatment modalities among the three deep bite groups. Forty-one percent of the sample was in the mild overbite group. Near half the sample was treated with 13 aligners (Invisalign Assist). In the severe overbite group, 37% underwent Invisalign Full treatment. The most programmed bite opening mechanism was lower incisor intrusion. More than half of the sample (62%) had 3 or 4 bite opening mechanisms programmed in the ClinCheck. Sixty-three percent of the total sample had attachments on all four mandibular premolars. Twenty-two percent of the sample had no optimized deep bite attachments included in their setup. None of the subjects had 4 optimized deep bite attachments.

As listed in Table 2, the mean pre-treatment overbite value of the studied sample was 4.60 mm (SD = 1.05). A mean 2.55 mm (SD = 1.17) overbite correction was predicted by ClinCheck. The mean post-treatment overbite obtained clinically was 3.60 mm (SD = 1.09). However, an overbite correction of 1.00 mm (SD = 0.79) was achieved overall clinically. The mean prediction accuracy of deep overbite correction for the total sample was 37.67% (SD = 34.42).

Results from Table 3 reveal that for every overbite group, there was a statistically significant difference between the predicted overbite as per ClinCheck and the overbite obtained clinically (overall $P < 0.001$).

As listed in Table 4, the overall Spearman correlation coefficient ($\rho = 0.049$) shows that there was no relationship between the magnitude of predicted overbite correction and the prediction accuracy.

Figure 3 shows there was a statistically significant difference ($P = 0.0102$) between the amount of predicted overbite correction within the mild, moderate and severe overbite groups. However, no statistically significant differences in prediction accuracy were found between the three overbite groups ($P = 0.2769$).

As displayed on Figure 4, no statistically significant difference in accuracy was found between subjects treated with Invisalign Express 10, Invisalign Assist and Invisalign Full treatment ($P = 0.3538$).

As listed in Table 5, statistically significant differences were found in subjects with lower incisor intrusion ($P = 0.0004$) and lower incisor proclination ($P = 0.0248$) programmed in ClinCheck. No statistically significant differences were found in the other mechanisms ($P > 0.05$).

Figure 5 shows that the accuracy was improved with a greater number of bite opening mechanisms, but this was not statistically significant ($P = 0.5339$).

Figures 6 and 7 show that there were no statistically significant differences in accuracy with an increased number of attachments ($P = 0.9276$) and optimized deep bite attachments ($P = 0.3385$).

DISCUSSION

The main purpose of this study was to investigate the predictability of deep bite correction using Invisalign. To date, there is a limited number of studies comparing the ClinCheck prediction and the treatment outcome in the orthodontic literature [4,10,16,18,19,20,21]. A few assessed the overbite parameter[4,11,16,20], but none of them have specifically focused on the accuracy of deep bite correction.

Our results showed large discrepancies between the predicted and clinical overbite correction. Overall, 37.67% of the planned vertical changes were clinically expressed throughout the first series of aligners. The ClinCheck software was not able to accurately predict the correction that would occur. These results correlate with the previous literature stating that the ClinCheck tends to overestimate the quality of the finished occlusion[16,19,20].

Kravitz and colleagues[16] reported an overall mean accuracy of tooth movement of 41%, which is similar to our results. They also highlighted that intrusion was more predictable than extrusion in the anterior region. The lowest intrusion accuracy was achieved by the maxillary lateral incisors. Our results also correlate with Krieger's studies[4,10] , who suggested that the overbite parameter was the least predictable to correct and that the vertical dimension was the most difficult to control with clear aligners. They also reported that additional refinements and overcorrection may be necessary. The prediction accuracy found in our study for overbite correction (37.7%) was higher than Krieger's (14.3%). This could be partly explained by the fact that our study was conducted after the introduction of the G5 deep bite protocol in 2014.

In this study, the prediction accuracy was significantly improved when lower incisor proclination was programmed in the ClinCheck software in contrast to when it was not ($P = 0.0248$) (Table 5). Mandibular incisor proclination was also previously reported to be the primary bite opening mechanism using Invisalign[11]. Relative intrusion occurring concomitantly with proclination is considered as a predictable movement with Invisalign[22]. This suggests that deep bite cases requiring labial movement of the lower incisors might be more predictable to correct.

In this study, the accuracy was found to be unrelated to other planned treatment modalities. Our results indicate that the magnitude of anticipated correction, the number of aligners, the bite opening mechanisms and attachments do not significantly affect tracking. However, the lack of association between the prediction accuracy and the factors mentioned should be interpreted with caution. A large variability was found in the general prediction accuracy (mean SD ± 34.42). The presence of outliers might have also affected the results. Additionally, the different groups within each treatment category were not evenly distributed in number. Also, most of the sample was treated with less than 13 aligners. Moreover, the more severe cases had longer treatment time and higher number of proper retentive attachments in general. Also, most subjects (75%) had either 1 or 2 optimized deep bite attachments and 22% had no optimized deep bite attachments. The optimized hierarchical attachment placement was likely followed and not substituted. Although the G5 protocol is specifically designed for deep bite for deep bite cases, it relies on the clinician to virtually substitute for optimized deep bite attachments providing adequate vertical control.

Our findings indicate that deep bite prediction accuracy seems to be low with Invisalign. This study highlights important limitations of the Invisalign software; therefore, specific strategies should be employed to overcome them. As suggested by several investigators[2,3,4,10,21], the addition of auxiliaries may help maximizing overbite reduction. Furthermore, in order to achieve the anticipated result, it has been recommended to build overcorrection in the finished occlusion[4,10,16,19,22,23]. Adequate incisor torque is mandatory in obtaining proper overbite correction[9,22]. Since torque control can be more challenging in cases requiring space closure, the clinician might want to be prudent when opening the bite in such situation. The power ridge feature may help achieving proper palatal root torque. Knowing the limitations of the Invisalign system may help reducing the number of midcourse corrections and refinements needed. However, when correcting severe deep bite, the clinician should expect a longer treatment time and additional mechanics to achieve an excellent clinical result.

This study should be interpreted within its limitations. Our findings cannot be generalized and may not reflect a typical course of deep bite treatment. First, this study only focused on mild to moderate crowding cases exclusively requiring correction in the vertical plane; subsequently, cases involving multidimensional correction might have a different predictability. Moreover, the emphasis was made on the first round of aligners and no refinements were included. Furthermore, the vast majority of the sample had a minimal number of optimized deep bite attachments. Additionally, since a wide variety of mechanics and attachments can be employed for overbite correction, predictability may differ from one clinician to another.

Despite the limitations, this study advances the scientific knowledge of deep bite correction using Invisalign.

Our findings highlight what can be accomplished with aligners and, therefore, may aid in better planning treatment for these cases. This study was designed to assess the predictability, not the efficacy of deep bite correction. Tooth movements that occurred clinically were not evaluated.

CONCLUSIONS

- The mean prediction accuracy of deep bite correction using Invisalign is 37.7%.
- The ClinCheck software significantly overestimates overbite improvement.
- Requesting a larger overbite correction does not seem to lead to poorer tracking.
- Programming mandibular incisor proclination in the ClinCheck seems to improve the prediction accuracy. Thus, deep bite cases with retroclined lower incisors and crowding resolved by increase in arch perimeter may be more predictable to correct.
- Overcorrection, additional retentive attachments for vertical anchorage and auxiliary methods may help reduce the rate of midcourse corrections and refinements.

REFERENCES

1. Lagravere MO, Flores-Mir C. The treatment effects of Invisalign orthodontic aligners: a systematic review. *J Am Dent Assoc*. 2005;136:1724–1729.
2. Ali SA, Miethke HR. Invisalign, an innovative invisible orthodontic appliance to correct malocclusions: advantages and limitations. *Dent Update.* 2012;39:254–256, 258–260.
3. Malik OH, McMullin A, Waring DT. Invisible orthodontics part 1: Invisalign. *Dent Update*. 2013;40:203–204, 207–210, 213–215.
4. Krieger E, Seiferth J, Saric I, Jung BA, Wehrbein H. Accuracy of Invisalign® treatments in the anterior tooth region. First results. *J Orofac Orthop*. 2011;72(2):141–149.
5. Proffit WR, Fields HW, Sarver DM. *Contemporary Orthodontics*. 5th ed. St. Louis, MO: Mosby; 2013
6. Van't Spijker A, Kreulen CM et al. Occlusal wear and occlusal condition in a convenience sample of young adults. *Journal of Dentistry*. 2015;43:72–77.
7. Riolo ML, Brandt D, TenHave TR. Associations between occlusal characteristics and signs and symptoms of TMJ dysfunction in children and young adults. *Am J Orthod Dentofacial Orthop*. 1987;92:467–477.
8. Amarnath BC, Prashanth CS, Dharma RM. Clinical overview of deep bite management. *Int J Contemporary Dent.* 2010;1:30-3.
9. Cobourne M, DiBiase A. *Handbook of Orthodontics.* 2nd ed. Elsevier; 2016.
10. Krieger E, Seiferth J, Marinello I, et al. Invisalign® treatment in the anterior region: were the predicted tooth movements achieved? *J Orofac Orthop*. 2012;73:365–376.
11. Khosravi R, Cohanim B, Hujoel P, et al. Management of overbite with the Invisalign appliance. *Am J Orthod Dentofacial Orthop*. 2017;151:691-699.
12. Vlaskalic V, Boyd R. Orthodontic treatment of a mildly crowded malocclusion using the Invisalign System. *Aust Orthod J.* 2001;17:41–46.
13. Kuster R, Ingervall B. The effect of treatment of skeletal open bite with two types of bite-blocks. *Eur J Orthod*. 1992;14:489-99.
14. Boyd RL, Miller RJ, Vlaskalic V. The Invisalign system in adult orthodontics: mild crowding and space closure cases. *J Clin Orthod.* 2000;34:203-12.
15. Align Technology, Inc. Invisalign G5 Innovations for Deep Bite. https://www.aligntech.com/documents/Invisalign_G5_Brochure.pdf. Accessed August 12, 2018.
16. 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;135:27-35.
17. Duncan LO, Piedade L, Lekic M, Cunha RS, Wiltshire WA. Changes in mandibular incisor position and arch form resulting from Invisalign correction of the crowded dentition treated nonextraction. *Angle Orthod.* 2016;86:577-583.

18. Papadimitriou A, Mousoulea S, Gkantidis N, Kloukos D. Clinical effectiveness of Invisalign® orthodontic treatment: a systematic review. *Prog Orthod.* 2018;19:37.
19. Houle JP, Piedade L, Todescan R Jr, Pinheiro FH. The predictability of transverse changes with Invisalign. *Angle Orthod*. 2017;87:19–24.
20. Buschang PH, Ross M, Shaw SG, Crosby D, Campbell PM. Predicted and actual end-of-treatment occlusion produced with aligner therapy. *Angle Orthod*. 2015;85:723–7.
21. 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.
22. Tai S. *Clear Aligner Technique*. 1st ed. Hanover Park, IL: Quintessence Pub Co; 2018.
23. Kravitz ND, Kusnoto B, Agran B, Viana G. Influence of attachments and interproximal reduction on the accuracy of canine rotation with Invisalign®. A prospective clinical study. *Angle Orthod*. 2008;78:682–7.

FIGURE LEGENDS

Figure 1. Maxillary incisor landmark. (Left) Pre-treatment landmark. (Middle) Target landmark. (Right) Post-treatment landmark.

Figure 2. Mandibular incisor landmark. (Left) Pre-treatment landmark. (Middle) Target landmark. (Right) Post-treatment landmark.

Figure 3. Distribution of prediction accuracy (%) as a function of pre-treatment overbite.

Figure 4. Distribution of prediction accuracy (%) as a function of number of aligners.

Figure 5. Distribution of prediction accuracy (%) as a function of the number of bite opening mechanisms programmed in ClinCheck.

Figure 6. Distribution of prediction accuracy (%) as a function of number of mandibular premolar attachments.

Figure 7. Distribution accuracy (%) as a function of the number of optimized deep bite attachments.