Mandibular Projection in Class II Division 2 Subjects Following Maxillary Incisor Proclination, Overbite Correction and Dentoalveolar Expansion Using Clear Aligners

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A Thesis submitted to
The Faculty of Graduate Studies of
The University of Manitoba

In partial fulfilment of the requirements for the degree of
MASTER OF SCIENCE
(Orthodontics)

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Abstract

Introduction: The purpose of this study was to evaluate the dental and skeletal changes of maxillary incisor proclination, overbite correction and maxillary dentoalveolar expansion with no planned Class II mechanics on the magnitude of mandibular growth and/or projection in growing patients with Class II Division 2 using Invisalign® clear aligners (Align technology, Santa Clara, CA, USA).

Methods: Pre (T1) and Post-treatment (T2) CBCT-generated lateral and posterioanterior cephalograms of 32 patients (12.86 ± 2.01 years), 16 in both the treatment and untreated control group, all with Class II skeletal and Class II Division 2 dental relationship, were obtained retrospectively to evaluate possible treatment-related changes (T2-T1). Proclination and protrusion of the maxillary incisors, as well as maxillary dentoalveolar expansion with no other Class II mechanics were carried out. A customized cephalometric analysis was performed and unpaired *t*-tests were used to compare the linear and angular measurements to determine if significant skeletal Class II correction was achieved in the treatment group ($p<0.05$).

Results: The maxillary incisors were proclined and protruded (U1-SN: 12.05°, $p<0.0001$; U1-NA: 11.27°, $p<0.0001$ and 3.72 mm, $p<0.0001$) in the treatment group as they were initially retroclined and retruded. In comparison to the control group, the treatment group showed an increase in intermolar width (2.64 mm, $p<0.0001$) while the overbite reduced significantly in the treatment group (-2.81 mm, $p<0.0001$). An increase in skeletal mandibular growth and forward projection was observed in the treatment group when compared to the control group: SNB (1.52°, $p<0.0001$), Ar-Go (0.42 mm, $p=0.01$), Go-Pog (1.14 mm, $p<0.0001$), and Co-Pog (1.96 mm, $p=0.04$). The skeletal relationship parameters showed improvements in the treatment group toward Class I compared to the control group as evidenced by a mean difference decrease in ANB (-1.92°, $p<0.0001$) and Wits (-2.92 mm, $p<0.0001$).

Conclusion: Proclination of the maxillary incisors, correction of the deep overbite and maxillary dentoalveolar expansion using clear aligners in growing patients with Class II Division 2 malocclusions were effective in improving the dental and skeletal Class II relationship.

Acknowledgements

I would like to express my sincerest appreciation to my committee members:

- Dr. Tarek El-Bialy, thank you for giving me the opportunity to do this project. I am truly grateful that I had the chance to work with such an experience and inspiring clinician.
- Dr. William Wiltshire, thank you for giving me the honor of being able to call myself and orthodontist. I feel very fortunate to be chosen to be a part of this amazing program. You are truly the best program director anyone can ask for.
- Dr. Fabio Pinheiro, thank you for your continued support and for spending hours to review every small detail and guiding me through this project.

A big thanks to my lovely family for your continued love and support. I would not be where I am today without you!

- Sima and Abbas, you have always taught me to push my limits and follow my dreams, just like you both did. Sima, sorry you had to spend more time in Winnipeg that I did over the past three years!
- Baharan, thank you for all the encouragement when I was feeling down. I know you always have my back, no matter what!

Table of Contents

List of Figures

List of Tables

Chapter One

Introduction

The concept of using consecutive clear thermoplastic appliances to align teeth was first introduced by Kesling in 1946. Align Technology (Santa Clara, CA, USA) in 1998 developed this idea into a feasible treatment modality with the introduction of computer-aided design and computer-aided manufacturing (CAD/CAM) technology. CAD/CAM stereolithographic technology has been used to forecast treatment outcomes and fabricate a series of custom-made aligners using a single silicone or digital impressions. In the past years, there has been a growing demand for esthetic treatment among both adolescents and adults. (Walton 2010, Feu 2012) According to the manufacturer, Invisalign® can effectively perform major tooth movements, such as root movements of maxillary central incisors up to 4 mm. Align Technology reports that roughly 20–30% of Invisalign patients require mid-course correction or post-alignment finishing in order to achieve the results prescribed on the setup. (Align Technology, Inc. The Invisalign reference guide. Santa Clara, Calif; 2002) Few studies have been published that assess the efficacy or the outcome of the orthodontic treatment with Invisalign clear aligners. If the accuracy percentage of a specific tooth movement is known, overcorrecting it by the appropriate amount or staging the movement in smaller increments may result in the desired outcome. (Charalampkis 2018)

Class II malocclusion is known as when the lower teeth bite further behind the upper teeth than ideal. A Class II Division 2 Malocclusion is characterized by maxillary anterior teeth that are retroclined and an increased overbite, which can cause oral problems such as attrition of the lower incisors as well as trauma to the palatal soft tissue, and may affect the appearance. Angle's definition of Class II Division 2 Malocclusion in a textbook published in 1907 is still descriptive: "Class II Division 2 is characterized specifically by distal occlusion of the teeth in both lateral halves of the lower dental arch, indicated by the mesiodistal relations of the first permanent molars, but with retrusion instead of protrusion of the upper incisors."

Class II Division 2 Malocclusion can be corrected by the use of orthodontic appliances that move the maxillary anterior teeth forward and in response, change the growth of the upper and/or lower jaws (Millett 2018). Each patient responds individually, but it would be reasonable to expect considerably more forward movement of the mandible, after bite opening, in patients with more horizontal growth directions after maxillary incisor proclination and bite opening are accomplished. It is possible to unlock dental malocclusions in a functional or mechanical manner, or in a combination of these two. Both functional and mechanical unlocking are often overlooked in orthodontic diagnosis and treatment planning. Mechanical unlocking, in contrast to functional unlocking, removes occlusal interferences that could interfere with the development and function of the entire stomatognathic system. Mechanical unlocking requires that the maxillary incisors be correctly positioned and the maxillary arch be expanded. (Gugino 1998) It is an important principle of the Bioprogressive philosophy that the overbite should be corrected before the overjet. (Ricketts 1998) During incisor unlocking, the incisors are often advanced, aligned, torqued, and intruded as part of the vertical unlocking process. This concept is based on the belief that a deep overbite can restrict mandibular development in a Class II malocclusion due to skeletal retrognathic mandible. This concept is yet to be proven by scientific research.

Skieller and Bjork in 1984 conducted a study to estimate the possibility of predicting the direction and the amount of growth and rotation of the mandible based on morphologic criteria observed on a single profile radiograph at pubertal age. A forward rotation seemed to be a general feature of the facial development. The mean forward rotation of the mandible described in Bjork's study was -6 degrees. For the maxilla, the corresponding means for forward rotation was -2.5 to -2.8 degrees. Although strongly correlated, the rotations were more than twice as great for the mandible as for the maxilla. (Skiller 1984)

The greater mean forward movement of Point B during treatment in the mesofacial and brachyfacial subjects than in the untreated controls seems to be consistent with the reports of previous authors who suggested that, in growing patients with a deep overbite, vertical overlap of the maxillary and mandibular incisors might cause considerable inhibition to forward movement of the dentoalveolus, and once the deep overbite has been reduced, the dentoalveolus might be carried farther forward with growth of the underlying skeletal structures than without treatment. Such greater forward movements of Point B during treatment in these relatively forward-growing deepbite patients would seem to provide a further quantitative description of the controversial term unlocking, which appears from time to time in the literature and would seem to apply to any device used at such a developmental stage to remove the potentially inhibitive effects of a deep incisal overbite, accompanied by upright or even retroclined maxillary incisors. (Woods 2008)

Cone beam computed tomography (CBCT) seems to be crucial in diagnosis and treatment planning of Class II cases, specifically in terms of detecting if there is any distal mandibular shift. When comparing TMJ tomograms with and without clear aligners, it was observed that when the patient wore clear aligners the condyles moved downward and forward as if the patient was wearing a functional appliance. (El-Bialy 2016) This could be an assumption that clear aligners could be working as a full time functional appliance, assuming the patient wears clear aligners all the time. Clear aligners disengage the occlusion allowing the mandible to be projected forward into central relationship if it is positioned backward in the temporo-mandibular fossa, especially in patients with a deep overbite before starting treatment. In deep overbite cases with severely retroclined maxillary incisors the clinician should apply labial crown torque even before retraction of the maxillary incisors. This is of particular importance in cases where patients initially present with underdeveloped or distally positioned mandibles.

Chapter Two

Literature Review

"Malocclusion is the perversion of the normal in the growth and development of the denture. Every case has a simple beginning in its variation from the normal. The same forces that contribute to maintaining the teeth in their normal positions and harmony in the sizes of the arches, are equally powerful in maintaining harmony in the sizes and relations of the arches and malocclusion of the teeth when once established." Edward H. Angle

Orthodontics is a branch of dentistry concerned with the growth of the jaws and development of the teeth. Orthodontic treatment is needed when the jaws and/or the teeth are not in a proper relation. Malocclusions can be due to any combination of problems in the positioning of the teeth, jaws or soft tissue. (Millett 2018). Understanding the skeletal and dental characteristics of each type of malocclusion is essential in order to determine treatment goals, formulate the appropriate treatment plan, treatment mechanics and to achieve successful long-lasting treatment outcomes. Profound knowledge of the etiology of malocclusions is essential for prevention as well as treatment of orthodontic problems. Understanding craniofacial growth and development is also essential in order to make a proper diagnosis and treatment plan for each individual, especially children and adolescents. During adolescence, the cooperation is usually better than preadolescence, and due to the active growth during this period, the skeletal changes and treatment effects are enhanced, leading to shorter treatment times. This knowledge can help the orthodontist to predict the magnitude and the direction of the facial growth in order to choose the best appliance to achieve the most favorable and stable results.

2.1. Definition of Class II Division 2 Malocclusions

Angle was the first clinician to correlate between sagittal occlusal relationship and the facial aesthetics. Angle suggested that anteroposterior disharmonies between the maxilla and the mandible can greatly affect the facial aesthetics. In 1899, he proposed a classification for sagittal occlusal relationship, based on the anteroposterior relationship of the maxillary and the mandibular canines and first permanent molars. Based on this classification, sagittal occlusal relationship is divided into Class I, II and III. In the 7^{th} edition of the "Treatment of malocclusion of the teeth and fractures of the maxillae" he divided Class II malocclusion into two Divisions. In Class II Division 1, the maxillary incisors are proclined and protruded, and there is an increased overjet. Angle's definition of Class II Division 2 Malocclusion is still descriptive: "Class II Division 2 is characterized specifically by distal occlusion of the teeth in both lateral halves of the lower dental arch, indicated by the mesiodistal relations of the first permanent molars, but with retrusion instead of protrusion of the upper incisors." Angle further stated, "The result of distal occlusion and recession of the jaw and chin greatly marks the facial line, thereby placing emphasis on the facial deformity caused by the distal position of the mandible and lack of vertical growth below the nose". Because of the lack of radiographs at that time, his definition was solely a dentoalveolar classification. This definition had been constantly modified (Moyers 1988, Graber 2017, Proffit 2019) and eventually simplified: in Class II division 1 maxillary incisors are proclined, and in Class II Division 2 they are retroclined.

Subjects with Class II Division 2 Malocclusion, commonly report aesthetic (Kiekens 2006) and social concerns (Seehra 2011), trauma to the palatal soft tissue behind the maxillary incisors (Millett 2018) and obstructive sleep apnea in very severe cases. (Flores-Mir 2013) They also have a higher risk of impacted maxillary canines due to their abnormal palatal eruption pattern. (Mossey 1999, Basdra 2000, Al-Nimri 2005)

2.2. Prevalence of Class II Division 2 Malocclusions

Prevalence of Class II malocclusion has been reported to range from 16% to 22.5% among different ethnic groups. (Kang 2021) This malocclusion is the most common disharmony in Caucasians and presents in almost one third of the population in the United States. (Al-Jewair 2020)

Class II Division I is the most common form of malocclusion, mainly caused by a retrusive mandible (McNamara 1981, Moyers 1988, Proffit 2019). Class II Division 2 accounts for 20% of all Class II malocclusions. The incidence of Class II Division 2 Malocclusion is reported to be about 10% within the United Kingdom population (Houston 1996), but a prevalence of 18% has been reported in the Croatian population (Legovic 1999). Recent Swedish and Turkish studies have reported a lower prevalence, from 1.8% to 4.7% (Bilgic 2015, Dimberg 2015).

2.3. Psychosocial Impact of Malocclusions

Even though malocclusion is not considered to be a disease per se, the benefits of orthodontic treatment have been proven to impact both the mental and the social well-being of individuals. Facial aesthetics plays a significant role in inter-human relationships. Facial attractiveness can have a positive effect in all aspects of interpersonal interactions. (Matoula 2006). More attractive children seem to have a more positive first impression, are more sociable, show higher intelligence and emotional quotient (IQ and EQ) and are more likely to receive positive treatment. (Shaw 1980, Hunt 2005).

In recent years, there has been a greater focus on the potential impact of malocclusion on quality of life (QOL) and oral health-relation quality of life (OHRQOL). Teeth were found to be the first target of bullying followed by strength and weight. Dissatisfaction with dental appearance has a strong predictive effort on self-esteem. It has been reported that patients who receive orthodontic treatment show greater self-esteem compared with those who did not receive any orthodontic treatment. (Badran 2010, Jung 2010).

2.4. Etiology of Class II Division 2 Malocclusions

This type of malocclusion has a strong genetic predisposition. Studies on twins and triplets suggested that genetics is the most important etiologic factor in development of Class II Division 2 Malocclusion. 100% of 20 monozygotic twin pairs were concordant for this malocclusion, compared with only 10.7% of 28 dizygotic twin pairs. (Markovic 1992, Peck 1998, Cakan 2012). With that said, heredity is not the sole factor accounting for the etiology of this malocclusion. Studies suggest that Class II Division 2 Malocclusion is of multifactorial etiology. (Hartsfield 2012).

Class II malocclusion can have any combination of skeletal and/or dental components. When formulating the best treatment options, whether orthodontic, orthopedic, surgical or a combination of these modalities, identifying and understanding the main etiology in order to come up with the most accurate diagnosis is essential. In most instances, the malocclusion is the result of a combination of different factors, including dental, skeletal and environmental. (Sharma 2013).

First skeletal signs of Class II malocclusion reported to be a narrow maxilla and reduced sagittal mandibular growth, whereas the other skeletal features may develop as secondary adaptation. (Varrela 1993). Both skeletal and dental clinical signs of Class II malocclusion are evident in the primary dentition and persist into the mixed dentition. It has been reported that early characteristics of Class II malocclusion are either maintained or become more prominent in the transition from primary to mixed dentition. (Baccetti 1997) Early identification of patients with a Class II malocclusion is helpful in order to start early intervention as soon as this trait is diagnosed.

2.5. Cephalometric Characteristics of Class II Division 2 Malocclusions

The first step in describing the anteroposterior relationship of the jaws was the introduction of Point A and Point B in 1948 by Downs. A few years later in 1952, Riedel introduced the ANB angle, which has become one of the most commonly used measurements in orthodontics. In 1975, Jacobson introduced the Wits appraisal based on the functional occlusal plane in order to eliminate the potential problems that can arise from using cranial landmarks that are farther away from the maxilla and the mandible, and closer to the dental bases.

There is conflicting evidence on the contribution of the maxilla and the mandible in the etiology of Class II malocclusion. The position of the maxilla has been reported to be normal in the majority of Class II subjects. In subjects where the position of the maxilla is abnormal, the maxilla tends to be retrusive more frequently than protrusive. (McNamara 1996) The maxilla can be too far forward (only seen in about 10 to 15% of Class II subjects) or more commonly (about 60%), the mandible is too far back. (McNamara 1981, 2001) Based on these findings, it has been suggested that altering the amount and direction of the mandibular growth can be more appropriate than restricting the maxillary growth and development.

Class II Division 2 Malocclusion is usually shown with an orthognathic maxilla, a relatively short and retrognathic mandible but a relatively prominent chin, and a hypodivergent facial pattern. The other most common skeletal characteristics seen in this type of malocclusion include flat mandibular plane angle, increased posterior facial height, decreased lower face heigh due to counter clockwise rotation of the mandible and acute gonial angle. The reduced anterior face height leads to counter clockwise autorotation of the mandible, which helps with camouflaging the sagittal underdevelopment of the mandible. (McNamara 1984)

In the literature, the mandible has been described to be relatively short and retrognathic in Class II skeletal relationship compared with Class I. However, the mandible has also been described to be more prognathic and longer by about 3 mm on average in Class II Division 2 subjects compared with Class II Division 1. (Kirschneck 2013) Some studies suggested that SNB angle is normal in this group, which can be interpreted as the mandible to be in a normal position. (Al-Khateeb 2009) However, this finding is in disagreement with some other studies that suggested that the mandible is retrognathic in Class II Division 2 subjects. (Renfroe 1948, Pancherz 1997, Karlsen 1999)

Studies comparing Class II Division 1 and 2 suggested that ANB angle in Class II Division 2 is significantly larger compared with Class I, but significantly smaller than Class II Division 1. Y-axis is significantly smaller while facial angle is significantly larger in Class II division 2 compared with Class II Division 1, which indicates the mandible to be more prognathic in these subjects. (Al-Khateeb 2009)

In several studies, the chin is reported to be more prominent in Class II Division 2 subjects compared with Class II Division 1. (Pancherz 1997, Isik 2006) This can be attributed to the more prognathic mandible and normal development of the body of the mandible and the symphysial area which are not restrained by retroclined maxillary incisors, while the development of the alveolar process is reported to be inhibited. (Arvystas 1990, Peck 1998) The chin in Class II Division 2 subjects has been reported to be overdeveloped, while the body of the mandible is underdeveloped with a retroclined symphysis. (Karlsen 1994) The pronounced chin can have a compensating effect on the retruded mandible to partially offset some of the disharmony of the facial profile. Many of subjects with Class II Division 2 Malocclusion have well-developed or hypertrophic mentalis muscles, which leads to a prominent chin from the standpoint of both skeletal (Pogonion) and soft tissue dimensions (Pogonion'). Furthermore, lack of proportionate vertical dimension in relation to the horizontal growth leads to overclosure of the mandible which projects the chin even farther forward. (Arvystas 1990) The prominent chin projection in Class II Division 2 develops only after the late mixed dentition, possibly due to increased growth inhibition of the dentoalveolar structure.

Soft tissue profile is often described as a “sharp” facial contour: protrusive tip of the nose and the chin, concave lower facial third, insufficient lip support and retruded lips. (Brezniak 2002, Dodda 2015)

2.6. Dental Characteristics of Class II Division 2 Malocclusions

Ideally, the mandibular incisors occlude with the lingual surface of the maxillary incisors, at the incisal third. In Class II malocclusion, the mandibular incisors occlude further behind the maxillary incisors. Class II Division 2 Malocclusion is characterized by retroclined maxillary centrals and a deepbite. (Millett 2018) Retroclination of the maxillary incisors is the most distinct sign and the main peculiar feature of this malocclusion. (Pereira 2013) This retroclination has a crucial role in the facial appearance of these patients and is perceived to be less attractive and give an aged appearance. (Kang 2021) Other dental characteristics of this type of malocclusion include: parallel maxillary and mandibular occlusal plans, retroclined maxillary incisors, obtuse interincisal angle, deep curve of Spee and deep bite. (Perovic 2017, Ansari 2018) In almost half of the subjects, mandibular incisors have a normal inclination, one third have retroclined incisors and less than one quarter have proclined incisors. (Pancherz 1997)

The clinical management of Class II Division 2 Malocclusion seems to remain a “mystery” entailing problems of diagnosis, treatment and retention. Correction of the molar relationship and inclination of the maxillary incisors are the two main goals of treating Class II Division 2 Malocclusion.

2.7. Normal Growth and Development of the Jaws Vs. individuals with Class II Malocclusions

Understanding the facial growth and development is essential in every step of orthodontic treatment, from diagnosis to prevention, interception or correction of different types of malocclusion. During adolescent growth, the mandible grows more and for a longer period than the maxilla. During this growth period from childhood to adulthood, the mandible moves more forward relative to the maxilla and consequently, the facial profile becomes less convex.

Studies have shown that in subjects with Class II malocclusion, mandibular growth is on average comparable with Class I subjects. However, most clinicians agree that a Class II malocclusion cannot be self-corrected without treatment. In 1959, Subtelny stated that "patients with a Class II malocclusion should not be misled in the hope that correction of the malocclusion will occur of its own volition. With succeeding years, the residual growth of the mandible in a horizontal direction will not correct a Class II molar relationship into a Class I molar relationship. This has not been observed to happen." Studies have shown little changes in Class II malocclusion relationship in growing patients. (You 2001)

From ages 3 to 18, the maxilla presents with a tendency toward a forward displacement but it seems to be in a relatively stable position in relation to the cranial base, while the mandible becomes more prognathic. (Ramos 2005) Björk (1964) said "It is important to bear in mind that on average, the rate of growth of the mandible is greater than that of the maxilla and that the mandible is still growing when the maxilla has ceased." This increase in mandibular prognathism usually happens after the age of 7 and leads to reduction in convexity of the face. (Lande 1952) The maxilla shows a faster growth in Class II subjects (Buschang 1986), while the mandible has three times larger anteroposterior growth than the maxilla during the growth spurt based on the data form the Burlington Study. (Pollard 1995) It seems that the mandible "outgrows" the maxilla during the post-pubertal period. When craniofacial growth of Class I and Class II subjects were compared from 11 to 14 years of age, there was no difference in growth velocity of the mandible between the two groups, although the Class II subjects had significantly shorter mandibular length. This indicates that the anteroposterior skeletal discrepancy in Class II malocclusion is established before age 11. (Buschang 1986, Pollard 1995) From ages 16 to 19, both groups show similar amount of growth. (Baccetti 2009)

Overall, the growth in individuals with normal and Class II malocclusion is similar at most developmental stages. The only exception is the significantly smaller increments in mandibular growth in Class II subjects during the growth spurt. As a result, in the long term, Class II subjects show less mandibular growth compared with Class I subjects. (Stahl 2008) The sagittal relationship usually improves during childhood, but worsens during adolescence, and the difference in the horizontal growth of the mandible between Class I and Class II subjects is found to be the primary reason. (Buschang 1998)

The growth-related reduction in ANB angle is 0.9° on average between ages 10 and 14 (Riolo 1974) which can be attributed to the differential maxillary and mandibular growth and an age-related reduction of anteroposterior distance between the maxilla and the mandible. (Williams 1985, Buschang 1986) The changes in SNA are mostly insignificant, which means an increase in SNB angle is primarily responsible for reduction in ANB angle. (Honn 2006) While the ANB angle decreases significantly with age, the Wits appraisal does not indicate any anteroposterior changes between the maxilla and the mandible between age 5 and 15. (Bishara 1983, Bhatia 1993, Lux 2005)

Subjects with Class II Division 2 are found to have a retruded Point B and a normally positioned Pogonion. (Fischer 1985) Point B and Pogonion both move forward with growth, with more growth at Pogonion compared with Point B. (Sherman 1988, Johnston 1998) Studies suggested that this forward movement can be inhibited by a significant forward-rotating growth pattern of the mandible and/or a deepbite. (Nanda 1955, 1995) Both of these features are more commonly seen in Class II Division 2 Malocclusion.

Among the linear measurements of the mandible, ramus height presents less variation in annual growth rates, ranging between 3.01 and 3.34mm. Mandibular length has an annual growth rate of 3.92 to 5.01mm, while mandibular body length has a lower annual growth rate of 1.81 to 2.64mm. (Gomes 2006)

2.8. Different Types of Growth Patterns

In 1964, Schudy proposed the term facial divergence, in reference to hypo and hyper divergence. If the vertical growth at the facial sutures and the alveolar processes are smaller than vertical growth at the condyles, the mandible would rotate upward and forward (counter clockwise), resulting in decreased anterior face height. Conversely, if the vertical growth at the condyles is smaller than the sum of the vertical growth at the facial sutures and alveolar processes, the mandible would rotate backward and downward (clockwise), resulting in increased anterior lower face height. These variations in facial patterns can intensify or conceal the clinical appearance of the malocclusion. Thus, the final position of the chin is a result of the “competition between vertical and horizontal growth.” It has been suggested that the ramus height indicates the divergence and not the body of the mandible. (Chung 2003)

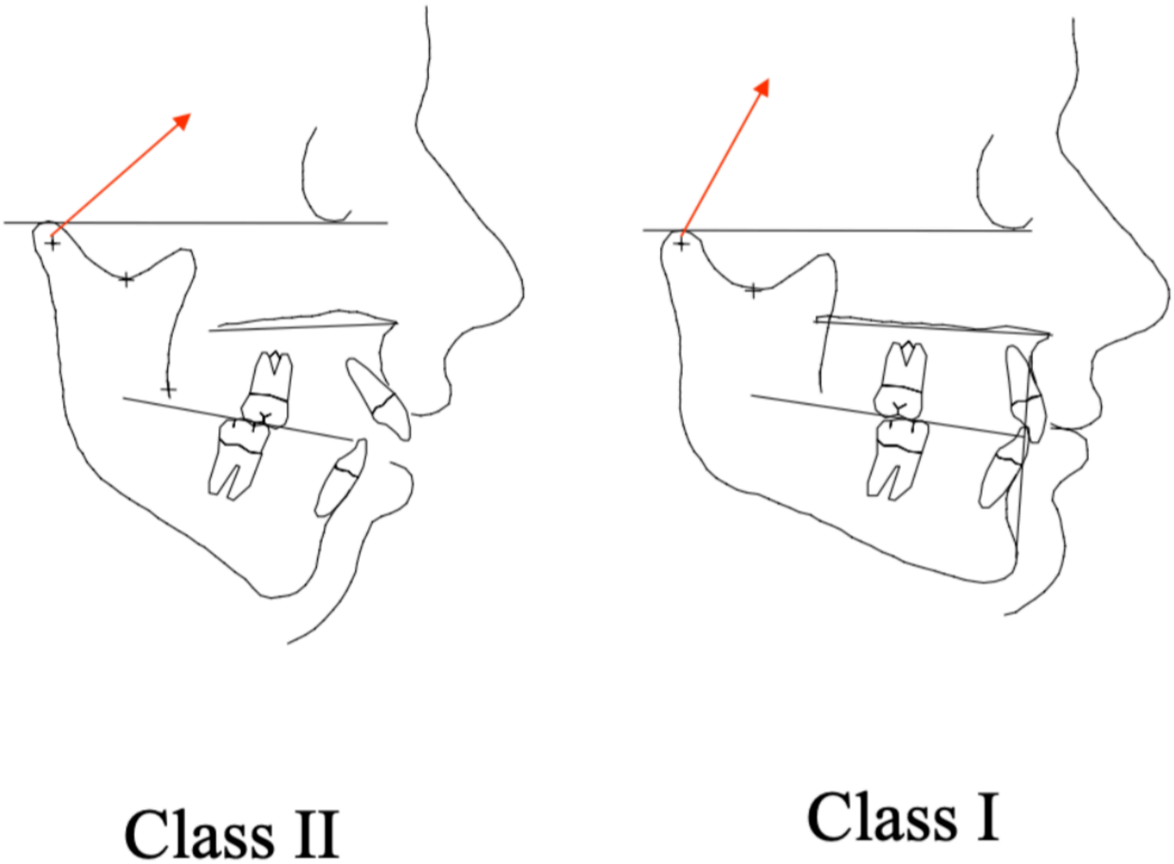
A few years later in 1969, Bjork explained different directions of condylar growth in subjects with different growth patterns. More vertical growth at the condylar region, will lead to a forward rotation of the mandible, while more sagittal growth at the condyle, would favor backward rotation of the mandible and increase in the lower facial height. He proposed some structures to facilitate the prediction of mandibular rotation and its final position and relation to the face: the inclination of the condylar head, the curvature of the mandibular canal, inclination of the symphysis and shape of the lower border of the mandible and symphysis. Validity of his proposed method was found to be reliable by many other authors. (Schmuth 1979, Ari-Viro 1983)

In 1967, Creekmore proposed similar assumptions on mandibular rotation by describing the vertical and horizontal growth increments of the different components of the mandible: the condyle, the chin (measured at Pogonion) and the molars. Due to the effect of the vertical condylar growth on augmenting forward mandibular rotation, a lesser horizontal condylar growth (1.65 mm) would displace Pogonion forward by a greater amount (3.48 mm). Accordingly, mandibular rotation is the result of the difference in the vertical growth at the condyle and the total vertical growth in the molar area. When no mandibular rotation occurs, the forward growth at pogonion equals the effective horizontal growth of the condyle, and the vertical growth of the condyle equals the vertical growth of the molars. When vertical growth of the condyles is greater than the vertical growth of the molars, as occurs in normal growth, the forward growth (forward projection) of the mandible is greater than the actual horizontal (bony) growth. Precise forecasts on amount of individual growth are still lacking and more research must be invested for improved determinations.

Another characteristic difference between the dolicofacial and brachyfacial subject is the thinner and longer symphysis in the former compared with a thicker and shorter symphysis in the latter. Histologic and metabolic analyses have shown the musculature to be different as well. A study by Al-Farra in 2001 indicated that as the facial divergence decreases, the resting metabolic activity of the masseter increases. Consequently, the muscles keep the bone under tension and influence its growth in a more horizontal direction. A more acute gonial angle has been associated with increased muscular activity, especially the masseteric activity. It has been shown that this muscular activity becomes more "normal" during treatment with functional appliances. (Moss 1975)

The condyle remains in constant contact with the glenoid fossa via the articular disk during jaw movements that consist of hinge, translation and excursive movements. The extent and direction of excursive condylar movements are regulated by the bone morphology of the glenoid fossa and condyle, and these movements are limited by the joint capsule and the articular disc. (Koide 2018) It has been proposed that differences in condylar morphology, eminence angle and condylar position relative to the glenoid fossa can be attributed to anteroposterior craniofacial morphology. Class II subjects had significantly lower condylar volume compared to Class I and Class III subjects. (Arieta 2013, Saccucci 2013) Furthermore, the condyles in Class II subjects were located more anteriorly and superiorly than Class I subjects. Subjects with Class II Division 2 Malocclusion were characterized by strong and high articular eminences. (Sulun 2001, Katsavrias 2002) It is known that the force vectors against the condyle during function and mastication are different in subjects with different anteroposterior skeletal relationship. In Class II subjects, the direction of the force vectors is significantly larger than Class I subjects. (Ueki 2008)

Figure 1.1. Growth pattern and anteroposterior skeletal relationship



The direction of condylar loading is influenced by anteroposterior skeletal relationship, and subjects with Class II malocclusion are reported to have the most anteriorly displaced craniofacial morphology. (Kurusu 2009) 50% and 40% of Class II Division 1 patients exhibited anterior and central condylar positions in the glenoid fossa, respectively (Pullinger 1987) With treatment, condylar positions changed from an anterior condylar position to a central condylar position. The bone apposition of the posterior slope of the articular eminence can be attributed to this change in condylar position. (Koide 2018)

2.9. Treatment of Class II Division 2

Treatment of Class II Division 2 Malocclusion is recognized to be difficult and prone to relapse. (Laptaki 2002, 2007) Over the years, various treatment modalities have been proposed for treatment of Class II malocclusion. These treatment modalities include a variety and combination of fixed appliances to correct the dental malocclusion, fixed or removable functional appliances to stimulate or redirect the growth of the mandible, extra-oral traction, extraction and more recently clear aligner therapy to address this type of malocclusion, either dentally or skeletally. (Rongo 2009) Each treatment approach is different in its effects on the skeletal and dentoalveolar structures of the craniofacial region, accelerating or limiting the growth or movement of various skeletal and dental structures. Clinicians select these modalities based on their personal preference, experience and previous success rate.

Treatment of Class II Division 2 Malocclusion for correction of the maxillary incisors' inclination and overbite reduction in subjects with normal or decreased lower facial height, mesofacial and brachyfacial growth patterns respectively, can lead to a mean of 4 to 5mm of forward movement of B point compared with the control group. It has been suggested that the facial growth pattern should be identified early, in order to maximize the favorable skeletal, dentoalveolar and soft tissue changes. (Wood 2008) Previous studies consistently reported greater mean forward movement of Pogonion and Point B during treatment in the mesofacial and brachyfacial patients compared with the untreated control groups. These studies suggested that in patients with increased vertical overlap of the maxillary and mandibular incisors, the forward movement of the mandible and the associated dentoalveolus can considerably be inhibited. Once the deep bite is reduced, the mandible can grow farther forward while carrying the dentoalveolar structures with it. This forward movement has not been seen in the subjects not receiving any orthodontic treatment. This forward movement of the mandible and its associated dentoalveolus have not been reported in dolicofacial patients, which can be an indication that the same inhibition or locking effect does not play a role in these subjects, even if the mandibular incisors are overerupted and contacting the palatal tissues around the maxillary incisors. Based on these studies, the proposition can be made that release of Pogonion and Point B occur in subjects with the underlying potential for forward growth, and not in the subject who might not have such potential. (Parker 1995, Gugino 1998) With this in mind, when treating Class II division 2 Malocclusions, based on the expected amount of forward movement of the mandible and its dentoalveolus with growth, the treatment plan for each individual can be quite different. It would be more reasonable to expect more forward growth in patients with horizontal growth pattern after treating the increased overbite. In these patients, there is less need to retract the maxillary teeth as the mandibular dentoalveolus would be carried forward with growth. On the contrary, in dolicofacial patients more retraction of the maxillary incisors might need to be included in the treatment plan as opening the bite is unlikely to be followed by forward movement of the mandibular dentoalveolus since the mandible itself would grow more vertically. (Woods 2008)

Although Class II malocclusion is mainly perceived as a sagittal problem, the vertical dimension should also be considered when treatment planning. An increased lower facial height is often associated with the chin being positioned backward and downward. On the contrary, a decreased lower facial height causes the mandible to rotate forward and upward which can camouflage the relatively small or retruded mandible relative to the midface, since the chin is being positioned more forward and upward. Understanding these differences is important when planning the treatment for Class II subjects. When maximum advancement of the chin is desired, increases in the vertical dimension during treatment should be minimized as this will tend to camouflage the positive changes in mandibular length. (McNamara 1996)

The final position and inclination of maxillary incisors can also be significantly modified, especially in Class II Division 2 cases. (Deregibus 2020) The labial and palatal cortical plates of the maxilla serve as the anatomical limits to orthodontic tooth movement. Excessive changes in the inclination of the incisors may infringe upon anatomic barriers and lead to loss of periodontal support. In the maxilla, studies reported the labial bone covering the incisors to be thin. When treating Class II Division 2 Malocclusions, a considerable amount of proclination of the maxillary incisors, 15 degrees on average, is required, but it has been reported that this significant change in inclination does not pose a high risk to the periodontal tissues. (Kang 2021) When treating Class II malocclusion with clear aligners using Class II mechanics, the inclination of the incisors, especially the mandibular incisor proclination can be controlled with the full coverage of clear aligners on the incisors. It has been shown that the mean IMPA angle decreases throughout the treatment. (Al-Jewair 2020)

2.10. "Unlocking" the Mandible

Haas has written, "Many orthodontists who have treated a patient with a Class II Division 2 Malocclusion by changing it to a Class II Division 1 contend that they have observed the mandible move forward as much as one-half premolar width virtually every time and the author concurs." (Haas 2000) Historically, there has been a belief that Class II Division 2 subjects have a posteriorly entrapped mandibles in the glenoid fossae. It has been assumed that the retroclined maxillary incisors, the deepbite and the minimal overjet commonly seen in this type of malocclusion potentially act as occlusal interferences for unrestricted mandibular growth. Based on this belief, elimination of these potential interferences could theoretically help with Class II correction with spontaneous repositioning of the mandible. (Feres 2020)

It has been stated that one-third of Class II Division 2 subjects have a posteriorly displaced mandible in maximum intercuspation. (Swann 1954, Thuer 1992) Based on cephalometric findings, it has been proposed that in 25% of subjects with Class II Division 2 Malocclusions, the mandible should be repositioned anteriorly during treatment. (Erikson 1985, Thuer 1992) On the contrary, other studies found no difference in the position of the mandible in Class II Division 2 and Class II Division 1 cases where there is no retroclination of the maxillary incisors or deep bite. There has been no evidence of a significant anterior mandibular repositioning after proclination of the retroclined maxillary incisors in maximum intercuspation, rest position or during function. (Thuer 1992)

It has been found that Class II Division 2 subjects have a larger distance between the maximum intercuspation and retruded positions of the mandible. (Ingervall 1968, Thuer 1992) This is also in contrast with the theory of a posterior mandibular displacement in this type of malocclusion, since it would not be possible to move the mandible further backward into a more retruded position. Furthermore, studying the pattern of the mandibular movement before and after correction of Class II Division 2 Malocclusion were inconclusive regarding a possible posterior mandibular displacement. (Milne 1970, Demisch 1992) This concept of posterior mandibular displacement in

Class II Division 2 Malocclusion is still controversial and not supported by evidence for or against it; However, this belief is still strong and should be further examined.

Based on the results of some of the aforementioned studies, it would be expected to see greater forward movement of Pogonion and Point B during treatment of subjects with deeper overbite compared with subjects with shallower overbite. Once the deep overbite has been reduced, the dentoalveolus might be carried farther forward with growth of the underlying skeletal structures than without treatment. Such greater forward movements of Point B during treatment in these relatively forward-growing deepbite patients would seem to provide a further quantitative description of the controversial term "unlocking", which appears from time to time in the literature and seems to apply to any orthodontic appliance used to remove the potentially inhibitive effects of a deep overbite, accompanied by upright or retroclined maxillary incisors. (Woods 2008) This "unlocking of the deepbite to unlock the forward movement of the mandible and its dentoalveolar bases to their full potential" has been a controversial topic for decades now. (Parker 1995, Gugino 1998, Woods 2001 and 2002) There is still little real evidence confirming the correlation between the so-called "unlocking of a deep bite" and "unlocking of the skeletal and dentoalveolar growth of the mandible" to correct a Class II malocclusion.

Class II Division 2 Malocclusions can be corrected by the use of orthodontic appliances that move the maxillary anterior teeth forward and in response, change the growth of the upper and/or lower jaws. (Millett 2018) Each patient responds differently, but it would be reasonable to expect considerably more forward movement of the mandible, after bite opening, in patients with more horizontal growth pattern after maxillary incisor proclination is accomplished. It is possible to unlock dental malocclusions in a functional or mechanical manner, or in a combination of the two. Both functional and mechanical unlocking are often overlooked in orthodontic diagnosis and treatment planning.

Mechanical unlocking, in contrast to functional unlocking, removes occlusal interferences that could interfere with the development and function of the entire stomatognathic system. The main goal of mechanical unlocking is to allow the mandible to have a mechanically unrestrained range of movement. Mechanical unlocking is carried out in all three planes of space, the transverse, the vertical and the anteroposterior planes, respectively. The first step of mechanical unlocking should be carried out in the transverse dimension, by expanding the maxillary arch, followed by reciprocal expansion in the mandibular dentition. The second step of mechanical unlocking is in the vertical dimension and requires that the maxillary incisors be correctly positioned. (Gugino 1998) It is an important principle of the Bioprogressive philosophy that the overbite should be corrected before the overjet. The incisors are often advanced, aligned, torqued and intruded as part of the vertical unlocking process. This concept is based on the belief that a deep overbite can restrict mandibular development in a Class II malocclusion. The third step of mechanical unlocking is carried out in the anteroposterior dimension in order to correct the malocclusion. This concept of “unlocking” is yet to be proven by scientific research.

Furthermore, it has been proposed that a five-dimensional functional model of the face and the dentition should be developed for each patient. The first four dimension represent the transverse, vertical and anteroposterior planes, with the fourth being the muscles. (Brodie 1954) The fifth dimension is the time, which determines the direction and the amount of remaining growth of each individual. This fifth dimension also takes the duration and the degree of potential dysfunctions into consideration. In presence of long-term oral dysfunctions, obtaining stable orthodontic results would be difficult since placing the dentition in a neutral zone in relation to the oral environment would be difficult. Based on this theory, every malocclusion is associated with some degree of orofacial dysfunction that should be removed to maximize the chances of obtaining stable orthodontic results. The dentition should be examined to determine if it is potentially locked in a transverse, vertical, anteroposterior or a combination. An important treatment objective should be to obtain a functional orthodontic occlusion that is free of any form of dysfunction. (Gugino 1998)

It has been proposed that virtually all Class II division 2 subjects present with mandibular functional retrusion. This retrusion has been attributed to the retroclination of the maxillary incisors. (Haas 1970) 50% of subjects with Class II Division 2 Malocclusion present with a distal path of closure before treatment. It has been postulated that the mandible is held in a distal position in centric relation (CR) because of the constricted maxilla. (Gianelly 2003) It is believed that during closure or function from the rest position into the maximum intercuspation, the mandible is trapped by the retroclined maxillary incisors and therefore forced backwards. (Demisch 1992) However, this presumed posterior displacement of the mandible is thought to be favorable after correction of the deep bite and the retroclined maxillary incisors, since the mandible can spontaneously move forward into a more anterior intercuspal position and simplify the orthodontic treatment of the Class II malocclusion.

2.11. Transverse Discrepancy in Class II Division 2 Malocclusions

Traditionally, maxillary expansion was mainly prescribed to address the tooth size/arch size discrepancies, or to correct crossbites. Historically, Class II malocclusion has been looked at as primarily a sagittal and vertical problem. Sagittal and vertical components of this malocclusion have been widely discussed, but the transverse component is often overlooked, and should also be taken into consideration when treatment planning. (Caprioglio 2017) In early 1980s, it was observed that there is spontaneous improvement of Class II relationship after maxillary expansion. This finding initiated a new theory in correction of Class II malocclusion.

There seems to be a correlation between the Angle classification, arch length and arch width. Several studies found the maxillary arch to be narrower in cases presenting with Class II malocclusion compared with maxillary arch widths in Class I cases. (Buschang 1994, Will 1996, Baccetti 1997, Franchi 2005, Deregibus 2020) In 1996, Tollaro found the width of the maxillary arch to be 3 to 5mm narrower than the ideal maxillary width relative to the mandible without any posterior crossbite in the centric occlusion. This dentoskeletal transverse deficiency in maxillary width has been confirmed with anteroposterior cephalography. (Franchi 2005) McNamara described this as a manifestation of "Maxillary Deficiency Syndrome". (McNamara 2000) In 1956, Schwarz concluded in his study that this transverse discrepancy is only dentoalveolar and not skeletal. Vargervik suggested that correction of Class II molar relationship without creating a posterior crossbite requires an approximately 2mm and 4mm increase in maxillary intermolar width for unilateral and bilateral Class II molar relationship, respectively. (Vargervik 1979) This transverse discrepancy might not be evident since the mandible is retrusive and therefore the maxillary posterior teeth occlude with the narrower part of the mandible. But this discrepancy should be clinically evaluated by asking the patients to posture the mandible in a forward canine Class I position to unmask the underlying transverse discrepancy. Based on the findings of these studies, maxillary expansion is commonly needed when treating Class II malocclusion.

It has been postulated that in these subjects, the mandible is kept in a retrusive position relative to centric relation by the constricted maxilla. (Gianelly 2003) The transverse discrepancy between the maxillary and the mandibular dental arches induces a backward position of the mandible as the occlusal goal is to obtain the highest number of functional contacts. (McNamara 2000) Maxillary expansion disrupts the occlusion and therefore the mandible moves forward, leading to an improved sagittal intermaxillary relationship. Based on these findings, it has been suggested that treating maxillary constriction can lead to spontaneous improvement of the Class II malocclusion, due to forward posturing of the mandible into a more comfortable position.

The correlation between the transverse dimension of the maxilla and the correction of Class II malocclusion was first described by Reichenbach in 1971. The mandibular arch "the foot" moves forward after the maxillary arch "the shoe" is widened. If the shoe is too small, the foot cannot slide fully into the shoe. However, when the shoe gets wider, the foot can slide forward into a comfortable position. McNamara suggested that teeth act as an endogenous functional appliance, in that palatal cusps of the over-expanded maxillary dental arch will encourage the patient to posture the mandible in a more protrusive position to establish a more comfortable contact in maximum intercuspation, ultimately leading to a stable occlusal change. (Baccetti 1997) This gradual forward posturing of the mandible leads to a slight but clinically significant increase in mandibular length, and subsequently a change in the intermaxillary relationship. (McNamara

1996) Several studies (Chung 2004, Guest 2010, McNamara 2010) suggested that the removal of occlusal interferences caused by the transverse discrepancy, will allow the mandible to posture forward in the retention phase after maxillary expansion, which can lead to improvement in the anteroposterior relationship of the maxilla and the mandible. (Marshall 2005, Wendling 2005) These studies reported statistically significant decreases in the ANB angle as a result of significant increase in SNB angle. (McNamara 1993, Wendling 2005, Baratieri 2011, Farronato 2011)

Class II Division 2 can be viewed as a condition where the mandible is restricted within the maxilla, by its vertical overlap. In mild cases, this restriction is only seen in the incisor region, whereas in more severe cases, this restriction extends back, restricting the mandible in both anteroposterior and lateral dimensions.(Barnett 1996) This theory was later confirmed by Bishara in 1988: Subjects with Class II Division 2 Malocclusion present with maxillary and mandibular transverse deficiency compared with Class I subjects. Based on this theory, the transverse discrepancy should be corrected first in order to establish an adequate base for the sagittal correction of the Class II malocclusion. (McNamara 1993, McNamara 2000, Gianelly 2003) These studies indicate that in a Class II subject, transverse maxillary deficiency impedes physiological sagittal mandibular growth. When the maxilla cannot develop normally in the transverse plane, it will develop more in the vertical plane instead. This consequently causes downward and backward displacement of the mandible. It has been proposed that maxillary expansion is commonly followed by a functional expansion in the mandibular dentition, in the ratio of 5:3. (Gugino 1998) A removable mandibular Schwartz can be used initially to upright the mandibular posterior teeth before over-expanding the maxillary arch, so that the palatal cusps of the maxillary posterior teeth approximate the buccal cusps of the mandibular posterior teeth. The use of the mandibular

Schwartz before maxillary expansion can lead to significantly more favorable results compared with maxillary expansion alone. (McNamara 2006) It should be mentioned that this improvement in Class II relationship is not due to enhanced mandibular growth but instead due to occlusal interferences being removed with maxillary expansion, and forward displacement of the mandible to a more forward and comfortable position. (Lima 2003, Marshall 2005) When the mandible is freed to move forward, it can grow to its full potential.

Improvement in molar relationship after maxillary expansion reported to be more than 1mm in 92% of the subjects and over 2mm in 50% of them without any Class II mechanics incorporated into the protocol. (Guest 2010, McNamara 2010) The net molar relationship improvement was 1.7mm in the treatment group compared to the control group. This improvement was mainly the result of significant increase the in the mandibular length. (Lione 2021) The skeletal changes after maxillary expansion in Class II Division 2 subjects compared with untreated Class II subjects includes: reduction of ANB angle, increased mandibular length and advancement of Pogonion. These improvements were significant 3.5years after active expansion was completed. (Guest 2010) Improvement in the Class II relationship following maxillary expansion appears to be clinically beneficial in mild to moderate Class II malocclusions. (McNamara 2010) Most of these patients had a half to full cusp Class II molar relationship at the start of treatment. Generally, they had mild to moderate mandibular skeletal retrusion, with no severe skeletal imbalance. (McNamara 2006)

This improvement in Class II malocclusion after maxillary expansion is more significant in patients with more acute gonial angle and smaller mandibular length. (Caprioglio 2017) Patients with more acute gonial angle have a more forward position of Articulare (Ar), which can be an indication of forward position of the glenoid fossa and a more horizontal growth pattern. Smaller mandibular length can be an indication of additional growth potential of the mandible which can take place after correction of the maxillary transverse deficiency. Both these factors can improve the prognosis of Class II correction. (Caprioglio 2017)

On the contrary, some studies suggested that maxillary expansion cannot predictably improve the anteroposterior relationship. (Chung 2003, Volk 2010) Other studies made the argument that maxillary expansion can be detrimental for correction of Class II malocclusion, since the maxilla might be displaced downward and forward causing clockwise rotation of the mandible and worsening of the Class II relationship. Immediately after expansion, the mandible rotates clockwise with a significant 1.5 mm backward displacement of Menton. (Baratieri 2011) This displacement has been attributed to inferior displacement of the maxilla following the opening of the midpalatal suture, and over-expanded palatal cusps of the maxillary teeth causing premature contacts. (Wertz 1970) This backward and downward positioning of the mandible worsens the skeletal pattern of Class II malocclusion.

Dentoalveolar expansion can be achieved with different orthodontic approaches such as fixed appliances, broad and expanded archwires or clear aligners. With the conventional fixed appliances, maxillary expansion occurs mostly with tipping the teeth in the buccal direction with subsequent bone remodeling.

2.12. Importance of Disarticulation in Treatment of Class II Division 2 Malocclusions

It has been proposed that disarticulation of the occlusion can greatly facilitate treating Class II malocclusions in growing patients. It has been shown that there is a strong linear relationship between the forward growth of the mandible and the anteroposterior changes in the maxillary and mandibular dentition. From childhood to early adulthood, the maxillary and mandibular dentition both move forward relative to the maxillary basal bone, while moving backward relative to the mandibular basal bone. Since the mandible grows more forward relative to the maxilla, the forward movement of the dentition relative to maxilla is greater, while the backward movement of the dentition relative to the mandible is greater. The greater forward growth of the mandible relative to the maxilla could potentially bring the mandibular dentition forward, but this effect is vanished into the adaptative movements of the dentoalveolar complex. Dentoalveolar adaptation acts as a system to maintain a relatively stable inter-arch relationship. This adaptation could be the reason that Class II malocclusions are not self-correcting without treatment even with significant mandibular forward growth. One explanation that has been proposed is the effect of intercuspation of the maxillary and mandibular dentition. This interdigitation maintains the anteroposterior occlusal relationship despite the anteroposterior skeletal changes between the maxilla and the mandible. This mechanism is advantageous in subjects with normal occlusion but disadvantageous in subjects with Class II malocclusion. (Solow 1980, You 2001) This idea can be supported by the study of malocclusions in medieval skulls where the prevalence of Class II malocclusion was significantly lower in the samples with heavy occlusal wear and therefore no interdigitation. (Helm 1979)

The direction of adaptive changes of the dentition could also be greatly influenced by the soft tissue envelope. In a Class II Division 2 subject with a brachycephalic facial pattern, the pressure of the lips and the muscles might prevent the forward movement of the dentition while the mandibular basal bone is growing forward, and therefore the major adaptive movement of the dentition could be directed backward, with a more prominent chin button. In Class II subjects, the average forward growth of the mandible is 4.36mm greater than the maxilla, which is usually large enough to correct the Class II relationship. Theoretically, unlocking the intercuspation of the maxillary and the mandibular dentition could negate the adaptive mechanism and allow the mandible to carry the lower dentition forward during normal growth. Almost all functional appliances that have been used to treat Class II malocclusion in growing patients unlock the interdigitation between the maxillary and the mandibular dentition, which can be a fundamental biological basis in treating Class II malocclusion in growing patients.(You 2001)

2.13. History of Clear Aligner Therapy

The history of dentistry is filled with the drive for greater treatment options and greater efficiency. The evolution from banding each tooth to bracketing, development of straight wire appliances, innovations in materials and customized appliances have significantly improved treatment efficiency and patients' experience. This efficiency can be attributed to an accurate diagnosis, skillful treatment planning and efficient biomechanics. (Hansa 2020)

The ideal orthodontic appliance should minimally interfere with function, hygiene and aesthetics. It should be as light and small as possible, while strong enough to withstand masticatory forces. It has to deliver optimal forces for orthodontic tooth movement while being gentle to the oral and dental tissues. (Proffit 2019)

In 1945, Kesling was the first clinician to introduce the concept of using a series of thermoplastic tooth positioners to progressively move misaligned teeth in order to improve teeth positions and relieve crowding. However, comprehensive orthodontic treatment using this technique was deemed impractical because of the extensive laboratory time required to fabricate each positioner. (Kesling 1945) A few decades later in 1971, Ponitz proposed the idea of a removable plastic retainer. In 1993, Sheridan popularized these retainers by incorporating interproximal reduction to resolve crowding.

In 1997, two students from Stanford University, Zia Chishti and Kelsey Wirth, together with a computer specialist, founded Align Technology in Palo Alto, CA, USA. Align Technology developed the idea of clear aligner therapy into a feasible treatment modality with the introduction of computer-aided design and computer-aided manufacturing (CAD/CAM) technology and tooth movement simulation software. Zia Chishti was an orthodontic patient who after receiving his clear retainer, designed a software with his partner to simulate a solid object with a computer-aided design model and then recreate that object using three-dimensional printing technology. Through this technology and sequential staging of tooth movement, the Invisalign system was developed under the company name Align Technology. (Patterson 2021) CAD/CAM stereolithographic technology has been used to forecast treatment outcomes and fabricate a series of custom-made aligners using a single silicone or digital impression. After approval by the Food and Drug Administration, their technology (Invisalign®) was presented at the American Congress of

Orthodontists in 1999; and 2 years later, it was introduced in Europe. Initially, the focus of Invisalign® system was to treat mild orthodontic relapse after fixed appliance therapy, mild to moderate spacing and crowding, and non-skeletal constricted arches. (Zhu 2021) However, with the ongoing research and development, this system can now be used to treat more complex cases to address anteroposterior, vertical and transverse discrepancies.

2.14. Increased Interest in Esthetic Orthodontics such as Invisalign

Even though orthodontic treatment aims to improve dentofacial esthetics, wearing an orthodontic appliance may temporarily affect the facial appearance. (Ziuchkovski 2008) Over the last few years, increased expectations about physical appearance have led people from all different ages and socioeconomic groups to seek orthodontic treatment to improve the aesthetics of their smile. However, the visibility of orthodontic appliances during treatment can raise some aesthetic concerns. In recent years, there has been a growing demand for aesthetic treatments among both adolescents and adults. (Feu 2002, Walton 2010)

When planning orthodontic treatment, any aesthetic concern should be taken into consideration. For patients that are concerned with the aesthetics of the traditional orthodontic appliances, alternative treatment modalities have become available: ceramic and plastic brackets, lingual orthodontics, clear aligners, as well as aesthetic auxiliaries such as clear elastic ties and white coated archwires. (Ziuchkovski 2008, Tai 2018, Ustdal 2020) When laypersons were asked to rank orthodontic appliances in regards to their attractiveness and acceptability, clear aligners and lingual appliances were found to be considered as the most appealing, followed by ceramic brackets, self-ligating brackets and finally metal brackets. (Ziuchkovski 2008, Rosvall 2009) These study also stated that patients are willing to pay the extra cost for the treatment modality they find to be more aesthetic.

Moreover, brackets, ligatures, archwires and other elements of conventional orthodontic treatment can make the oral hygiene practice difficult, especially for younger patients and adolescents. Since clear aligners maintain aesthetics and minimally interfere with function, speech and oral hygiene during orthodontic treatment, their acceptability and popularity has significantly increased. Clear aligners have increasingly gained popularity among both clinicians and patients as an effective, patient- and clinician-friendly treatment modality. Clear aligner therapy has been accepted as a mainstay in orthodontic world and is rapidly gaining more popularity among both patients and clinicians. Currently, Invisalign® is widely used in orthodontic practices all over the world as an aesthetic and more comfortable alternative to fixed orthodontic appliances. Invisalign was used to treat over 300,000 orthodontic patients in its first decade. (Jiang 2021) With growing patient demand and the professional use of this technology, more than 7.5 million cases have shipped worldwide by now with yearly net revenue exceeding $2.3 billion. (Align Technology Q3 2019 corporate fact sheet) Invisalign clear aligners are by far the most commonly used clear aligners and therefore chosen for this study. (Al-Jewair 2020)

2.15. Invisalign Technology

This treatment modality involves the sequential use of software-fabricated clear plastic aligners that fit over the buccal, palatal (lingual) and occlusal surfaces of the teeth in order to move each tooth to a specific predetermined position. A PVS impression or a digital intraoral scan is needed to fabricate custom aligners using the stereolithographic technology. This step provides a replication of patients' teeth as a 3D model which is then used by the orthodontist using the ClinCheck® software (Align Technology) to move the teeth to their final position. This software allows the clinician to virtually see the movements from initial to the final corrected position in increments. The treatment, which is designed by the orthodontist, is then implemented by the clear aligners. Invisalign aligners are made of 0.75mm thick polyurethane, (Lagravere 2005, Ali 2012) and each aligner is programmed to produce tooth movement of 0.15-0.30mm. (Al-Balaa 2020) Patients are instructed to wear the aligners for a minimum of 20 to 22hrs or more per day, and are changed every 7 days before progressing to the next aligner as per current protocols from the manufacturer. Previously, the recommended wear schedule was a total of 400 hours or 14 days, but since most orthodontic tooth movement occurs during the first week, the protocol has been changed. The aligners are removable and therefore patient compliance is mandatory in order to achieve the desired results. Failure in compliance can result in poor tracking, need for mid-course refinement, longer treatment time and inferior treatment outcome. (Tai 2018)

Many studies were performed to assess the efficiency and accuracy of Invisalign treatment. Some of the most notable findings proposed by studies comparing treatment outcomes of Invisalign and fixed appliances include the following: shorter treatment duration by 5.7 months on average, higher Peer Assessment Rating (PAR) scores, but poorer root control during extraction space closure. (Patterson 2020) The number of emergency appointments was also reported to be significantly lower than fixed orthodontic appliances. (Borda 2020)

The technology behind Invisalign has made great progress in all aspects including treatment planning, materials and manufacturing over the past few years. Throughout the last decade, there have been major changes in materials and protocols to help address issues with more complex cases. The improvements brought by Align Technology include: SmartTrack material, Smartforce feature, optimized attachments and different protocol innovations. (G3-G8) Their powerful marketing also has increased public's awareness and demand for clear aligners, which has made clear aligner therapy an inevitable part of orthodontic practices. There is much speculation regarding its future and the future of orthodontics, however there is yet no strong evidence regarding its limitation and capabilities. (Charalampakis 2018)

2.16. Limitations of Invisalign

A recent systematic review examined the existing orthodontic literature to assess the level of evidence of clinical effectiveness of Invisalign®. To date, most of the literature regarding clinical effectiveness of the Invisalign® system consists of retrospective and prospective studies. In general, the level of evidence is found to be moderate, and the risk of bias ranged from low to high. Due to a high heterogenicity amongst the studies, no clear recommendations have been made. (Papadimitriou 2018) Invisalign clear aligners were initially introduced to treat mild to moderate malocclusions such as spacing, crowding and minor relapse cases. There is still no absolute consensus in the literature whether moderate and severe malocclusions can be routinely treated with aligners. (Boyd 2008) The majority of studies consist of case reports based on individual anecdotal experiences. (Shin 2017) Successful treatment of moderate to severe malocclusions has been reported, however, earlier reports raised important limitations in the treatment of severe malocclusions with Invisalign. (Taylor 2003, Djeu 2005) It should be kept in mind that earlier studies were carried out during the first years after the introduction of Invisalign® into the orthodontics world, even before the existence of attachments. In the past few years, the technology behind clear aligners has undergone significant changes and improvements. Improved materials, new biomechanically customized attachments, enhanced software simulation and staging of tooth movement, and improvements in CAD/CAM technology have all helped with efficiency of orthodontic treatment using clear aligners and increased the popularity of plastic orthodontics among clinicians. (Galan Lopez 2019, Deregibus 2020)

2.17 Predictability of Invisalign®

More than two decades after its introduction to the orthodontic world, with all the advancements in the technology and the materials, it is being used by clinicians to move teeth with larger distances, and to treat more complex cases. Invisalign® claims that it can achieve extrusions and intrusions of 2.5 mm in anterior teeth; and radicular movements of 4 mm and 2 mm in anterior and posterior teeth, respectively. The accuracy of orthodontic tooth movement using clear aligners has improved drastically in recent years, reaching values of 70-80%. (Tuncay OC. The Invisalign System. Chicago, Ill: Quintessence; 2006) These improvements can be contributed to the continuous research performed by Align Technology over the years.

Align Technology reports that roughly 20–30% of Invisalign® patients require mid-course correction or post-alignment finishing in order to achieve the results prescribed on the setup. (Align Technology 2002) Few studies have been published that assess the efficacy or the outcome of orthodontic treatment with Invisalign® clear aligners. If the accuracy of a specific tooth movement is known, overcorrecting it by the appropriate amount or staging the movement in smaller increments may result in the desired outcome. (Charalampakis 2018)

The efficiency of tooth movement during treatment with Invisalign® clear aligners varies significantly with different types of movements and different teeth. A prospective study in 2009, showed that the mean accuracy of tooth movement in the anterior region was 41%, and that 70 to 80% of the patients require a midcourse correction or a refinement. These numbers suggest that the accuracy of tooth movement compared to the ClinCheck® is relatively low. (Kravitz 2009) This inaccuracy can lead to increased costs for the orthodontists and longer treatment time for the patients. A major limitation of these studies is that most of them were performed before the introduction of Invisalign's new material called SmartTrack in 2013. According to Align Technology's research, this material has superior properties and can exert continuous optimal orthodontic forces over a longer period of time.

A systematic review in 2015 assessed the effectiveness of clear aligner therapy in orthodontic tooth movement. (Rossini 2015) Intrusive movements were most effective in maxillary (45%) and mandibular (47%) central incisors and least effective in maxillary lateral incisors (33%). Extrusion, the least accurate tooth movement, was most difficult with maxillary (18%) and mandibular (25%) central incisors. The most accurate movement has been reported to be molar distalization (87%) and the least accurate to be extrusion (29.6%). Moreover, pure tipping has been reported to be the most accurate (72.5%), followed by controlled tipping, translation and torque (35.2%) which was the least accurate. (Jiang 2021) Some studies reported less than ideal treatment outcomes with aligners compared with fixed orthodontic appliances in more challenging tooth movements and malocclusions.

Arch expansion can also be achieved using Invisalign for different purposes: broadening the dental arch to improve smile aesthetics by reduction of unaesthetic buccal corridors, creating space to resolve crowding, facilitate eruption of permanent canines or correction of dentoalveolar crossbites. A recent study (Houle 2017) on transverse outcomes reported the mean accuracy of expansion to be 72.8%, with 82.9% at the cusp tips and 62.7% at the gingival margins.

Despite all the technological advances and all the changes, clinicians still find refinements to be necessary. (Charalampkis 2018) Despite the advocated efficiency of tooth movement, its clinical efficiency still remains debatable. Advocates are convinced by successful treatment outcomes, and opponents have remained doubtful with its limitations when treating more complex cases.

2.18. Invisalign for Treatment of Class II Division 2 Malocclusions

With clear aligners, maxillary expansion can be digitally planned with a combination of buccal dental tipping and bodily translation. However, several studies indicated that more dental tipping than bodily translation was observed. While treating Class II malocclusions with Invisalign®, significant increase in the arch width can be programmed and achieved in both arches. 2 to 4mm of buccal expansion in each quadrant can be programmed with minimal risk of gingival recession and relapse. (Lione 2020)

When treating patients with Invisalign®, the thickness of the aligners causes disarticulation between the maxillary and the mandibular dentition. When comparing TMJ tomograms with and without clear aligners, it was observed that when the patients wear clear aligners the condyles moved downward and forward as if the patient was wearing a functional appliance. (El-Bialy 2016)

This could be an assumption that clear aligners could be working as a full-time functional appliance, assuming the patient wears clear aligners all the time. Clear aligners disengage the occlusion allowing the mandible to be projected forward into central relationship, especially in patients with deep bites before starting the treatment. In deep overbite cases with severely retroclined maxillary incisors the clinician should apply labial crown torque even before retraction of the maxillary incisors. This is of particular importance in cases where patients initially present with under-developed mandibles.

2.19. CBCT in Orthodontics

Cone-beam computed tomography (CBCT) allows orthodontists to accurately create three-dimensional models of the patients' hard tissue that can be used for diagnosis, treatment planning and monitoring the treatment progress. Accurate measurements can be made for any anatomical structures and the teeth. Studying treatment outcomes using CBCT can be very useful since these images provide authentic quantitative data permitting images to be compared with accuracy and precision but without any magnification. These images can also provide volumetric measurements, and can be used to assess any changes in the shapes or the contours of the structures which are often limited in two-dimensional images. (Al-Balaa 2020) CBCT seems to be crucial in diagnosis and treatment planning of Class II cases, specifically in terms of detecting any distal mandibular shift.

Chapter Three

Purpose and Hypothesis

3.1. Purpose of The Study:

The purpose of this study was to evaluate the skeletal and dental treatment effects of Invisalign® clear aligners on subjects with Class II skeletal relationships and in particular the magnitude of mandibular forward growth or/and projection attained in growing patients following maxillary incisor proclination, overbite correction and dentoalveolar expansion compared to untreated control patients.

3.2. Hypotheses

The Null hypothesis states that no change in mandibular growth nor forward projection of the mandible will occur after using Invisalign clear aligners to advance the maxillary incisors, overbite correction and dentoalveolar expansion in skeletal Class II patients. The alternate hypothesis is that proclination of the maxillary incisors, overbite correction and dentoalveolar expansion using Invisalign clear aligners will allow skeletal mandibular changes via anterior mandibular projection.

Chapter Four

Materials and Methods

4.1. Ethics

This retrospective study was approved by the University of Manitoba (U of M) Bannatyne Campus Health Research Ethics Board (HREB) on March 19, 2020. (HS23737; H2020:133)

4.2. Sample Selection

Sample size calculation was based on a power of 80%, a confidence interval of 95%, a mean difference to be detected of 5.6 mm for mandibular forward projection, and a standard deviation (SD) of 2.57. A sample size of 11 patients was estimated for a 5% level of significance. The values for mean difference and SD were based on the average of five previous publications with similar methodology.

Informed consent was obtained for each patient included in this study to allow the use of records needed for research purposes. Consent forms were previously signed by each patient participating in this study.

The study sample was obtained from a single orthodontist specialist experienced with the Invisalign technique located in Edmonton, Canada. The collected records included:

1. Patients' age at the start of treatment
2. Patients' gender

3. Pre- and post-treatment CBCT-generated lateral and posterioanterior cephalograms (T1 and T2)

The following inclusion criteria were applied:

- Adolescent patients (ages 8-17 years)
- Skeletal Class II (ANB > 4°)
- Dental Class II Division 2 Malocclusion (molar and canine Class II, retroclined maxillary incisors, increased overbite)
- Planned dual arch orthodontic treatment (maxillary dentoalveolar expansion, maxillary incisors proclination, overbite correction) exclusively using Invisalign, except for the control group
- Available T1 and T2 CBCT-generated lateral and posterioanterior cephalograms of acceptable quality
- Aligners made of SmartTrack material (year 2012 to present)
- Good compliance during treatment as assessed by the practitioner
- No planned Class II elastics or other Class II mechanics.

The subjects were excluded using the following exclusion criteria:

- Surgical cases
- Extraction cases
- Missing teeth (excluding 3rd molars)
- Patients treated with TADs

- Patients treated with headgear or functional appliances
- Presence of a cleft lip or palate or any other syndromic orofacial malformations
- Medical condition or prescription medication that may affect growth
- Lack of compliance whenever documented in the charts

4.3. Treatment Group

A sample of 16 Class II subjects served as the treatment group. All subjects were treated by a single orthodontist using Invisalign clear aligners over the span of 18-24 months. CBCT imaging was done for all subjects prior to the orthodontic treatment and after the treatment was completed.

4.4. Control Group

A sample of 16 untreated Class II subjects served as the control group. The control group were the patients matched with the treatment group based on their age, gender, growth pattern, malocclusion and Class II severity, whom had CBCT imaging taken at similar time points as the treatment group but did not receive treatment after the initial CBCT due to personal or financial reasons and returned 1.5-2 years after maturation time was exceeded, to start treatment at which time new CBCTs were taken again prior to orthodontic treatment.

4.5. Data Collection

All the subjects included in this study were seated in a natural head position with their back as perpendicular to the floor as possible, with maximum intercuspation and refrained from swallowing during scanning. CBCT data were saved in digital imaging and communications in medicine (DICOM) format. T1 and T2 CBCT scans were imported into a commercial software

(Dolphin Digital Imaging System, Chatsworth, CA, USA) and were used to construct lateral and anteroposterior cephalometric x-rays.

All images were given an independent numerical code in order to de-identify patient's personal information and maintain their confidentiality. A master list that contained the original information was linked to the numerical code and was kept locked in a secure location in the dentistry building at 780 Bannatyne Ave, Winnipeg, R3E 0W2, Manitoba, Canada.

Each radiograph was digitally traced by identification of each of the cephalometric landmarks according to the definitions in Tables 4.2 and 4.3. The custom cephalometric analysis included a combination of variables selected from Steiner's (1953), Rickett's (1981) and McNamara's (1984) analyses. The description of such variables can be found in Tables 4.2 and 4.3.

4.6. Definition of Cephalometric Landmarks

A cephalometric landmark is a distinguishable point on a radiograph that represents the location of an anatomical structure, either hard or soft tissue. Constructed landmarks, however, are not true anatomic structures, but are formed by the intersection of lines. Cephalometric planes or lines are drawn by connecting various landmarks. The landmarks and planes are then used for numerical determination of cephalometric measurements. The cephalometric landmarks used in this study are illustrated in Figure 4.1. Al cephalometric landmarks and measurements used in this study are described in Tables 4.2 and 4.3.

Figure 4.1. Cephalometric landmarks

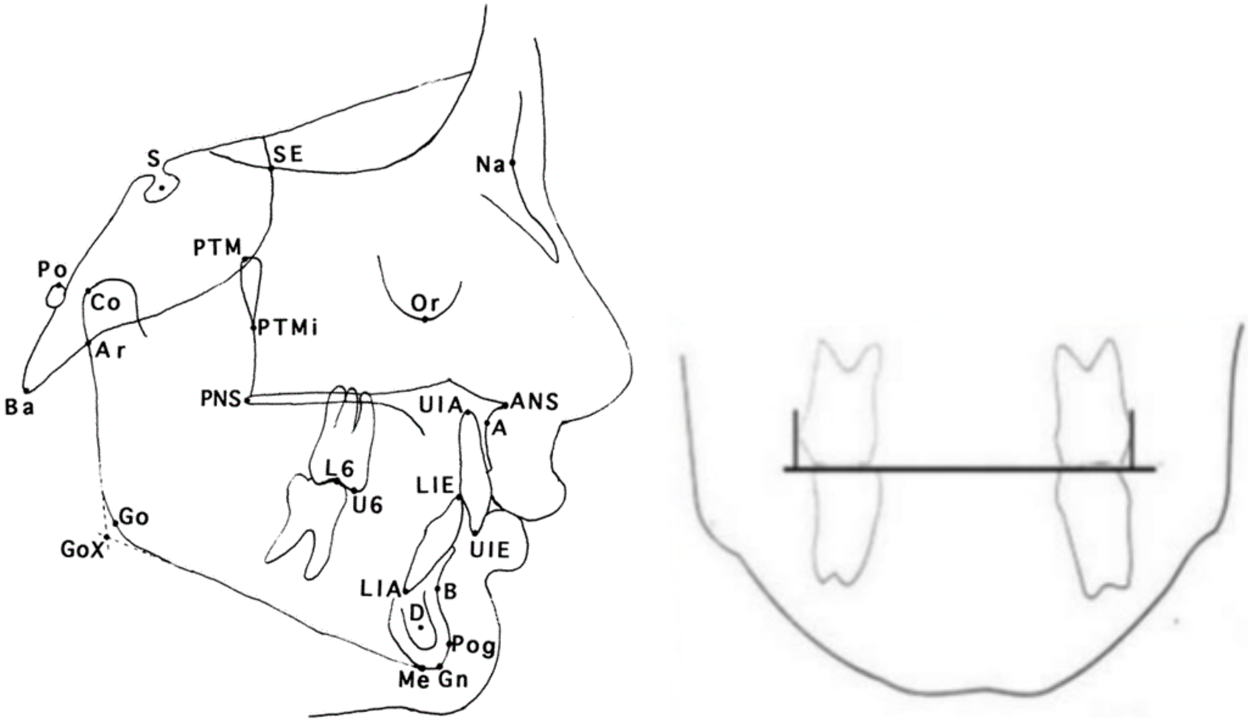


Table 4.1: Description of cephalometric landmarks (Jacobson 2006)

Landmark	**Description**
Skeletal	
Articulare (Ar)	Midway point between the two posterior borders of the left and right mandibular rami at the intersection with the basilar portion of the occipital bone.
A point (Subspinale)	Deepest, most posterior midline point on the curvature between the ANS and prosthion.
B point (Supramentale)	Deepest most posterior midline point on the bony curvature of the anterior mandible, between infradentale and pogonion.

Condylion (Co)	Most superior posterior point on the head of the mandibular condyle.
Gonion (Go)	Most posterior inferior point on the outline of the angle of the mandible. Constructed by bisecting the angle formed by the intersection of the mandibular plane and the ramal plane and by extending the bisector through the mandibular border.
Nasion (N, Na)	Intersection of the internasal and frontonasal sutures, in the midsagittal plane.
Pogonion (Pog, Pg)	Most anterior point on the contour of the bony chin, in the midsagittal plane.
Sella (S)	The geometric center of the pituitary fossa (sella turcica).

Dentoalveolar	
Distal L6	Most distal surface of the lower first molar crown.
Distal U6	Most distal surface of the maxillary first molar crown.
L6 occlusal	Mesiobuccal cusp tip of the mandibular first molar.
L1 root	Root apex of the lower central incisors.
L1 tip	Tip of the lower central incisors.
Mesial L6	Most mesial surface of the lower first molar crown.
Mesial U6	Most mesial surface of the maxillary first molar crown.
U6 occlusal	Mesiobuccal cusp tip of the maxillary first molar.
U1 root	Root apex of the maxillary central incisors.
U1 tip	Incisal tip of the maxillary central incisors.

Table 4.2: Description of cephalometric measurements (Jacobson 2006)

Measurement	Landmarks Involved	Description
Maxillary Skeletal		
SNA, °	S, N, A point	The inferior posterior angle formed by the intersection of lines S-N and N-A. Assessment of the anteroposterior position of the maxilla with respect to the cranial base.
Mandibular Skeletal		
SNB, °	S, N, B point	The inferior posterior angle formed by the intersection of lines S-N and N-B. Assessment of the anteroposterior position of the mandible in relation to the cranial base.
Co-Gn, mm	Co, Gn	The linear distance between condylion and gnathion. Measurement for the length of the mandible.
Co-Pg, mm	Co, Pg	The linear distance between condylion and Pogonion. Measurement of the unit length of the mandible for the Harvold difference measurement.
Ar-Go, mm	Co, Go	The linear distance between articulare and gonion. Measurement for the length of the mandibular ramus.
Inter-maxillary		
ANB, °	A point, N, B point	The difference between the SNA and SNB angles. Evaluates the anteroposterior relationship between the maxillary and mandibular skeletal bases.

Wits, mm	A point, B point, U6/L6 occlusal	Perpendicular lines to the functional occlusal plane are drawn from A-point and B-point. The linear distance between the two points of intersection along the occlusal plane gives the measurement. An evaluation of the anteroposterior relationship between the maxilla and mandible.
Vertical Skeletal		
FMA, °	Po, Or, Go, Me	The anterior-inferior angle formed by the Frankfort Horizontal plane and the Mandibular line (gonionmenton). Assessment of the steepness of the mandibular plane; indicator of mandibular growth direction.
MPA, °	S, N, Go, Me	The anterior-inferior angle formed by the S-N line and the Go-Me line. Assessment of the steepness of the mandibular plane relative to the cranial base; indicator of growth pattern.
Maxillary Dentoalveolar		
U1-NA, mm	Na, A-point, U1-tip	The linear distance between the NA line and the U1 tip. Assessment of the anteroposterior position of the maxillary incisors.
U1-NA, °	Na, U1 tip, U1 root	The angle formed by the long axis of the maxillary central incisor and the NA line. An assessment of the angulation of the maxillary incisors.

U1-SN, °	S, N, U1 tip, U1 root	The posterior-inferior angle formed by the long axis of the maxillary central incisor and the S-N line. An assessment of the angulation of the maxillary incisors.
Interdental		
OB, mm	U1/L1 tip, U6/L6 occlusal	The vertical distance between the incisal edges of the upper and lower central incisors measured perpendicular to the occlusal plane.

4.7. Reliability of Measurements

The principal investigator (P.M) carried out all tracings and measurements. In order to demonstrate how reproducible these measurements are, it was decided to also measure the intra-examiner reliability. 25% of the sample that was randomly selected two weeks later after completion of the initial measurements. Eight patients were re-measured by the principal investigator. The intra-examiner reliability assessments were performed based on intra-class correlation coefficient (ICC) tests and the values interpreted according to the method suggested by Fleiss et al (1999).

4.8. Statistical Analysis

Shapiro-Wilk test has been proposed to be the most appropriate normality test for small sample size (n<50), and therefore, it was performed to determine that both groups had a normally distributed population.

After the hypothesis of normality was confirmed, an unpaired t-test (*P<0.05)* compared the linear and angular measurements from the two time points (T1 and T2) for both control and treatment groups to determine if significant Class II correction was achieved with treatment. The simultaneous interaction of different cephalometric variables, two groups and two timepoints (T1 and T2) called for utilization of Analysis of Covariance (ANCOVA) regression models. The statically significant differences encountered and the regression graphs both indicated an increased power and that mode residues had met distribution assumption, being approximately normal, something that was confirmed by residue Q-plots and histograms. Descriptive statistics (mean and SD) and treatment effect were calculated to compare the two groups (treatment vs. control). For each measurement, T2-T1 difference was the dependent variable and was regressed upon the treatment group. Using the baseline value as a covariate/predictor of the treatment effect leads to increased explanatory power and hence increased statistical power. To guard against a large number of false positives, the *p*-value was adjusted to be more stringent and to have a limited overall false discovery rate. R^2 values were reported to denote the percent of variation in the T2 value of a variable explained by the predictors. It was fairly high for the most part due to the strong correlation between T1 and T2 values.

Chapter Five

Results

5.1. Reliability and Reproducibility

ICC agreement values can be poor (<0.40), fair to good (0.40-0.75) or excellent (>0.75), according to the method suggested by Fleiss (1999). All intra-examiner ICC values showed excellent agreement. (Table 5.1) Based on these results, it seems appropriate to state that there was an overall good reproducibility of all involved cephalometric measurements. (SNA, SNB, ANB, MPA, FMA, Wits, Ar-Go, Go-Pog, Co-Pog, U1-SN, U1-NA, Overbite, Maxillary inter-molar width)

5.2. Demographic Details of the Two Groups

The sample characteristics of the two groups, Control and Treatment groups, are shown in Table 5.2. A total of 32 patients were included in this study, 20 females and 12 males. The final sample group that met the inclusion criteria was comprised of 16 subjects in both the control and the treatment groups. With equal distribution, the majority of subjects in both the study and the control group were female (n=10 in each; 62.5%)

The mean age of the sample in the study group and the control group was 13.25 and 12 years old respectively. The age range of the subjects included in this study was from 8 to 15 years old.

Table 5.1. Intra-rater Agreement

Variable	Intra-rater reliability
SNA°	0.78
SNB°	0.88
ANB°	0.82
Wits (mm)	0.89
Ar-Go (mm)	0.76
Go-Pog (mm)	0.87
Co-Pog (mm)	0.88
IMW (mm)**	0.9
U1-SN°	0.84
U1-NA°	0.84
U1-NA (mm)	0.91
Overbite (mm)	0.92
Average	0.86

Table 5.2: Demographic Data

Group	n	Gender		Age Mean (SD)	Age Range
		Male (n/%)	Female (n/%)		
Treatment	16	6 / 37.5	10 / 62.5	13.25 (2.11)	8-16
Control	16	6 / 37.5	10 / 62.5	12.0 (1.84)	8-15

5.3. Skeletal Changes in Study Group Versus Control Group

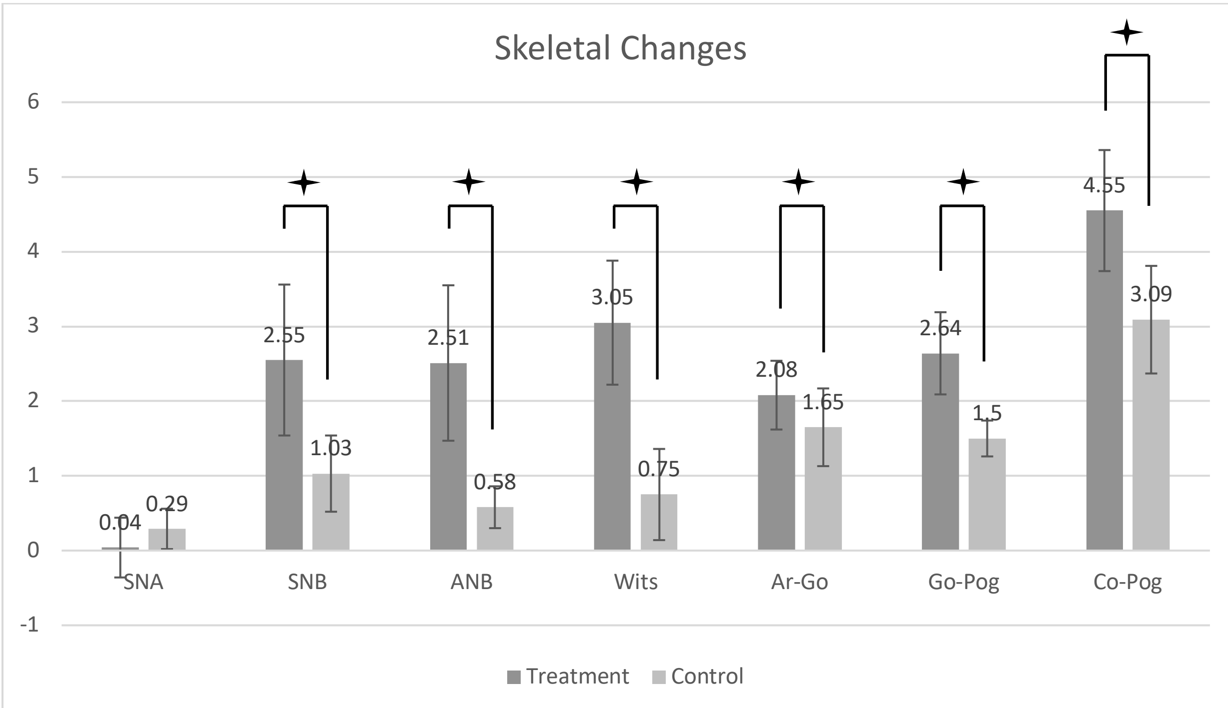
The treatment-related changes of the clear aligner therapy is shown in Table 5.3 . These measurements are in comparison to the changes seen in the untreated control group. The variables that showed significant treatment effects (*P<0.05)* are mentioned below.

In comparison with the control group, the treatment group showed an increase in skeletal mandibular growth and forward projection (SNB:2.55°, p=0.0002; ramus height Ar-Go: 2.08mm, p=0.0311), as well as mandibular length (Go-Pog: 2.64mm, p<0.0001; Co-Pog: 4.55mm, p<0.0001).

The inter-maxillary skeletal parameters which showed improvements toward Class I in the treatment group were ANB (2.5°, p<0.0001) and Wits (3.04mm, p<0.0001). The pattern of growth (FMA, MPA) did not change significantly in neither of groups (p=0.4 and 0.34, respectively).

As per the measurements reported in Table 5.3, there was no difference in the skeletal maxillary growth (SNA) in the treatment group compared to the control group (0.08, p=0.4945).

Figure 5.1. Skeletal changes in both groups



✦significant difference

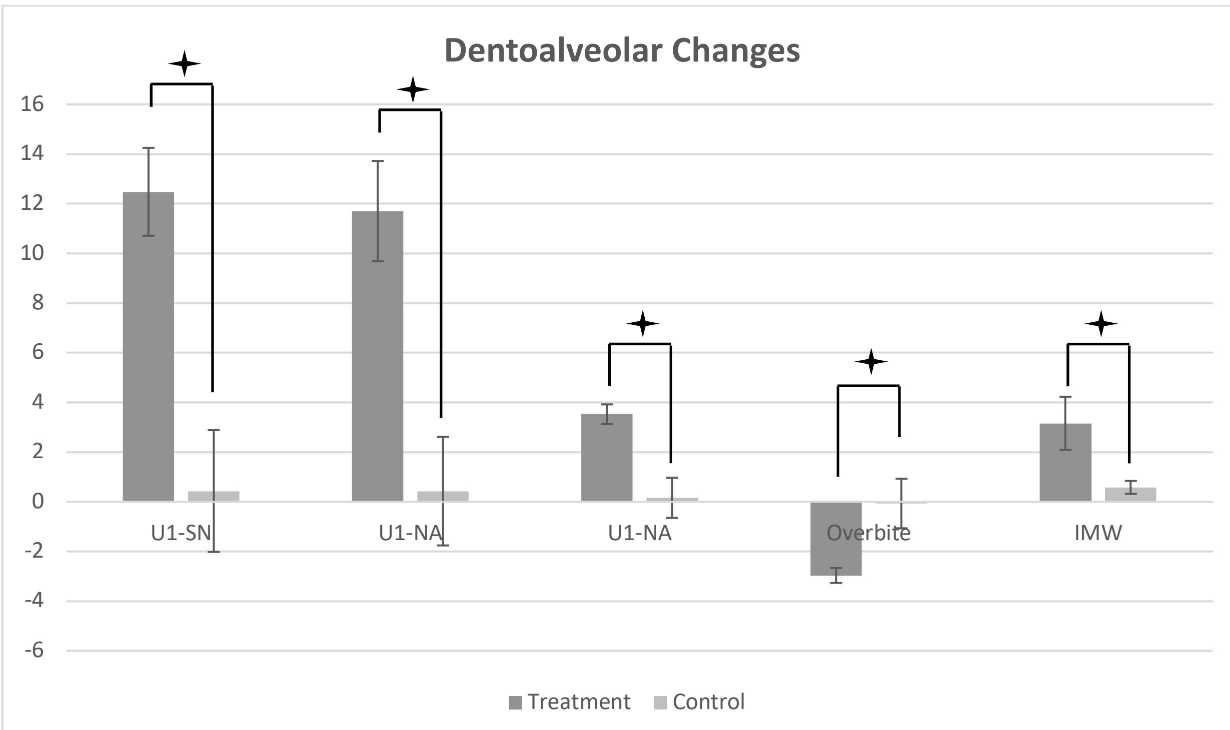
5.4. Dentoalveolar Changes in Study Group Versus Control Group

The treatment effect of the clear aligner therapy is shown in Table 5.3. These measurements were compared to the changes seen in the untreated control group. The variables that showed significant treatment effects (*P<0.05)* are mentioned below.

The maxillary incisors were proclined and protruded in the study group due to the treatment mechanics compared to the control group (U1-SN: 12.48°, p<0.0001; U1-NA: 11.7° and 3.53mm, p<0.0001). The overbite was also reduced significantly in the treatment group compared to the control group (-2.97mm, p<0.0001)

In comparison with the control group, the study group showed an increase in intermolar width (3.16mm, p<0.0001) due to the maxillary expansion that was engineered in the treatment mechanics.

Figure 5.2. Dentoalveolar changes in both groups



✦significant difference

Table 2. Cephalometric data at T1 and T2

Variable	Treatment Mean (SD)			Control Mean (SD)			Intergroup Comparison at T1	Intergroup Mean Difference
	T1	*T2*	*Δ T2-T1 p-value*	*T1*	*T2*	*Δ T2-T1 p-value*	*p-value*	*Δ T2-T1 (CI) p-value*
SNA°	83.11 (1.56)	83.15 (1.70)	0.07 (0.41) 0.47	82.9 (1.39)	83.19 (1.39)	0.29 (0.28) 0.28	0.34	-0.22 (-0.47,0.04) 0.09
SNB°	77.08 (1.98)	79.63 (1.61)	2.55 (1.04) 0.0002*	77.03 (2.12)	78.06 (2.16)	1.03 (0.53) 0.50	0.47	1.52 (0.93,2.12) <0.0001*
ANB°	6.03 (1.74)	3.52 (0.99)	-2.50 (1.07) <0.0001*	5.84 (1.67)	5.26 (1.60)	-0.58 (0.29) 0.16	0.38	-1.92 (-2.49,-1.36) <0.0001*
MPA°	33.78 (5.82)	33.29 (6.34)	-0.5 (2.26) 0.41	35.15 (4.38)	34.73 (5.42)	-0.14 (2.51) 0.41	0.24	-0.36 (-2.14,1.43) 0.34
FMA°	26.71 (4..91)	26.57 (5.58)	-0.15 (2.16) 0.47	28.19 (4.15)	28.92 (4.88)	0.73 (2.95) 0.33	0.19	-0.88 (-2.81,1.05) 0.18
Wits (mm)	3.84 (1.16)	1.19 (1.16)	-2.64 (0.86) <0.0001*	2.76 (1.67)	3.01 (1.96)	0.26 (0.64) 0.35	0.04*	-2.92 (-3.47,-2.37) <0.0001*
Ar-Go (mm)	44.75 (3.15)	46.83 (3.06)	2.08 (0.48) 0.03*	45.01 (2.24)	46.66 (2.0)	1.66 (0.53) 0.01*	0.4	0.42 (0.05,0.79) 0.01*
Go-Pog (mm)	70.10 (2.68)	72.74 (2.58)	2.64 (0.55) 0.004*	69.55 (2.54)	71.05 (2.51)	1.5 (0.24) 0.05	0.28	1.14 (0.82,1.45) <0.0001*
Co-Pog (mm)	108.40 (6.11)	113.45 (6.23)	5.05 (0.83) 0.01*	105.54 (4.13)	108.63 (3.99)	3.09 (0.74) 0.01*	0.06	1.96 (1.39,2.53) 0.04*
U1-SN°	91.10 (1.56)	103.58 (1.25)	12.48 (1.82) <0.0001*	90.34 (2.07)	90.78 (1.87)	0.43 (2.53) 0.27	0.13	12.05 (10.46,13.64) <0.0001*
U1-NA°	10.92 (1.14)	22.62 (1.39)	11.70 (2.09) <0.0001*	10.15 (2.48)	10.58 (1.48)	0.43 (2.27) 0.28	0.13	11.27 (9.7,12.84) <0.0001*
U1-NA (mm)	0.11 (0.64)	3.64 (0.40)	3.53 (0.41) <0.0001*	0.40 (0.31)	0.24 (1.02)	-0.19 (0.84) 0.28	0.06	3.72 (3.24,4.2) <0.0001*
Overbite (mm)	5.84 (0.37)	2.97 (0.31)	-2.88 (0.30) <0.0001*	6.51 (1.05)	6.44 (0.48)	-0.07 (1.03) 0.41	0.01*	-2.81 (-3.35,-2.26) <0.0001*
IMW (mm)**	55.7 (2.29)	58.86 (2.03)	3.16 (1.11) 0.0001*	55.06 (2.77)	55.64 (3.04)	0.52 (0.2) 0.29	0.24	2.64 (2.06,3.22) <0.0001*

*p-value: significant if ≤ 0.05
** Inter-molar width (buccal cusp tips of the maxillary first molars)
CI = Confidence interval

5.4. Sample Superimposition for the Treatment and Control Groups

Sample Ricketts' superimposition of each treatment group and the control groups are shown in Figures 5.3. through 5.8. These represent the general trend of the skeletal and dentoalveolar changes seen in both groups. These trends will be discussed in the next chapter.

Figure 5.3. Cranial base (Sella-Nasion at Sella) superimposition of a patient in the treatment group at T1(black) and T2 (green)

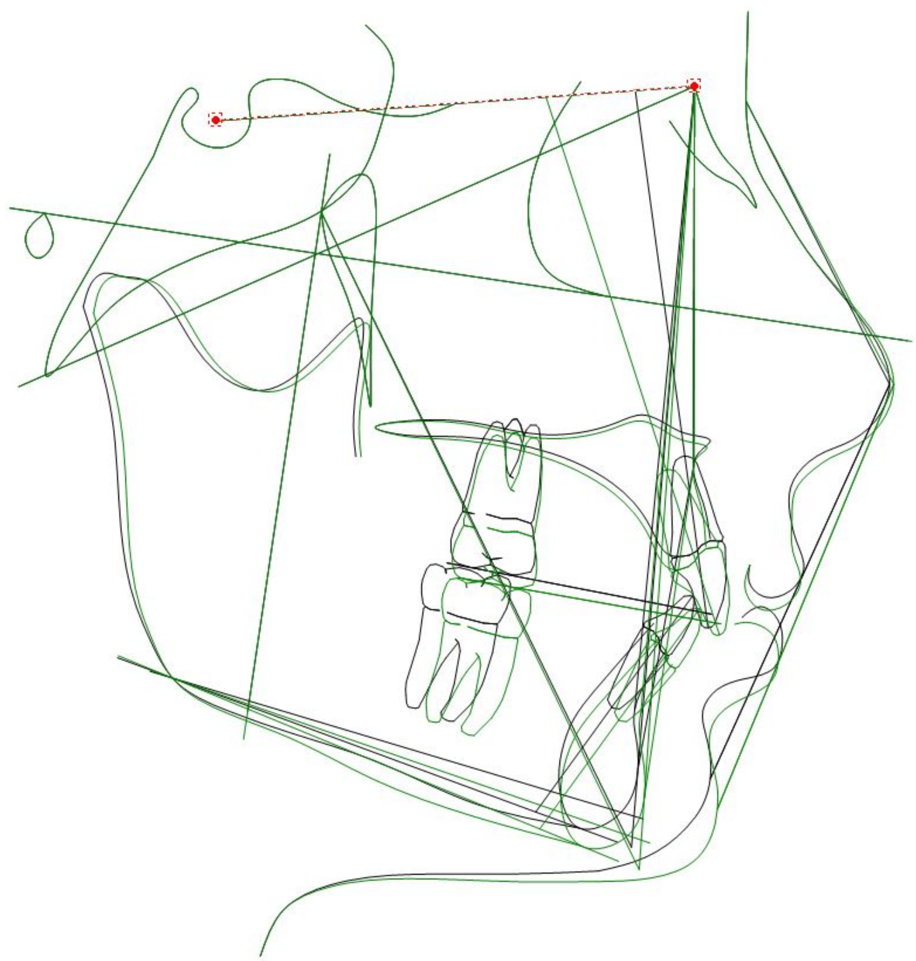


Figure 5.4. Cranial base (Sella-Nasion at Sella) superimposition of a patient in the control group at T1(black) and T2 (green)

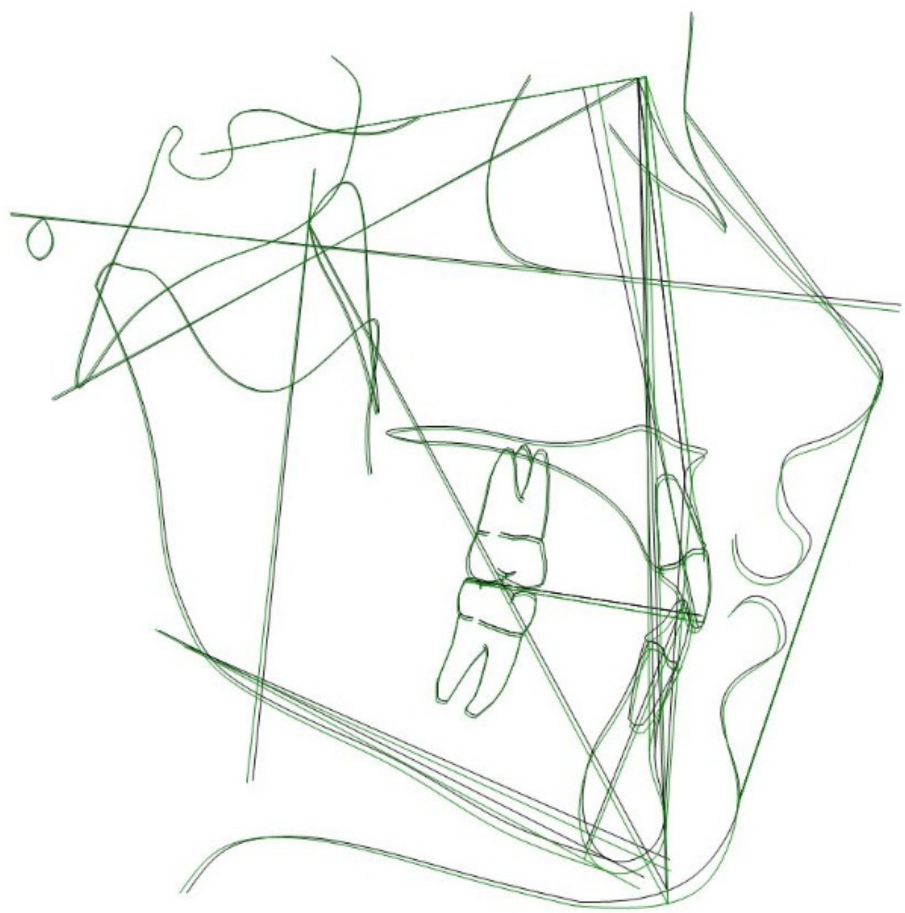


Figure 5.5. Mandibular (Ba-Na at CC - Center of Cranium) and maxillary (Ba-Na at Na) superimpositions to evaluate skeletal changes in the treatment group at T1 (black) and T2 (green)

Figure 5.6. Mandibular (Ba-Na at CC - Center of Cranium) and maxillary (Ba-Na at Na) superimpositions to evaluate skeletal changes in the control group at T1 (black) and T2 (green)

Figure 5.7. Mandibular (Corpus axis at PM – Protuberence menti) and maxillary (ANS-PNS at ANS) superimpositions to evaluate dentoalveolar changes in the treatment group at T1 (black) and T2 (green)

Figure 5.8. Mandibular (Corpus axis at PM – Protuberence menti) and maxillary (ANS-PNS at ANS) superimpositions to evaluate dentoalveolar changes in the control group at T1 (black) and T2 (green)

Chapter 6

Discussion

The controversial term “unlocking” has been used in the literature to address any orthodontic appliance used to remove the potentially inhibitive effects of a deep overbite, accompanied by upright or retroclined maxillary incisors. (Woods 2008) This “unlocking of the deepbite to unlock the forward movement of the mandible and its dentoalveolar bases to their full potential” has been a controversial topic for decades now. (Parker 1995, Gugino 1998, Woods 2001 and 2002) There is still little real evidence confirming the correlation between the so-called “unlocking of a deep bite” and “unlocking of the skeletal growth of the mandible” to correct a Class II malocclusion.

This unlocking should be considered in all three planes of space, the transverse, the vertical and the anteroposterior planes, respectively. The transverse dimension should be addressed in the first step, by expanding the maxillary arch, which is then followed by reciprocal expansion in the mandibular arch. The vertical dimension is considered to be the second step and requires the maxillary incisors to be moved into the correct position. (Gugino 1998) The maxillary incisors are often advanced, proclined, and intruded as part of the vertical unlocking. As an important principle of the Bioprogressive philosophy, the overbite should be corrected before the overjet, vertical dimension before the anteroposterior. This concept is based on the belief that a deep overbite can restrict mandibular development in a Class II malocclusion. The anteroposterior dimension is addressed as the third and last step of mechanical unlocking in order to correct the malocclusion.

The main purpose of the present study was to compare the skeletal and dentoalveolar effects of Invisalign clear aligners in the correction of Class II malocclusions and in particular the magnitude of mandibular forward projection attained in growing subjects.

In summary, Invisalign clear aligners improved the intermaxillary relationship (ANB angle and Wits value) by allowing the mandible to project forward and reach its full growth potential. However, this treatment modality had minimal effect on the maxilla.

The null hypothesis, that there would be no change in the mandibular growth nor forward projection of the mandible will occur after using Invisalign clear aligners, was rejected.

6.1. Intergroup Baseline Differences

At T1, both treatment and control groups had an equal gender distribution. Including a similar number of males and females resulted in a more balanced study sample. In addition, other baseline radiographic measurements were comparable for both groups. Both groups started with a skeletal Class II Malocclusion, based on the ANB angle and Wits measurement. The angular measurements of both the maxilla and the mandible (SNA and SNB angles), as well as the ANB angle, were similar in both groups at baseline. The Class II skeletal relationship was mainly due to retrognathic mandibles, while the maxillae were well-positioned. This is in accordance with the literature suggesting that the position of the maxilla is normal in the majority of Class II Division 2 subjects, while the mandible has been described to be relatively retrognathic. (Renfroe 1948, Pancherz 1997, McNamara 1998, Karlsen 1999) On the contrary, this finding is in disagreement with another study that suggested that SNB angle is normal in a Class II Division 2 Malocclusion, which can be interpreted as the mandible to be in a normal position. (Al-Khateeb 2009) Both treatment and control groups had moderately increased ANB angle values at baseline, 6.03 and 5.86 respectively, which is in accordance with the literature suggesting that the ANB angle in Class II Division 2 is larger compared to Cl I, but smaller than Class II Division 1. (Al-Khateeb 2009) This can be attributed to the more prognathic mandible and normal development of the body of the mandible and the symphysial area in Class I malocclusions, which are not restrained by retroclined maxillary incisors, (Arvystas 1990, Peck 1998) while the development of the alveolar process is reported to be inhibited, leading to the dental Class II relationship in Class II Division 2 subjects. (Hausser 1953, Korkhaus 1953)

At T1, the Wits values were larger in the treatment group compared with the control group (4.24mm and 2.26mm respectively) and this difference was statistically significant. ($p < 0.05$) This can be due to the different inclination of the occlusal plane in the treatment and the control group rather than an indication for severity of the skeletal Class II relationship, since the treatment group started with a larger overbite compared with the control group. Some studies have shown that the Wits appraisal does not indicate any significant anteroposterior changes between the maxilla and the mandible between age 5 and 15 without receiving any orthodontic treatment. (Bishara 1983, Bhatia 1993, Lux 2005) Contrarily, other studies (Roth 1982, Sherman 1988) described a growth-related increase in Wits, which was attributed to the influence of geometric cofactors. Based on these findings, the Wits appraisal might not be a good measurement for our study as orthodontic treatment usually causes changes in the inclination of the occlusal plane, and therefore, make the skeletal appraisal questionable considering the Wits measurements.

The linear (Ar-Go, Go-Pog, Co-Pog) and angular (MPA, FMA) measurements of the mandible were also comparable in both groups, with no statistically significant difference. The Co-Pog measurement The maxillary intermolar-width at baseline did not show a statistically significant difference between the two groups. ($p > 0.05$)

All the subjects in the treatment and the control group were Class II Division 2, and therefore, the maxillary incisors in both groups were retroclined and retruded (U1-SN, U1-NA) and the measurements were comparable at baseline with no statistically significant difference. Both groups also started with an increased overbite, which is also reported to be one of the main characteristics of dental Class II Division 2 Malocclusion.

6.2. Mandibular Changes

The reduced sagittal mandibular growth has been reported to be the main skeletal component of Class II malocclusion. (Varrela 1998) The SNB angle in the Class II Division 2 subjects has been reported to be $76.42^0 \pm 4.14$ degrees (Isik 2006) which is similar to the SNB values of the subjects in this study, $77.08^0 \pm 1.98$. According to SNB angle, the mandibles in the treatment group projected 1.52^0 more than the values of the control group. This was similar to the results of a meta-analysis that studied the treatment effects of various functional appliances, which showed an increase of 1.53^0 for the SNB value in comparison to the control group. (Antonarakis 2007) Studies have shown that in subjects with Class II malocclusion, mandibular growth is on average comparable with Class I subjects. (Varrela 1998) Among the linear measurements of the mandible, ramus height (Ar-Go) presents less variation in annual growth rates, ranging between 3.01 and 3.34mm. Mandibular length (Co-Pog) has an annual growth rate of 3.92 to 5.01mm, while mandibular body length (Go-Pog) has a lower annual growth rate of 1.81 to 2.64mm. (Gomes 2006) In our study, all the mandibular measurements in the treatment group superseded the same values in the control group (Ar-Go, Go-Pog, Co-Pog) There seems to be a general agreement that the growth of the mandible can be increased by 2 to 4mm more than that which occurs normally over the short-term. (Lione 2020) This is in accordance with the findings of our study, where all the linear mandibular measurements increased significantly in the treatment group compared to the control group. The long-term effects, however, remain open to question.

It has been reported that one-third of Class II Division 2 subjects have a posteriorly displaced mandible in maximum intercuspation. (Swann 1954, Thuer 1992) Based on cephalometric findings, it has been proposed that in 25% of subjects with Class II Division 2 Malocclusions, the mandible is repositioned anteriorly during orthodontic treatment. (Erikson 1985, Thuer 1992) This is in accordance with the results of this study where B Point was advanced by 2.55^0 in the treatment group compared to 1.03^0 in the control group. This 1.52^0 difference between two groups is comparable with the treatment effects of functional appliances used for growth modification in treatment of Class II skeletal relationship, which showed an increase of 1.53^0 for the SNB value in comparison to the control group. (Antonarakis 2007) On the contrary, another study found no change in the position of the mandible in Class II Division 2 and Class II Division 1 cases where there is no retroclination of the maxillary incisors or deep bite. This study found no evidence of a significant anterior mandibular repositioning after proclination of the retroclined maxillary incisors in maximum intercuspation, rest position or during function. (Thuer 1992)

Class II Division 2 Malocclusion is characterized by retroclined maxillary centrals and a deepbite. (Millett 2018) Retroclination of the maxillary incisors is the most distinct sign and the main peculiar dental feature of this malocclusion. (Pereira 2013) All subjects of our study had retroclined (U1-SN: 91.1^0 ± 1.51, U1-NA: 10.92^0 ± 1.11 in treatment group, U1-SN: 90.34^0 ± 2, U1-NA: 10.15^0 ± 2.4) maxillary incisors, as well as increased overbite (5.84 ± 0.36 in treatment group, 6.51 ± 1.02) at T1. These values were similar to the findings of Brezniak (2001), who studied the cephalometric characteristics of Class II Division 2 Malocclusion. (U1-SN: 90.7^0 ± 6.1, U1-NA: 9.7^0 ± 6.3, Overbite: 6.8 ± 2.1mm)

It has been proposed that treatment of Class II Division 2 Malocclusions with correction of the maxillary incisors' inclination and overbite reduction can lead to a mean of 4 to 5mm of forward movement of B point compared with the control group. (Wood 2008) This study suggested that in patients with increased vertical overlap of the maxillary and mandibular incisors, the forward movement of the mandible and the associated dentoalveolus can be considerably inhibited. Once the deep overbite is corrected, the dentoalveolus can be carried farther forward with growth of the underlying skeletal structures than without treatment. This forward movement has not been seen in the subjects not receiving any type of orthodontic treatment. This is in accordance with the results of our study where Point B moved forward significantly in the treatment group compared to the control group. Based on these studies, the proposition can be made that release of Pogonion and Point B occurs in subjects with the underlying potential for forward growth. (Erikson 1985, Parker 1995, Gugino 1998, Honn 2006)

6.3. Maxillary Changes and Dentoalveolar Expansion Contributing to Correction of the Class II Malocclusion

From ages 3 to 18, the maxilla presents with a tendency toward a forward displacement but it seems to be in a relatively stable position in relation to the cranial base (SNA angle). (Ramos 2005) This is in accordance with results of our study where SNA angle changed minimally in both groups. Total changes in the position of Point A relative to the cranial base (SNA angle) is in a forward and downward direction: 0.46mm anteriorly and 0.84mm inferiorly. (Bjork 1972, Al-Nimri 2009) Local changes in the position of Point A has been associated with proclination of the maxillary incisors during the treatment of Class II Division 2 Malocclusion, although this change was not statistically significant. (Al-Nimri 2009) It could be suggested that the local changes in the position of Point A result from both bone resorption in the anterior maxilla associated with normal growth and bone remodeling associated with orthodontic tooth movement and proclination of the maxillary incisors. These findings are in agreement with other studies that suggested Point A is affected by dentoalveolar movement. (Arvysts 1990 1991, Erverdi 1991, Nanda 2004) This contradicts the findings of another study that reported during the treatment of Class II Division 2 maalocclusion, the SNA angle was reduced by a mean of 1.6 degrees. (Cleall 1982)

Historically, Class II malocclusion has been looked at as primarily a sagittal and vertical problem. Sagittal and vertical components of this malocclusion have been widely discussed, but the transverse component is often overlooked (Caprioglio 2017) A narrow maxilla has been reported as one of the skeletal signs of Class II Division 2 Malocclusion, and special attention should be paid to the transverse dimension in both the initial diagnosis and during treatment planning. (Varrela 1998)

Buschang (1994) and Walkow (2002) indicated in their studies that Class II Division 2 subjects show a reduced maxillary intercanine and intermolar width. In 1996, Tollaro found the width of the maxillary arch to be 3 to 5mm narrower than the ideal maxillary width relative to the mandible without any posterior crossbite in centric occlusion. This dentoskeletal transverse deficiency in maxillary width has been confirmed with anteroposterior cephalography. (Franchi 2005) In 1956, Schwarz concluded in his study that this transverse discrepancy is only dentoalveolar and not skeletal. Based on these findings, an average of 3mm of maxillary dentoalveolar expansion was engineered in the treatment mechanics in our study. In this respect, reconstructed frontal view radiographs from CBCTs seem to be crucial to stable transverse plane corrections. Frontal cephalometric analyses provide metric data about the dental arches and the widths of the jaws that could be used to keep the teeth in the underlying bony housing and place them in a neutral zone in relationship to the facial musculature.

The correlation between the transverse dimension of the maxilla and the correction of Class II malocclusion was first described by Reichenbach in 1971. The mandibular arch “the foot” moves forward after the maxillary arch “the shoe” is widened. If the shoe is too small, the foot cannot slide fully into the shoe. However, when the shoe gets wider, the foot can slide forward into a more comfortable position. An explanation can be that the maxillary expansion disrupts the occlusion, and therefore, patients are more comfortable to posture the mandible in a more forward position. (McNamara 2002) Presumably, subsequent mandibular growth will make this initial postural change permanent. McNamara suggested that teeth act as an endogenous functional appliance, in that palatal cusps of the over-expanded maxillary dental arch will encourage the patient to posture the mandible in a more protrusive position to establish a more comfortable contact in maximum intercuspation, ultimately leading to a stable occlusal change. (Baccetti 1997) This gradual forward posturing of the mandible leads to a slight but clinically significant increase in mandibular length, and subsequently a change in the intermaxillary relationship. (McNamara 1996) Several studies (Chung 2004, Guest 2010, McNamara 2010) suggested that the removal of occlusal interferences caused by the transverse discrepancy, will allow the mandible to posture forward in the retention phase after maxillary expansion, which can lead to improvement in the anteroposterior relationship of the maxilla and the mandible. (Marshall 2005, Wendling 2005) These studies reported statistically significant decreases in the ANB angle as a result of significant increase in SNB angle. (McNamara 1993, Wendling 2005, Baratieri 2011, Farronato 2011)

In 1979, Vargervik suggested that correction of Class II molar relationship without creating a posterior crossbite requires an approximately 2mm and 4mm increase in maxillary intermolar width for unilateral and bilateral Cl II molar relationship, respectively. (Vargervik 1979) This transverse discrepancy might not be evident since the mandible is retrusive and therefore the maxillary posterior teeth occlude with the narrower part of the mandible. But this discrepancy should be clinically evaluated by asking the patients to posture the mandible in a forward canine Class I position to unmask the underlying transverse discrepancy. Based on this study, maxillary expansion is commonly needed when treating Class II malocclusion. Maxillary expansion disrupts the occlusion and therefore the mandible moves forward, leading to an improved sagittal intermaxillary relationship.

In the early 1980s, it was proposed that there can be spontaneous improvement of Class II relationship after maxillary expansion. This finding initiated a new theory in correction of Class II malocclusion. This theory suggested that almost all Class II Division 2 subjects present with mandibular functional retrusion. This retrusion has been attributed to the retroclination of the maxillary incisors. (Haas 1970) Fifty percent of subjects with Class II Division 2 Malocclusion present with a distal path of closure before treatment. It has been postulated that the mandible is held in a distal position in centric relation (CR) because of the constricted maxilla. (Gianelly 2003) It is believed that during closure or function from the rest position into the maximum intercuspation, the mandible is trapped by the retroclined maxillary incisors and therefore forced backwards. (Demisch 1992) However, this presumed posterior displacement of the mandible is thought to be favorable after correction of the deep bite and the angulation of the retroclined maxillary incisors, since the mandible can spontaneously move forward into a more anterior intercuspal position and simplify the orthodontic treatment of the Class II Division 2 Malocclusion.

On the contrary, some studies suggested that maxillary expansion cannot predictably improve the anteroposterior relationship. (Chung 2003, Volk 2010) Similar studies made the argument that maxillary expansion can be detrimental for correction of Class II malocclusion, since the maxilla might be displaced downward and forward causing clockwise rotation of the mandible and worsening of the Class II relationship. Immediately after expansion, the mandible rotates clockwise with a significant 1.5 mm backward displacement of Menton. (Baratieri 2011) This displacement has been attributed to inferior displacement of the maxilla following the opening of the midpalatal suture, and over-expanded palatal cusps of the maxillary teeth causing premature contacts. (Wertz 1970) This backward and downward positioning of the mandible worsens the skeletal pattern of Class II malocclusion.

A lateral cephalometric study of the long-term cephalometric effects of patients treated with rapid maxillary expansion used to treat Class I and Class II patients did not have a significant long-term effect on either the vertical or the anteroposterior skeletal dimensions of the face when compared with a matched group of patients treated with fixed appliances alone or with untreated controls. (Chang 1997)

The study done by Volk in 2010 does not support the "foot in the shoe" theory. Only about half of the subjects showed some Class II correction; while the Class II got worse in some of the other subjects. It can be postulated that maxillary expansion might help with Class II correction in some patients but is unpredictable in determining which patients would benefit from maxillary expansion. According to such study, there was improvement in Class II malocclusions in about half of the patients; and this can be clinically significant for orthodontists.

An experimental study showed that even after Class II Division 2 patients had been subjected to maxillary expansion, and incisors protrusion and intrusion, no significant changes were observed for either anterior nor posterior joint spaces. (Coskuner 2015) Based on the findings of these studies, spontaneous mandibular correction remains unconfirmed as assumed before. (Volk 2010, Feres 2015, Feres 2020)

6.4. The Importance of Disarticulation

The intercuspation of the maxillary and mandibular dentition maintains the anteroposterior occlusal relationship despite the anteroposterior skeletal changes between the maxilla and the mandible during growth and/or treatment. This mechanism can be disadvantageous in subjects with Class II malocclusion. (Solow 1980, You 2001) The average forward growth of the mandible is 4.36mm greater than the maxilla, which is usually large enough to correct the Class II relationship. Theoretically, unlocking the intercuspation of the maxillary and the mandibular dentition could allow the mandible to carry the lower dentition forward during normal growth. (You 2001)

The thickness of the aligners disarticulates the maxillary and the mandibular dentition. This disengagement, especially in patients with deep bites, allows the mandible to be projected forward into central relationship. When TMJ tomograms were compared with and without clear aligners, it was observed that when the patients wear clear aligners the condyles moved downward and forward as if the patient was wearing a functional appliance. (El-Bialy 2016) This could be an assumption that clear aligners could be working as a full-time functional appliance, if the patient wears them as instructed.

6.5. Intermaxillary Relationship

Cephalometric variables, such as ANB angle and Wits appraisal, are commonly used in studies because of their common use in orthodontic diagnosis. Conclusions concerning sagittal jaw relationship should be based on a combination rather than on a single measurement. This is in keeping with Bishara (1983) and Jacobson (1988) who recommended the combined use of Wits analysis and ANB measurement.

During growth, the maxilla seems to be in a relatively stable position in relation to the cranial base, while the mandible grows more and for a longer period and becomes more prognathic. (Ramos

2005) The growth-related reduction in ANB angle is 0.9° on average between ages 10 and 14 (Riolo 1974) which can be attributed to the differential maxillary and mandibular growth and an age-related reduction of anteroposterior distance between the maxilla and the mandible. (Williams 1985, Buschang 1986) The changes in SNA are mostly insignificant, which means an increase in SNB angle is primarily responsible for reduction in ANB angle. (Honn 2006) In our study, the treatment group showed more ANB reduction (mean T2-T1: 2.51^0) than the control group (mean T2-T1: 0.6^0), being statistically significant. It has been previously proposed that angular measurement changes of 1^0 or more are considered clinically significant. (Aelbers 1996) From a clinical viewpoint, the 1.91^0 more reduction in the ANB angle in the treatment group should be considered clinically significant, especially in comparison with the average growth-related reduction in ANB angle of 0.9°.

While the ANB angle decreases significantly with age, the Wits appraisal does not indicate any significant anteroposterior changes between the maxilla and the mandible between age 5 and 15. (Bishara 1983, Bhatia 1993, Lux 2005) In our study, the treatment group statistically superseded the control group in reducing the Wits value. The mean T2-T1 reduction in the treatment group was 3.05mm while the Wits value increased by 0.75mm in the control group. Similarly, Bhatia (1993) found no increase in Wits between 9 and 15 years of age without receiving any orthodontic treatment. Contrarily, other studies (Roth 1982, Sherman 1988) described a growth-related increase in Wits, which was attributed to the influence of geometric cofactors. Sherman (1988) reported that the age-related horizontal (counterclockwise) rotation of the functional occlusal plane, can lead to an increase in the Wits value. Roth (1982) suggested that the age-related vertical increase in the distance between Point A and Point B can have a positive summation effect, which can lead to an increase in the Wits value. Based on these studies, it can be concluded that the Wits appraisal might not be the best measurement to describe the severity of the skeletal relationship, since it can be affected by many factors during growth and/or orthodontic treatment.

Historically, there has been a belief that Class II Division 2 subjects have posteriorly entrapped mandibles in the glenoid fossa. It has been assumed that the retroclined maxillary incisors, the deep bite and the minimal overjet commonly seen in this type of malocclusion potentially act as occlusal interferences for unrestricted mandibular growth. Based on this belief, it would be reasonable to expect forward movement of the mandible after elimination of these potential interferences in order to help with Class II correction with spontaneous repositioning of the mandible. (Feres 2020) Pullinger (1987) reported higher frequency of posteriorly positioned condyle among Class II Division 2 subjects, although the study sample size might be considered too small for meaningful conclusions. If the mandible had been displaced posteriorly by the underlying malocclusion, and if it would spontaneously reposition anteriorly following proclination of the maxillary incisors and correction of the deep bite, an increased distance between the retruded and the intercuspal mandibular positions would have been expected.

The hypothesis that the conversion of a Class II Division 2 Malocclusion to a Class II Division 1 will by advancing the maxillary incisors allow the mandible to move forward has been tested. Demisch advanced the maxillary incisors in subjects with Class II Division 2 Malocclusions and tracked the movement of the mandible cephalometrically and gnathologically. They could not detect any significant mandibular forward movement in their study. The anteroposterior distance between the retruded and the intercuspal positions before treatment and its development during the period of the study did not favor the concept of posterior mandibular displacement in Class II Division 2 Malocclusion. (Demisch 1992) Other studies reported no statistically differences when the anteroposterior distance for the retruded to the intercuspal mandibular position was compared from the start of treatment with after the maxillary incisors were advanced. These findings suggest that the mandible does not move anteriorly during treatment of Class II Division 2 Malocclusion. (Demisch 1992, Thuer 1992) The findings of these study did not support the concept that the mandible is posteriorly displaced in Class II Division 2 Malocclusion and tends to reposition anteriorly when the retroclination of the maxillary incisors and the deep bite are corrected. Moreover, Song (2020) reported larger posterior joint spaces and smaller anterior joint spaces in Class II Division 2 subjects, when compared to class I patients. These finding actually oppose the original theory, according to which Class II Division 2 patients present with posteriorly displaced condyles, and the spontaneous mandibular anterior repositioning after correcting the overbite in Class II Division 2 subjects. (Stack 1977, Thompson 1986) The different results of these studies compared with our study can be due to the fact that all three dimesnions (transverse, vertical and anteroposterior) were addressed in our study, while these studies addressed one or two aspects. This comprehensive approach can lead to more promising results when treating Class II Division 2 mlocclusions.

6.6. Clinical Relevance

It has been reported that early characteristics of Class II malocclusion are either maintained or become more prominent with normal growth (Baccetti 1997). Based on the results of our study, treatment with Invisalign clear aligners resulted in a modest ANB reduction of 1.91^{0} more than the control group. In view of the potential releasing effects of incisor proclination and maxillary arch expansion on mandibular skeletal and dentoalveolar structures. Thus, these patients should be treated early enough to ensure that facial growth is still present. This conclusion is valid as a general statement for a group of subjects with Class II Division 2 Malocclusion but may not hold true for every single patient.

6.7. Limitations of the Study

To be able to interpret the results properly, certain limitations of this study should be considered. The nature of retrospective studies can introduce selection bias. The risk of selection bias could not be avoided because retrospective studies have been argued to have limited ability to control patient cooperation. (Kravitz 2009) Nevertheless, reviewing patient charts to confirm whether patients changed their aligners at regular time intervals that was prescribed and attended their appointments seems to be as effective as the compliance logs used in other studies. (Charalampakis 2018, Al-balaa 2020)

The applied inclusion and exclusion criteria led to a small final sample size compared to the initial sample of this study. On the other hand, this methodology assured a greater homogeneity among the selected patients which might be challenging in a retrospective study. There is always non-homogeneity in any sample of orthodontic patients. This can be applied to both pre-treatment characteristics and the effects of growth and treatment.

Due to the smaller field of view of the available CBCTs compared to the traditional lateral cephalograms, cervical vertebral maturation (CVM) staging could not have been assessed for all patients, and therefore, the age of the patients was used as an indication for growth. The CVM method is based on the analysis of the second through fourth cervical vertebrae. (Baccetti 2005) This method has become a reliable indicator and a practical index for growth and maturation. (Grave 2003, Wong 2009) Identification of skeletal maturational stage allows the clinicians to detect the optimal time to start treatment for certain type of malocclusions.

Clinician's expertise is a key factor in treatment success with clear aligners. (Tai 2018) All the subjects in this study were treated with Invisalign by a single highly experienced practitioner, so that treatment could be provided as consistently as possible for all subjects. Since a wide variety of mechanics can be used for correction of Class II Division 2 Malocclusions, predictability of the treatment may vary widely from one clinician to another. It might be possible that the results of this study differ from those achieved by other clinicians.

On the other hand, our sample had an equal amount of untreated cases that, instead of being part of a historical control, were contemporary subjects living in the same area. This creates a unique opportunity to eliminate other types of bias. Moreover, the equal gender distribution and the similar ages must have contributed to minimizing any intergroup growth differences. Despite these limitations, our findings can provide a baseline value to what can be accomplished with clear aligners when correcting Class II Division 2 Malocclusions. This study can provide some insight on predictability of Class II correction using Invisalign clear aligners, and therefore, may aid in better patient selection for this treatment modality and better planning the mechanotherapy. Even though a future prospective randomized clinical trial with equal gender distribution and CVM staging should be considered to confirm the current study results, ethics issues related to the use of a contemporary untreated control group may render it unfeasible, what substantiates the rarity of the present study.

6.8. Revisiting the Null Hypothesis

Null hypothesis: There is no change in mandibular growth nor forward projection of the mandible after using Invisalign clear aligners to advance the maxillary incisors and expand the maxillary dental arch in skeletal Class II Division 2 patients.

- Statistically significant differences were found between the treatment and the control group ($p<0.05$). Therefore, the null hypothesis is **rejected**.

Chapter Seven

Conclusions

Despite the expected limitation of this study, it is possible to draw the following conclusions:

1. Proclination of the maxillary incisors, correction of the deepbite and transverse maxillary dentoalveolar expansion using Clear Aligners in growing patients with Class II Division 2 Malocclusions seemed to be effective in improving the skeletal Class II relationship.
2. Clear Aligner therapy produced modest skeletal changes that favored the correction of the Class II skeletal relationship, notwithstanding that the maxilla was found to be in a relatively stable position, while the effective length of the mandible was increased and it was found to be more anteriorly positioned after treatment.

7.2. Future Studies

In our study, an attempt was made to make the groups large enough to ensure that a realistic assessment is possible. The number of subjects in each group, although sufficient to detect statistically significant changes may need to increase in order to generalize the results. Future research with a larger sample size is warranted to explore the factors that may influence the predictability of Class II Division 2 malocclusion correction using clear aligners in order to improve the level of evidence. A randomized clinical trial might be the best study design to measure the dental and skeletal effects of orthodontic treatment in Class II Division 2 subjects, but due to ethical reasons, the current study design is pertinent.

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American Journal of Orthodontics & Dentofacial Orthopedics

Mandibular Projection in Class II Division 2 Subjects Following Maxillary Incisor Proclination, Overbite Correction and Dentoalveolar Expansion Using Clear Aligners

--Manuscript Draft--

Manuscript Number:	AJODO-D-22-00277
Article Type:	Original Article
Keywords:	Class II Division 2, Clear aligners, maxillary dentoalveolar expansion, Deepbite correction, growing patients, Class II correction
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Abstract:	Introduction: The purpose of this study was to evaluate the dental and skeletal changes of maxillary incisor proclination, overbite correction and maxillary dentoalveolar expansion with no planned Class II mechanics on the magnitude of mandibular growth and/or projection in growing patients with Class II Division 2 using Invisalign® clear aligners. Methods: Pre and Post-treatment CBCT-generated lateral and posterioanterior cephalograms of 32 patients, 16 in both the treatment and untreated control group, all with Class II skeletal and Class II Division 2 dental relationship, were obtained retrospectively to evaluate possible treatment-related changes. Proclination and protrusion of the maxillary incisors, as well as maxillary dentoalveolar expansion with no other Class II mechanics were carried out. A customized cephalometric analysis was performed and unpaired t -tests were used to compare the linear and angular measurements to determine if significant skeletal Class II correction was achieved in the treatment group. Results: The maxillary incisors were proclined and protruded in the treatment group as they were initially retroclined and retruded. In comparison to the control group, the treatment group showed an increase in intermolar width while the overbite reduced significantly in the treatment group. An increase in skeletal mandibular growth and forward projection was observed in the treatment group when compared to the control group. The skeletal relationship parameters showed improvements in the treatment group toward Class I compared to the control group as evidenced by a mean difference decrease in ANB and Wits. Conclusion: Proclination of the maxillary incisors, correction of the deep overbite and maxillary dentoalveolar expansion using clear aligners in growing patients with Class II Division 2 malocclusions were effective in improving the dental and skeletal Class II relationship.

Mandibular Projection in Class II Division 2 Subjects Following Maxillary Incisor Proclination, Overbite Correction and Dentoalveolar Expansion Using Clear Aligners

Abstract

Introduction: The purpose of this study was to evaluate the influence of maxillary incisor proclination, overbite correction and maxillary dentoalveolar expansion with no planned Class II mechanics on the magnitude of mandibular growth and/or projection in growing patients with Class II Division 2 using Invisalign® clear aligners.

Methods: Pre and Post-treatment CBCT-generated lateral and posterioanterior cephalograms of 32 patients, 16 in both the treatment and untreated control group, all with Class II skeletal and Class II Division 2 dental relationship, were obtained retrospectively to evaluate possible treatment-related changes. Proclination and protrusion of the maxillary incisors, as well as maxillary dentoalveolar expansion with no other Class II mechanics were carried out. A customized cephalometric analysis was performed and unpaired *t*-tests were used to compare the linear and angular measurements to determine if significant skeletal Class II correction was achieved in the treatment group.

Results: The maxillary incisors were proclined and protruded in the treatment group as they were initially retroclined and retruded. In comparison to the control group, the treatment group showed an increase in intermolar width while the overbite reduced significantly in the treatment group. An increase in skeletal mandibular growth and forward projection was observed in the treatment group

when compared to the control group. The skeletal relationship parameters showed improvements in the treatment group toward Class I compared to the control group as evidenced by a mean difference decrease in ANB and Wits.

Conclusion: Proclination of the maxillary incisors, correction of the deep overbite and maxillary dentoalveolar expansion using clear aligners in growing patients with Class II Division 2 malocclusions were effective in improving the dental and skeletal Class II relationship.

INTRODUCTION AND LITERATURE REVIEW

The prevalence of Class II malocclusion has been reported to range from 16% to 22.5% among different ethnic groups[1], and is the most common disharmony in Caucasians, presenting in almost one third of the United States population[2], while Class II Division 2 accounts for 20% of all Class II malocclusions. It has been reported that early characteristics of Class II malocclusion are either maintained or become more prominent with growth.[3]

A Class II Division 2 malocclusion is characterized by retroclination of the maxillary incisors and increased overbite, which can cause oral problems such as attrition of the lower incisors and/or trauma to the palatal soft tissue[4], as well as affecting the appearance[5]. This type of malocclusion usually presents with an orthognathic maxilla[6], a relatively short and retrognathic mandible but a relatively prominent chin[7], and a hypodivergent facial pattern.[8] The counter clockwise rotation of the mandible helps to camouflage the sagittal underdevelopment of the mandible[9], which has been described to be more prognathic and longer by about 3 mm on average when compared to Class II Division 1.[7] The chin has been reported to be overdeveloped, while the body of the mandible is underdeveloped with a retroclined symphysis.[10] This has been attributed to the normal development of the body of the mandible and the symphysial area which are not restrained by retroclined maxillary incisors, while the development of the alveolar process is reported to be inhibited.[11, 12] Based on this belief, elimination of these potential interferences could theoretically help with Class II correction with spontaneous anterior repositioning of the mandible.[13]

Over the past years, there has been a growing demand for esthetic orthodontic treatments among both adolescents and adults [14, 15], leading to an increased demand for clear aligner therapy. In this treatment modality, the clinician can either request or perform virtual alterations to the tooth position to simultaneously procline the maxillary incisors, expand the maxillary arch, and reduce the overbite, which can altogether facilitate the anterior repositioning and/or growth of the mandible.

The purpose of this study was to evaluate the magnitude of mandibular forward growth and/or projection in Class II Division 2 growing patients following maxillary incisor proclination, overbite correction and dentoalveolar expansion using Invisalign clear aligners. A group of untreated subjects served as control.

MATERIAL AND METHODS

This retrospective study was approved by the Health Research Ethics Board of the University of Manitoba Bannatyne Campus, Canada (protocol number HS23737; H2020:133). Sample size calculation was based on a power of 80%, a confidence interval of 95%, a mean difference to be detected of 5.6 mm for mandibular forward projection, and a standard deviation (SD) of 2.57. A sample size of 11 patients was estimated for a 5% level of significance. The values for mean difference and SD were based on the average of five previous publications with similar methodology.[16-20] The study sample was obtained from a single orthodontist experienced with the Invisalign technique (T.E). The following inclusion criteria were applied: (1) Adolescent patients (ages 8-17 years), (2) Skeletal Class II (ANB > 4°), (3) Dental Class II Division 2 Malocclusion (Class II molar and canine, retroclined maxillary incisors, increased overbite), (4) Planned dual arch orthodontic treatment (maxillary dentoalveolar expansion, maxillary incisors proclination, and overbite correction) exclusively using Invisalign, except for the control group, (5) Available T1 and T2 cone beam computed tomography (CBCT) generated lateral and posterioanterior cephalograms of acceptable quality, (6) Aligners made of SmartTrack material (year 2012 to present), (7) Good compliance during treatment as assessed by the orthodontist, and (8) No planned Class II elastics or other Class II mechanics.

All the subjects were in a natural head position with their back as perpendicular to the floor as possible, with maximum intercuspation and refrained from swallowing during CBCT scanning. T1 (before treatment) and T2 (after treatment) CBCT scans were imported into a commercial software (Dolphin Digital Imaging System, Chatsworth, CA, USA) and were used to construct lateral and anteroposterior cephalometric radiographs. The identification of cephalometric landmarks and the measurements shown in Table 2 were performed by the principal investigator (P.M). Twenty five percent of the sample was randomly selected to be re-measured two weeks after the first assessment. The reliability of measurements was assessed by the mean of an intraclass correlation coefficient (ICC). The Shapiro-Wilk test, which is recommended when sample size is smaller than 50, indicated normal distribution, thereby allowing for the use of descriptive statistics parameters such as mean and SD as well as comparison of intergroup differences by means of parametric test. An unpaired *t*-test ($P<0.05$) compared the linear and angular measurements from the two time points (T1 and T2) for both groups to determine if significant Class II correction had been achieved following treatment.

RESULTS

A total of 32 patients (16 per group) were included in this study, the majority being females (n=10 in each; 62.5%). The mean age in the treatment and control groups was 13.25 ± 2.11 and 12 ± 1.84 year respectively, ranging from 8 to 15 years (Table 1).

The ICC test showed excellent agreement in regards to inter-examiner reliability with a score of 0.87. The value for the intra-examiner reliability, a score of 0.95, also showed an almost perfect agreement.

The maxillary incisors were proclined and protruded in the treatment group due to the treatment mechanics compared to the control group (U1-SN: 12.05°, p<0.0001; U1-NA: 11.27, p<0.0001; U1-NA: 3.72 mm, p<0.0001). The treatment group also showed an increase in intermolar width (2.64 mm, p<0.0001) due to the maxillary expansion that was engineered in the treatment mechanics. The overbite was also reduced significantly in the treatment group compared to the control group (-2.81 mm, p<0.0001) (Table 2).

There was no difference in the skeletal maxillary growth (SNA) in the treatment group compared to the control group (p=0.09). In comparison with the control group, the treatment group showed an increase in skeletal mandibular growth and forward projection according to SNB (1.52°, p<0.0001), ramus height (Ar-Go: 0.42 mm, p=0.01), and mandibular length (Go-Pog: 1.14 mm, p<0.0001; Co-Pog: 1.96 mm, p=0.04). The inter-maxillary skeletal parameters which improved toward Class I in the treatment group were the ANB (-1.92°, p<0.0001) and Wits (-2.92 mm, p<0.0001). The pattern of growth (MPA, FMA) did not change significantly in either group (p=0.34 and 0.18) (Table 2).

DISCUSSION

The purpose of this study was to evaluate the magnitude of mandibular forward growth and/or projection in growing patients with Class II Division 2 malocclusion following maxillary incisor proclination, overbite correction, and dentoalveolar expansion with Invisalign clear aligners. To our knowledge, no study has yet evaluated the effects of Invisalign clear aligners on Class II Division 2 malocclusions in all three dimensions (vertical, transverse, sagittal). In our study, both groups started with a skeletal Class II relationship and dental Class II Division 2 malocclusion based on the ANB angle, Wits appraisal, molar/canine classification, retroclination of the maxillary incisors and increased overbite. The Class II skeletal relationship was mainly due to retrognathic mandibles, while the maxillae were well-positioned. This is in accordance with the literature suggesting that the position of the maxilla is normal in the majority of dental Class II Division 2 subjects, while the mandible has been described to be relatively retrognathic.[21-23] Maxilla presents with a tendency toward a forward displacement but it seems to be in a relatively stable position in relation to the cranial base (SNA angle), while the mandible grows more and for a longer period and becomes more prognathic.[24] This is in accordance with results of our study where SNA angle changed minimally in both groups.

The SNB angle in Class II Division 2 subjects has been reported to be $76.42^{0} \pm 4.14$ degrees[25] which is similar to the SNB values of the subjects in our study, $77.08^{0} \pm 1.98$ in the treatment group and $77.03^{0} \pm 2.12$ in the control group. Both the treatment and the control group had moderately increased ANB angle values at baseline, $6.03^{0} \pm 1.74$ and $5.84^{0} \pm 1.67$ respectively, which is in accordance with the literature suggesting that the ANB angle in Class II Division 2 malocclusion is larger compared to Cl I, but less than Class II Division 1.[15] This can be attributed to the fact that Class II Division 2 subjects have retroclined maxillary incisors that hinder horizontal growth of the mandible, thus resulting in mandibular retrognathism as opposed to Class I subjects who experience unrestrained and normal development of the mandible.[11, 12]

Between the ages of 10 to 14, ANB angle normally reduces by 0.9 degrees because of differential mandibular growth that increases SNB angle while SNA stays constant.[26-29] In our study, the treatment group showed ANB reduction of $2.50^0 \pm 1.07$, which was 1.92 degrees more than the control group ($0.58^0 \pm 0.29$), being statistically significant ($p<0.0001$). From a clinical viewpoint, this reduction in the ANB angle in the treatment group should be considered clinically significant, especially in comparison with the average growth-related reduction in ANB angle of 0.9°.

It is possible to unlock malocclusions in a functional or a mechanical manner, or a combination of both. Mechanical unlocking, in contrast to functional unlocking, removes occlusal interferences that could interfere with the development and function of the entire stomatognathic system. Mechanical unlocking in Class II Division 2 malocclusion often requires the maxillary incisors to be advanced, aligned, torqued, and intruded as part of the vertical unlocking process. Additionally, the maxillary arch frequently needs to be expanded to help mechanical unlocking in the transverse dimension.[30]

It has been proposed that disarticulation of the occlusion can greatly facilitate treatment of Class II malocclusions in growing patients. The reason why Class II maloclussions do not self-correct without treatment may be due to tight intercuspation of the maxillary and mandibular dentition which maintains a relatively stable inter-arch occlusal relationship despite significant differential mandibular growth. The average forward growth of the mandible is 4.36 mm greater than the maxilla, which is usually large enough to correct the Class II relationship, however the maxilla will be carried forward along with the mandible if intercuspation is maintained.[31] Theoretically, unlocking the intercuspation of the maxillary and the mandibular dentition could allow the mandible to carry the lower dentition forward during normal growth. When using Invisalign clear aligners, the thickness of the aligners disarticulates the maxillary and the mandibular dentition. This disengagement, especially in patients with deep bites, allows the mandible to be projected forward into centric relation (CR). When comparing TMJ tomograms with and without clear aligners, it was observed that for patients who wore clear aligners, the condyles moved downward and forward as if they were wearing a functional appliance.[32]

Retroclination of the maxillary centrals and deep bite are the most distinctive dental features of Class II Division 2 malocclusion.[4, 33] At T1, all subjects in the treatment and the control group had retroclined maxillary centrals (U1-SN: $91.1^0 \pm 1.56$, U1-NA: $10.92^0 \pm 1.14$ and U1-SN: $90.34^0 \pm 2.07$, U1-NA: $10.15^0 \pm 2.48$ respectively), as well as an increased overbite (5.84 ± 0.37 and 6.51 ± 1.05 respectively). These values were similar to the values found in the literature on cephalometric characteristics of Class II Division 2 malocclusion (U1-SN: $90.7^0 \pm 6.1$, U1-NA: $9.7^0 \pm 6.3$, Overbite: 6.8 ± 2.1mm).[34] It has been proposed that in patients with retroclined maxillary incisors and increased vertical overlap of the maxillary and mandibular incisors, the forward movement of the mandible and the associated dentoalveolus can be considerably inhibited. Correction of the deep overbite and the inclination of the maxillary incisors can lead to a mean 4 to 5 mm forward movement of B point, and the dentoalveolus can be carried farther forward with growth of the underlying skeletal structures. This forward movement has not been seen in subjects not receiving any orthodontic treatment.[35] This is in accordance with the results of our study where

B Point moved forward significantly in the treatment group compared to the control group. Based on this, a proposition can be made that release of Pogonion and B Point occurs in subjects with the underlying potential for further forward growth.[29, 30, 36, 37] Thus in deep overbite cases with severely retroclined maxillary incisors, the clinician should apply labial crown torque as the first step in correcting the anteroposterior discrepancy. This is of particular importance in cases where patients initially present with underdeveloped or distally positioned mandibles.

Historically, Class II Division 2 malocclusion has been regarded as primarily a sagittal and vertical problem, with the transverse component being overlooked.[38] However, a narrow maxilla has been reported from time to time as one of the dentoalveolar signs of this malocclusion, and therefore, special attention should be paid to the transverse dimension during treatment planning.[39] Class II Division 2 can be viewed as a condition where the mandible is restricted within the maxilla. In mild cases, this restriction is only seen in the anterior region due to retroclined maxillary incisors, whereas in more severe cases, this restriction extends back, restricting the mandible in both anteroposterior and lateral dimensions.[40] It has been concluded that this transverse discrepancy is only dentoalveolar and not skeletal,[41] and the width of the maxillary arch was found to be 3 to 5 mm narrower than the ideal relative to the mandible.[42] This transverse discrepancy might not be clinically noticeable since the mandible is retrusive and therefore the maxillary posterior teeth occlude with the narrower part of the mandible without producing any posterior crossbite. Based on this knowledge, an average of 3 mm of maxillary dentoalveolar expansion was planned into the aligners of the subjects in this study. The intermolar width was increased by 2.64 mm more in the treatment group which was statistically significant compared to the control group ($p<0.0001$).

Fifty percent of subjects with Class II Division 2 malocclusion present with a distal path of closure before treatment. It has been postulated that during closure or function from centric relation into maximum intercuspation, the mandible is forced backwards and trapped by the retroclined maxillary incisors[43] and constricted maxillary arch.[44-48] These studies indicate that in these subjects, transverse maxillary deficiency impedes physiological sagittal mandibular growth. However, this presumed posterior displacement of the mandible is thought to resolve after maxillary arch expansion, correction of the deep bite and the retroclination of the maxillary incisors, since the mandible is free to spontaneously move forward into a more anterior intercuspal position and thereby reduce the anteroposterior discrepancy.[49-52] Based on cephalometric findings, it has been proposed that in 25% of subjects with Class II Division 2 malocclusions, the mandible is repositioned anteriorly during orthodontic treatment.[37, 46] When the mandible is freed to move forward, it can grow to its full potential.[53] In our study, a potential explanation for the 1.52 degree difference in ANB reduction between the treatment and control groups could be that the maxillary expansion disrupt the occlusion, while teeth act as an endogenous functional appliance, in that palatal cusps of the expanded maxillary dental arch will encourage the patients to posture the mandible in a more forward position to establish a more comfortable contact in maximum intercuspation, leading to an improved sagittal intermaxillary relationship. This gradual forward posturing of the mandible leads to a clinically significant increase in mandibular length and this subsequent mandibular growth will make the initial postural change permanent and ultimately lead to a stable change.[12, 13] This is in accordance with the findings of our study, where all the linear mandibular measurements (Ar-Go, Go-Pog, Co-Pog) increased significantly in the treatment group compared to the control group.

On the contrary, one study found no change in the position of the mandible in Class II Division 2 in comparison with Class II Division 1. No significant anterior mandibular repositioning after proclination of the retroclined maxillary incisors was noted in maximum intercuspation, rest position or during function.[46] In addition, some studies argue that maxillary expansion can be detrimental for correction of Class II malocclusions, since the maxilla might be displaced downward following the opening of the midpalatal suture, and over-expanded palatal cusps of the maxillary teeth could cause premature contacts, leading to clockwise rotation of the mandible and worsening of the Class II relationship.[50, 54, 55] In another study, maxillary incisors were advanced in subjects with Class II Division 2 malocclusion and the movement of the mandible was tracked cephalometrically and gnathologically. The authors could not detect any significant mandibular forward movement in their study. The lack of difference in anteroposterior positioning of the mandible in the retruded and the intercuspal positions before treatment and during the period of the study did not favor the concept of posterior mandibular displacement in Class II Division 2 malocclusion.[48] A third study reported no statistically significant difference when the anteroposterior distance between the retruded and intercuspal mandibular positions were compared from the start of treatment to when the maxillary incisors were advanced. These findings actually oppose the original theory, which assumes that Class II Division 2 patients present with posteriorly displaced condyles, and there is spontaneous mandibular anterior repositioning after overbite correction in these subjects.[46] The different results of these studies compared with our study can be due to the fact that all three dimensions (transverse, vertical and anteroposterior) were addressed in our study, while these aforementioned studies addressed only one or two aspects. This comprehensive approach can lead to more promising results when treating Class II Division 2 malocclusions in growing individuals while facial growth is still present.

The limitations of the current study includes the use of chronologic age for standardization in the study sample instead of skeletal age (cervical vertebral maturation staging, CVMS). Due to the smaller field of view of the available CBCTs compared to the traditional lateral cephalograms, CVMS could not be assessed for all patients, and therefore, chronologic age was used as an indication for growth. In terms of strengths of the study, our control group were contemporary subjects living in the same area as the treatment subjects, and there was an equal number of control and treatment subjects, which helped to minimize other types of bias. Moreover, the equal gender distribution and narrow age range must have helped minimize any intergroup growth differences. Even though a future prospective randomized clinical trial with equal gender distribution and CVMS should be considered to confirm the current study results, ethics issues related to the use of a contemporary untreated control group may render it unfeasible.

CONCLUSIONS

Within the limitations of the current study, it can be concluded that treatment with Invisalign clear aligners resulted in a modest ANB reduction of 1.92^0 more than the control group. In view of the potential releasing effects of maxillary incisor proclination, overbite correction and maxillary arch expansion on mandibular skeletal and dentoalveolar structures, Clear Aligner therapy resulted in modest skeletal changes that favored the correction of the Class II skeletal relationship in the studied growing patients.

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